Integrated Pest Management in Vegetables, Wheat and Cotton in the Sudan:
A Participatory Approach

Edited by Z.T. Dabrowski

FAO/Government of the Sudan
Cooperative Project
GCP/SUD/025/NET
Wad Medani, Sudan

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FAO/ARC IPM Project:

Development and Application of Integrated Pest Management in Vegetables, Wheat and Cotton, Phase IV GCP/SUD/025/NET

Food and Agriculture Organization of the United Nations

Agricultural Research Corporation, Wad Medani, the Sudan

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Contents

Foreword

N. A. van der Graaff
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Integrated Pest Management (IPM) has been advocated by the Food and Agriculture Organization of the United Nations (FAO) as the preferred pest control strategy since the mid-1960s. It is the careful integration of a number of available pest control techniques that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and safe for human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms.

In developing countries, during the green revolution, pesticides were considered a necessary part of crop intensification. A number of policy instruments were applied to make purchased inputs, including subsidized pesticides, available to the farmer. Pesticides also became part of loan packages and extension messages. This often resulted in substantial mis- and overuse of pesticides. Such methods of plant protection have proved to be increasingly unsustainable and cost-ineffective due to the development of pest resistance, the rising costs of pesticide use, pesticide-induced outbreaks of insect pests and the negative effects of pesticide use on human health and the environment.

The present value of pesticides sold worldwide annually is in the range of US$25 billion. Pesticide use remains highest in developed countries, but these markets are stagnating or contracting. Environmental concerns have become overwhelming, and in several countries, programmes have been established to reduce pesticide use.

IPM adds three dimensions to pest control; it contributes to ecological, social and economic sustainability. It relies primarily on environmentally-benign processes, including the use of pest resistant varieties, the actions of natural enemies and cultural control. It is institutionalized at the level of the farming community and local government, and it reduces farmers' dependence on procured inputs. Successful IPM implementation has three components: applicable research results, a policy change away from pesticide subsidies and a participatory farmer training programme.

IPM is being implemented in a number of developed countries. However, its successful implementation in Asia has added a new dimension, not only to IPM but to extension in general. IPM stresses the responsibility of farmers for diagnosing pest problems and for participating in the development of solutions. It uses a process of human resource development through which farmers' expertise is recognized and enhanced. IPM programmes involve farmers and field staff from national and local government units and non-governmental institutions. It enhances ecological awareness, decision-making, business skills and farmer confidence. IPM thus has long-lasting socioeconomic benefits far beyond the area of plant protection. Experience gained in IPM implementation in rice now needs to be extended to other crops and to other regions where non-sustainable crop protection practices occur. In many national programmes in Asia, IPM implementation is expanding to cotton, vegetables, legumes and maize.

In view of the need for further expansion of IPM practices, we have noticed with pleasure that significant progress in developing and implementing of IPM principles has been achieved in the Sudan. After the catastrophic consequences of over-reliance on intensive chemical control were observed in the cotton agro-ecosystem during the 1970s in the Gezira scheme, IPM was the subject of deliberations in a Crop Pest Management Symposium held in Khartoum, 6–8 February 1978 (S. El Bashir, K. B. El Tigani, Y. M. El Tayeb and H. Khalifa, 1986). The symposium recommended the initiation of adaptive research leading to an integrated pest control approach.

In response to an official request from the Government of the Sudan, the project, entitled 'Development and Application of Integrated Pest Control in Cotton and Rotational Food Crops in the Sudan', was initiated on 28 March 1979 for a first phase of three years to 1982 and later reactivated in 1985 for four consecutive phases to October 1996. The FAO/Government of Sudan cooperative project on IPM of cotton financed since 1979 by the Government of the Netherlands has made an impressive contribution in demonstrating that pesticide spraying cannot provide sustainable protection for crops. It was proven that natural enemies occurring in the agro-ecosystems should play an integral part as control measures; pesticides should only be applied when there is justification that high numbers of pests are present and that biological control is insufficiently effective.

Since January 1993, the IPM project has shifted its major activities from cotton and wheat to vegetables where pesticide misuse and risks for health and environment are large. The participatory approach for IPM development and training by means of farmer and rural women field schools was successfully introduced. The FAO/ARC IPM project activities have been regularly presented and discussed by researchers, extensionists, plant protectionists, horticulturalists and representatives of farmers' unions during annual review and planning meetings in addition to national workshops organized on selected topics.

This publication documents the presentations and discussions held at the Third Annual Review and Planning Meeting that took place 10–12 June 1996 at the Conference Hall, Agricultural Research Corporation, Wad Medani. Around 220 participants attended a three-day conference which included two days of presentations of project achievements. The third day focused on developing sustainable mechanisms for further development, validation and implementation of IPM principles in the Sudan.

It is our deep conviction that the model of participatory research and extension adopted for the Sudanese conditions can serve as an example for other IPM projects in Africa and the Near East.

Preface

A major part of the reports presented herewith has been supported through the FAO/ARC Project on Development and Application of the Integrated Pest Management in Vegetables, Wheat and Cotton, Phase IV. Other papers referred to as contributory reports also have been included due to their relevance and importance in developing and implementing pest management in the Sudan. The activities presented in the contributory papers were not financed by the IPM project.

The FAO/ARC IPM project was funded by the Government of the Netherlands through the FAO/Government Cooperative Programme GCP/SUD/025/NET, Wad Medani, Sudan from 1979 to 1996.

Throughout this book, certain units in common use in the Sudan have been used to express land area and yields:
1 feddan = 0.42 hectares
1 kantar = 142 kg of seed cotton
1 sack = 100 kg

1 Policy Statements

Government Policy on Integrated Pest Management

Abdel Galil Abdel Gabbar
Under Secretary
Ministry of Agriculture and Forestry, Khartoum

It gives me great pleasure to participate with you in the Opening Ceremony of the Third Annual Review and Planning Meeting of the FAO/ARC IPM Project, discussing important issues concerning our agricultural production, environment and health. First, I would like to convey to you gratitude and best wishes from His Excellency, Dr Nafie Ali Nafie, the Federal Minister of Agriculture and Forestry.

In front of this audience, I do not need to emphasize that the Sudan's economy is strongly dependent on agriculture. During the 1990s, agriculture accounted for roughly 30–35% of the GDP (down from 57% after independence and 40% in 1971) and provided employment for over 60% of the population. Agricultural exports made up more than 80% of the value of merchandise exports (average financial years 1984–1989). During the 1980s, the Sudanese economy showed signs of stagnation and even decline. GDP at constant factor cost fluctuated around the same level; with the rising population the head GDP per capita seriously declined. In agriculture, cotton is the most important cash crop and alone represents almost 40% of the total value of exports (average FY 1984–1989, down from 53% in the 1970s). Cotton is the backbone of the major irrigated schemes (Gezira including Managil extension, Rahad and New Halfa).

The predominant role of cotton has shown a declining trend over the past two decades, though it is picking up at present. The combined effect of the agricultural diversification policies that reduced the area planted by cotton, rising production costs and stagnant yields sent cotton growing in Sudan into a state of crisis during the 1970s. While a rehabilitation programme in the late 1980s helped to restore the cotton area and improve levels of yield, production costs continued to escalate. The rising costs were, for the major part, attributable to the increased expenditure on crop protection, e.g., in the Gezira scheme, this represented 25% of the total production costs during the period 1975–1984, and reached a high level of over 30% during the 1985/1986 season. Pesticides were sprayed up to eleven times during "the package deal area" of plant protection in the irrigated schemes during the mid-1970s. During the 1980s usually 6–8 sprayings were carried out per cropping season without, however, having a decisive impact on the incidence of pest attacks. Furthermore, it became obvious that in addition to rising production costs, the overuse of pesticides had negative implications on the environment and human health.

Massive amounts of toxic chemicals were used, and, as a result, there is an accumulation of 700 tons of expired insecticides purchased over the years. Accordingly, revision of cotton pest control measures based on economic, environmental and human health considerations became a necessity.

As the response to the crisis faced by the Gezira scheme in chemical control of cotton pests, the Minister of Agriculture in 1980 issued a decree abolishing DDT mixtures for crop protection. The so-called "package deal" arrangements on cotton spraying with agro-chemical companies was also discontinued at the end of 1980. This was after our scientists and scheme managers noticed that the number of sprayings had escalated and that new, major pests such as the cotton whitefly had emerged. The package deal was a contract system between the scheme management and a pesticide firm whereby the firm assumed full responsibility for cotton pest control on a specific area for specific payment per unit area and on specific yield guaranty irrespective of the kind of chemical used. This created the situation of mono-chemical control whereby companies tried to use their own products for all pests.

In July 1989, the Minister of Agriculture issued a directive requesting the Agricultural Research Corporation to formulate recommendations for a pest management package for cotton based on the findings of the FAO/ARC IPM project. The first economic threshold levels for major cotton pests in the Rahad and Gezira scheme were included in large-scale validation experiments.

Based on these large-scale field experiments, economical threshold levels for four major cotton pests were approved by the Pest and Diseases Committee and fully implemented since the 1992/1993 growing season by the Rahad and Gezira scheme. From 1996, the cost of agricultural inputs, including pesticides, is based on true cost by eliminating differences between the official exchange rate and a preferential foreign exchange term granted to the Agricultural Bank of Sudan.

The Ministry of Agriculture involvement in the IPM activities has always been strongly assured by setting priorities for the FAO/ARC IPM project in the Sudan. In 1991, the IPM Steering Committee under the chairmanship of the First

Secretary of the Ministry of Agriculture was formed with its main objective to assist in determining the overall IPM strategy for the country and to find ways and means to reach the relevant objectives. In 1995, the committee upgraded its status into the National IPM Steering Committee integrating all policy makers related to IPM in the Sudan.

The developments of IPM are in line with our Ten-Year National Strategy of the Sudan (1992 – 2002) which focuses on privatization as a means to achieve more efficient resource allocation with overall objectives of food security, growth of the agricultural sector's contribution to GDP and exports and balanced regional development. The present IPM approach to train farmers in better cultural practices and more efficient use of mineral fertilizers and pesticides supports our efforts of transition to a market economy. Since 1990 the Sudanese economy has been growing through a series of profound changes; these include the enhancement of the role of the private sector, less governmental regulations and more reliance on self-regulating free markets. Changes include the reorientation of financial, economic and institutional structures to create an environment more conducive to private sector participation. The large-scale production or periodic overproduction of onion, tomato and eggplant in the last two years may indicate that a large proportion of farmers have already taken the initiative to shift from traditional crops to potentially more attractive vegetable crops.

In the context of agriculture in the large-scale irrigation schemes, the Ministry supports the general trend in releasing tenants from dependency on the scheme management and permitting them to develop into small-scale entrepreneurs and independent decision makers. We are aware that among some planners there appears to be little awareness of the fundamental importance of this step to eliminate the inefficiencies of the past and to really raise productivity. Even within the present scheme administration, the more dynamic farmers have extended the area of high value crops up to the maximum proportion that is feasible within their scheme and existing regulations. There is no doubt that this group of farmers welcomes change and could easily cope with a free market situation.

By establishing Farmer Field Schools, the FAO/ARC IPM project has already significantly contributed to the dissemination of knowledge to farmers; community extension and farmers schools teach that yields can be maintained or even increased without excessive use of synthetic pesticides. On both the federal and state levels, the Ministry of Agriculture will provide more support for expanding IPM activities. We have recently learnt that the Minister of Agriculture of Sennar has adopted the IPM system to establish field school network for the vegetable farmers. We all know the good support given to Farmer Field Schools by the Ministers of Gezira and Khartoum States. Their involvement and the interest shown in these new developments can serve as an example for the other states.

Future governmental support for IPM is well defined in the recent publication, *Sudan Country Strategy Note, 1997–2001: Partnership Towards Sustainable Human Development.* The document emphasizes that the Government of the Sudan is in pursuit of an integrated programme for environmentally sustainable development arising from challenges identified by the National Economic Salvation Conference and in Agenda 21 of the United Nations Conference on Environment and Development. There is, in the Sudan, substantial public awareness of the national ecological manifestations of environmental degradation and the socioeconomic dimensions underlying them. Government policy is to maintain biological diversity: to protect soils, forests and human settlements; reduce desertification and land degradation; ensure sustainable resource management through energy conservation programme components; integrate environmental accounting in economic planning and strengthen environmental assessment capacities at the national and regional levels. The government will strongly encourage and support integrated programmes which take into account the complex interrelations between agriculture, food security, environmental protection and poverty reduction.

On behalf of H.E., the Minister of Agriculture and Forestry, I wish to confirm that we consider the IPM an important vehicle for integrating all the above priorities, and we will provide all necessary support in using the IPM approach, especially the Farmers' First methodology used in the Field School developmental projects. New management in the Ministry will not only continue support to IPM but will also maintain the good tradition established by the previous Minister, Professor Ahmed Ali Genaif, in presenting IPM achievements in the Sudan to international forums. This experience will be used in further regional cooperation.

At last, I would like to take this opportunity to thank the Government of the Netherlands and the Food and Agriculture Organization for the long-term technical and financial support to the IPM activities in the Sudan. The savings on pesticide imports; the improvement of environmental quality in the Rahad and Gezira schemes due to the reduced aerial sprayings; development of IPM options for cotton, wheat and vegetable pests and the training of numerous researchers, extensionists, field inspectors and farmers are clear achievements and highlight the project's contributions and strong base for sustainable IPM in the Sudan.

Gezira State Policy on Integrated Pest Management

Anthony Achor Michael
Minister of Agriculture and Animal Resources
Gezira State, Wad Medani

I wish to express my sincere appreciation for your presence at the opening and closing ceremony of the Third Annual Review and Planning Meeting of the FAO/ARC IPM Project. On behalf of Gezira State, I would like to seize this opportunity to express my profound gratitude and appreciation to the Government of the Netherlands for the invaluable financial support rendered to this project for the last 15 years from the beginning through its different phases without any interruptions.I would also like to thank the Food and Agriculture Organization (FAO) for its great technical support which has contributed tremendously to the smooth execution of the project phases jointly with the ARC/IPM personnel.

The success of the project, as you may now realize, is the acquired great changes in knowledge, skills and attitudes of the farmers towards the proper use of pesticides, adoption of safety measures for the production of wholesome fruits and vegetables and general awareness about the protection of the environment against contamination through pesticide mismanagement. This has been achieved through the Farmer Field Schools (FFSs) with direct and effective participation of the farmers themselves in the development and implementation of the IPM options. There was a remarkable increase in the production of tomato, onion, eggplant and sweet melon crops especially in villages where FFSs were established. However, the IPM project has reached only approximately 1,000–1,200 vegetable farmers while the needs are much larger. We have 100,000 feddans (46,000 in irrigated schemes and 54,000 feddans with small-scale farmers) under vegetable production in our state. Our small-scale farmers produced 57% of the total vegetables and 84% of the fruits during the last two years.

It must be stressed here that national and international cooperation is essential. Closer harmony between different disciplines is very much needed to make IPM strategies workable for the control of pests and diseases of all crops in Gezira. It is my belief that this project has provided an alternative direction in pest control with which we are concerned and that the practice of IPM is absolutely essential to our situation in the Sudan, and Gezira State in particular. To confirm the relevance and usefulness of the IPM project and to emphasize its sustainability in Gezira, we have ventured a step forward. The State Department of Extension now has 40 male extensionists and 32 female extensionists. There are already 11 extension centres established in the remotest parts of the state. These centres are fully staffed; their main function is the distribution of agricultural tools, seeds, agrochemicals and sprayers. Our present plan is to transform these centres into IPM centres for FFSs and Rural Women Schools and integrate them with the four former Sudanese-German centres established by the services for vegetable and fruit farmers. There is already a well established IPM network in this state, and there are 17 FFSs and five RWSs.

The main task for our extension staff is the training of farmers, particularly in the rural communities where there is a tendency to use pesticides without taking the necessary precautions to avoid hazards and risks from uncorrected selection of pesticides. Farmers are to be trained to observe good methods of producing vegetables and fruits. They will aim at maximum crop returns with minimum production costs, reduce the number of pesticide sprays, consider ecological and sociological constraints of the ecosystem and ideally exploit natural resources of the state for self-dependency.

All departments of the Ministry of Agriculture are requested to work with the farmers' unions to improve crop production, marketing facilities and investment for seed production in order to increase the crops for export. Gezira is fully committed to continue state government support with basic cooperation from the farmers' unions. This is in addition to the support expected from the federal government.

The challenge to improve production of nutritious vegetables and fruits in Gezira State is tremendous. We have 73,700 feddans occupied by smallholders along the Blue Nile in addition to 2,375,600 feddans under large corporations. Our State Ministry policy is to increase food and cash production with a target of reaching self-sufficiency in sorghum, wheat, fruits, vegetables and livestock and to produce surplus for export. We are promoting an increase of cotton, groundnuts, sorghum, vegetables and fruits for export.

Our cooperation in the execution and continuity of the IPM programme in Gezira with the IPM Research and Training Centre of the ARC will be uninterrupted. With this statement, I am requesting the National Programme Director to prepare a complete budget for the period after October 1996, the terminal date for the project, and he should commit himself in writing as soon as possible.

Finally, I would like to congratulate all the participants and particularly those who have been involved in the practical drawing up of the recommendations during the last three days. I promise to put the recommendations related to our joint venture under the obligation of the State Ministry of Agriculture and will continue to render my support to these recommendations at the State Government level.

Statement: Netherlands Government

Peter R. Post
Counsellor
Royal Netherlands Embassy, Khartoum

It is a great honour and pleasure for me to be able to participate in this Annual Review and Planning Meeting, the more so since during the last 15 years the Netherlands Government has consistently supported the FAO in additional financing of several programmes on IPM in rice and rotational crops in Asia as well as in other continents. The IPM cotton programme has been financed for 15 years in the Sudan. I have been informed that at this very moment several FAO proposals in the field of IPM are being considered by my authorities for funding in addition to projects already initiated in Asia and Latin America. These are the Inter-country Programme on Development and Application of IPM for ten countries in Asia and Inter-country Programme for IPM Development in Vegetable Growing in south and southeast Asia for four countries.

Within the general framework of the Netherlands development cooperation policy, eradication of poverty has always been a central issue, and in this context a focus has been and will be on the rural poor. During the 1980s, a new dimension emerged: ecological crises and their consequences for poor farmers, men and women.

The uniform emphasis during the 1970s and 1980s on production and export has led to extreme over-exploitation of one of the most fundamental natural resources of humankind: the living soil, the basis for our food. Modern agriculture based on vast inputs of fossil fuel based chemicals, as well as fertilizers, pesticides, herbicides and engine power for traction and irrigation has led to top-soil erosion, salination and poisoning of the soil and underground water.

Depletion of natural resources and environmental degradation require a new approach. The UN Conference on Environment and Development in Rio de Janeiro was the culmination of political acceptance of the inter-linkage between environment and development. As of that moment sustainable development stood high on the agenda, if not to say Agenda 21.

While preparing my presentation today, I had to look into the IPM project file at our embassy. The first reports were gloomy and dramatic. Dr K. G. Eveleens (first project manager) and Prof. El Tigani El Amin (National Coordinator for Entomology Research at that time) reported in 1981 during the Xth Session of the FAO/UNEP Panel of Experts on Integrated Pest Control (Rome, 23–27 March 1981) as follows:

> Reviewing the problems of cotton crop protection in Sudan, the IX Session of the FAO/UNEP Panel in 1979 characterized cotton production in the country as being in the crisis phase and rapidly approaching the disaster phase. Developments in the year elapsed since this sombre assessment have done little to brighten the picture. Yields in the 1979/1980 season in the Gezira turned out to be the lowest in sixteen years, and provisional estimates for the 1980/1981 season indicated even worse harvests.

After 12 years, the project reported that the biological and ecological bases of IPM of cotton pests has been developed and fully implemented by all three major cotton schemes: Gezira, Rahad and New Halfa since the 1992/1993 season. Prof. Musa Mohamed Musa, the State Minister of Agriculture and the Chairman of the IPM Steering Committee informed me that a few years ago the average import of pesticides reached US$40 million and during the last two years only US$14 million, while the yield was at the same level.

I read with satisfaction the Tripartite Review Mission report of 1994 that the savings on chemical control of cotton and wheat pests during the last two years covered the total donor contribution for IPM over the last 12 years. More savings can be expected in the coming growing seasons. The quality of Sudanese cotton, I have been told, is increasing, whereas lint stickiness due to whitefly damages has significantly decreased. In 1995, the Gezira scheme was awarded the Gold Star by J. Ban Imagine Acrate S. A. of Spain for the quality of its cotton and in recognition of more than 70 years in the agricultural business. It is obvious that IPM implementation by scheme management and plant protectionists contributed to this success.

However, our deepest satisfaction comes from the partnership and close relations between researchers of the Agricultural Research Corporation with extensionists, field plant protectionists, agronomists and international staff.

We are very pleased with recent developments in the project: the focusing on developing and implementing IPM on vegetables where overuse of pesticides was noted in the past. The project is using the Farmer Field Schools approach which integrates researchers/extensionists and farmers in partnership relations. Other development projects supported by our grants are using or planning to introduce the concept of Farmer Field Schools in various areas of Darfur and Kordofan.

One of the challenges ahead is the further dissemination of information and implementation of IPM technologies in the vegetable sector. The international community, first and foremost the FAO (where possible and appropriate supported by bilateral donors) and the appropriate authorities and institutes of the Sudan have to face this challenge, thereby making use of experiences gained so far. The Annual Review and Planning Meeting provides a good opportunity to prepare for the challenges ahead.

The FAO/IPM project is trying to link our modern agricultural knowledge with basic and broader understanding of the ecosystem; this is only a beginning to more sustainable and healthy agricultural practices. The project priority is in the spirit of Agenda 21 to listen and cooperate with all partners in finding new ways to a really healthy and sustainable agriculture, including people and nature. The project, however, not only aims at reduced health hazards for farmers, increased production, higher revenues or environmentally sound and sustainable agricultural development, but it also aims at a sound ecological environment for our children and grandchildren.

Statement: Food and Agriculture Organization of the United Nations

G. G. M. Schulten
Senior Entomologist, Plant Protection Service (AGPP)
FAO, Rome

On behalf of the Director-General of FAO, I welcome you to the Third Review and Planning Meeting of project GCP/SUD/025/NET: Development and Application of Integrated Pest Management in Vegetables, Wheat and Cotton.

This meeting is more important than the two meetings that were held earlier. Let me explain why. This year the financial support given by the Netherlands through FAO will terminate. The reason is not that the project did not fulfil its objectives. On the contrary, FAO and the Government are convinced that this project has been very successful. It is the donor's policy, however, to provide assistance to projects for a limited period only. In our case, financial and technical assistance was given for about 15 years, which is more an exception than the rule.Therefore, at this meeting we should not only review the achievements of the past season, but we should also look for possibilities to continue the activities with national funds and identify priorities for additional multilateral fundings.

In our discussions we should ask ourselves if the activities undertaken really contributed or will contribute to the increase of farmer' incomes and to the improvement of their life in general.

The relevance of project activities for the farmer should be well documented to facilitate obtaining of funds for future activities.

Our views on agriculture, the use of inputs and the role of the farmer are rapidly changing. The need for sustainable agriculture with due attention to environmental concerns and the cost-effective use of inputs is becoming recognized worldwide. Sudan has made considerable progress in meeting these objectives since the start of the project in 1979. Many achievements will be reported at this meeting. I would like to highlight some of them. It can be stated without exaggeration that initially cotton production was focused on maximum obtainable yields with much pesticide usage. Pesticide-induced pest problems and ever increasing costs dictated the need for IPM. The project developed cost-effective IPM strategies for cotton and wheat that were adopted by the production schemes. The road to achieve this was not always easy, but the number of sprays has now been reduced to the absolutely necessary. It is now widely accepted that the objective of present days is no longer maximum yield but the most profitable yield. All efforts should be made not to fall back into the 'pesticide treadmill' after the termination of this project.

A second major achievement is the increase in IPM stakeholders. The development of IPM initially started as an ARC activity. During the four phase of the project, the number of collaborators increased considerably. The project at present is not only implemented by the ARC, but there is a strong collaboration with the production schemes, other entities of the Ministry of Agriculture, Natural Resources and Animal Wealth, in particular the Extension Department, the universities and, last but not least, the farmers' union and the farmers themselves. This collaboration should be maintained and further expanded.

At the start of the project in 1979, farmer participation was virtually nil. At a later stage, the farmers' union became involved and in the fourth phase, Farmer Field Schools became the main focus of attention. The necessity to involve farmers as early as possible in IPM development and to empower them with knowledge that allows them to take informed decisions for their particular situation has become widely accepted. This is a major achievement of the project.

A last achievement I would like to mention is the better understanding of IPM. The need for a holistic approach, in particular the growing of a "healthy" crop, based on improved varieties and the use of good agronomy has been adopted in the project implementation. In short, much progress has been made in IPM development and implementation that should be emphasized when national or external funding is being sought.

The main constraint for IPM and its sustainability has been the lack of national funds; I mean funds in cash and not in kind. I do not have to go into further details. We all know that the activities were almost exclusively financed from donor funds.

The question arises as to what action should be taken to continue IPM activities. In further planning, we should be aware that international technical assistance attaches more and more importance to the sustainability of programmes. National execution and commitment of national funds are considered important instruments in reaching this objective. Fund allocation depends on national priorities.

I have noted that the Ministry of Finance and Economic Planning has prepared a Country

Strategy Note 1997–2001 describing government priorities for the coming years. The further development and application of IPM can be a major contribution towards reaching objectives related to agricultural production, protection of the environment and human resource development.

Therefore, a national IPM programme needs to be formulated with realistic objectives, with well defined roles for the collaborating institutions. This programme should have two budgets, one for national funding and one for donor funding; It should be sent to competent authorities in order to secure the necessary funds. A time-table should be set for the preparation and submittal of this programme to ensure a smooth continuation of on-going IPM activities.

As I mentioned before, nowadays much importance is attached to national planning, funding and execution. This does not, however, mean that further assistance cannot be expected from FAO. Within the limitations of available funds, FAO will continue its assistance in promoting IPM, but this assistance will likely be different from the assistance that has been provided up till now.

It remains to thank the Organizing Committee for the preparations for this meeting and the IPM trainers, implementers and researchers who will present their findings and experiences in the coming days.

2

From Over-Reliance on Chemical Control to IPM

The Development of Integrated Pest Management in the Sudan: A Historical Perspective

El Tigani M. El Amin
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Wad Medani, Sudan

The development of the IPM programme on cotton in the Sudan is considered part of the activities initiated under the FAO/UNEP cooperative global programme on the development and application of integrated pest control in 1974. A number of developed and developing countries witnessed, in the 1960s and 1970s, the intensification of crop production accompanied by excessive use of pesticides. This led to the spread of pesticide resistance, particularly among insect pests, outbreaks caused by pesticide-induced resurgence of pests and unacceptable pesticide residues in market produce. These developments have identified a need to reduce dependence on chemical pesticides and to develop an integrated approach to pest management.

Chemical Pest Control on Cotton

Cotton is the most important cash crop upon which the Sudan relies for its foreign currency earnings. Most of the production is exported,but about 20% is locally used for the textile industry. Foreign currency earnings from cotton exports in 1989 exceeded US$ 200 million.

The most important constraint facing production since the1960s is pest control, which is continuously escalating due to the rise in prices of pesticides and the cost of application by air. Pest problems are due to insects, diseases and weeds. The important economic pests of cotton are the cotton jassid (*Jacobiasca lybica* [de Berg]), the American bollworm (*Helicoverpa-[Heliothis] armigera* [Hb.]), the cotton whitefly (*Bemisia tabaci* [Genn.]) and the cotton aphid (*Aphis gossypii* Glover) which were responsible for about 40% loss of yield and the reduction of cotton quality due to stickiness caused by honeydew excreted by whiteflies and aphids.

Entomological research in the Sudan began as early as 1907. At that time, the work was mainly confined to surveys and identification of crop pests with emphasis on the desert locust (*Schistocerca gregaria* Forsk).

With the advent of cotton growing under irrigation in 1911, many insect pests occurred as major pests to the crop. Agricultural entomological research was mainly concerned with solving these pest problems, e.g., the pink bollworm (*Pectinophora gossypiella* Saund), cotton flea beetle (*Podagrica puncticollis* Weise), termites (*Microtermis thoracalis* Sjost) and thrips (*Caliothrips fumipennis* Bagn and Cam. and *Caliothrips sudanensis* Bagn and Cam.). Until the mid-1940s, non-chemical measures were the only methods used for reducing insect damage to cotton. These measures mainly included legislative, cultural, breeding and physical methods of control. Much attention was given to field sanitation, proper tillage practices, balanced crop rotations and strict adherence to the recommended agronomic practices. In addition, legislative control measures were strictly enforced, thus the carry-over of pests and diseases from one season to another was minimal.

Modification of the non-chemical control strategy was inevitable after the 20–66 % increase in cotton yield resulting from a single application of DDT (Snow and Taylor, 1952). This modified strategy aims mainly at helping the farmer to produce cotton economically by depending both on chemical and non-chemical methods of pest control. It also aims at minimizing ecological imbalance and pest control measures during the first two decades following the implementation of this strategy (i.e., during the period 1946–1965). However, in the late 1960s it was found both technically feasible and economically justifiable to lay greater emphasis on chemical pesticides. This change in policy was probably dictated by two main factors: The increasing importance of minor pests, namely *H. armigera* and *Bemisia tabaci*, for which no specific non-chemical control measures were known; and the considerable yield response due to incremental application of insecticides (El Bashir, 1986a,b).

The continuous use of DDT for the control of jassids and other cotton pests has created conditions favourable for the development and multiplication of the cotton whitefly (Joyce, 1955; Joyce and Roberts, 1959). Similarly, the frequent application of DDT and other chlorinated hydrocarbons, the increasing use of organophosphate (OP) insecticides and changes in cropping patterns have all led to the resurgence of the bollworm (*H. armigera*).

However, the strategy for dealing with these damaging pests has, unfortunately, depended entirely on chemical pesticides. Hence, each cotton production scheme or corporation created its own plant protection unit with the specific objective of achieving good control of pests without increasing current crop protection budgets. These plant protection units have also been entrusted with the costly enforcement of phytosanitary laws which used to be carried out by the Plant Protection Department of the Ministry of Agriculture, Food and Natural Resources. Under these circumstances, strict implementation of the necessary legislative and cultural pest control measures was highly improbable. Furthermore, the lack of properly equipped extension service together with the lenient attitude of management towards undisciplined and careless tenants have helped to diminish the value of proper cultural practices within the farming community (El Bashir, 1986a).

Cultural methods of control necessitated the use of rotation involving too much fallow. Later, during the 1960s, the Gezira rotation was considered wasteful. This came at about the same time cotton prices fell very sharply in international markets. Prices of extra-long staple cotton fell from about US$ 1.30 per pound in 1951 in the Liverpool market to below US$ 0.40 in the early 1960s. Farmers' incomes followed a similar fall. The net income of farmers fell to less than £2/feddan in the 1963/1964 season but then rose to about £10/feddan until the season of 1967/1968. Hence, a farmer's annual income from cotton was about £20 pounds per year in 1963/1964 and only about £100 thereafter until the 1967/1968 season (Hakim and Mohamed, 1986). The fall in farmers' incomes led to serious unrest. The Nile Water Agreement in 1959 intensified the rotation in Gezira and other cotton producing schemes. The purpose of the intensification programme was to utilize wasteful fallow, raise the farmers' incomes and utilize water of Roseires Dam.

The area under wheat and groundnuts was gradually increased. The wheat area increased from about 7,000 feddans in 1961/1962 to 600,000 feddans in 1975/1976. Similarly, the area under groundnuts increased from about 57,000 feddans to about 450,000 feddans in 1975/1976. The intensification programme increased the incidence of insect pests and limited the effectiveness of cultural methods of control. Spraying chemicals against pests started as early as 1946 when DDT was used against jassids in Gezira. However, since the mid-1960s, spraying against insect pests has gradually increased from an average of four sprays in 1966/1967 to seven sprays in 1976/1977. The increasing use of insecticides on cotton became a big burden on the foreign exchange reserves of the country.

The cotton jassid was considered a principal insect pest of cotton before 1964. In the 1970s, it was still potentially one of the most damaging pests, yet it was not encountered at economic threshold levels after the first spray which was targeted against the American bollworm *(H. armigera* [Hbn]) and the whitefly *(Bemisia tabaci* [Genn]). The American bollworm and the whitefly have dominated the scene since the early 1960s and are now considered to be the major pests of cotton.

The outbreaks of previously secondary pests on cotton have attracted the attention of national and international plant protection researchers. The critical evaluation of pest control strategies was included in the International Workshop on Agricultural Research and Development in the Sudan jointly organized by the Agricultural Research Corporation and the Ford Foundation (USA) in November 1976. Dr Lukas Brader, Chief, Plant Protection Services and Coordinator of the FAO/UNEP Global Programmes for Integrated Pest Control had invited researchers to present papers (Brader, 1976). He stressed the need to shift emphasis from testing new pesticides to more integrated research by developing a nucleus of well-trained entomologists specialized in specific crops. They should first develop a better insight in the pest problems of the major crops and then establish the economic importance of the present pests and study and develop the most effective and economic chemical control programme to cover immediate needs. The next step should be developing and implementing an integrated pest control programme on cotton. New IPC should be tested as early as possible to demonstrate and implement results in practice. This would be the only approach to overcome the ever increasing use of pesticides in cotton growing. Development of an IPM strategy would require research on the economic importance of the major insect pests species in various crops; relationships between pest numbers and crop losses; relationships between crop development and pest attack to identify the best possibilities for cultural control methods; breeding pest resistant varieties; toxicity of pesticides towards the natural enemies of major pest species.

Symposium on Crop Pest Management, Khartoum, February 1978

The negative consequences of over-reliance on pesticides and escalating costs of chemical pest control since 1960s were addressed by national and international participants of the symposium on crop pest management in the Sudan held in February 1978 in Khartoum. Special focus was on the effect of DDT on the cotton pests and on "package deals". Prof. El Sayed El Bashir presented documented justification to critically review "the package deal". He emphasized that the package deal concept appealed to many cotton producers, epecially the Sudan Gezira Board, late in the 1960s when severe crop losses caused by *Helicoverpa armigera* were experienced. This highly mobile insect was, at that time, a relatively new pest for which effective control programmes had not yet been fully developed in the Gezira. Besides, little was known about its behaviour, flight activity, dispersal and breeding behaviour.

The package deal system looked as if it were a serious attempt by competing pesticide manufacturing firms to transfer advanced pest control technology to developing countries. That was probably why the research component of these projects was carefully worked out to produce some dramatic results which could be used to convince production managers and politicians of the value of this system (El Bashir, 1986b).

However, as soon as the success of the small-scale project was shown, the whole activity became a difficult commercial undertaking because the size of the project was too small to justify the heavy investment in research and demonstration. Hence, a request was automatically put forward for more land to be treated against cost so that the prohibitive spending on research could be met.

Large-scale implementation of the package deal quickly showed that the strategy was totally incompatible with the concept of IPC. This was because it was based mainly on an economic use of a single proprietary insecticide or mixtures containing it during the short period of one season. Besides, spraying schedules and dosage rates of these chemicals were left entirely to the choice of the contracting firm. CIBA-GEIGY was mainly using Nuvacron: Montedison, Dimethoate and Rhone Poulenc, Thimul. All three companies used the ultra low volume spraying technique, with CIBA-GEIGY opting for the so-called sequential spraying (Joyce, 1975) or split dose application method. Crop spraying was performed with the objective of saving the growing plants but without much forward looking pest management considerations. Accordingly, frequent applications amounting to 12 sprays in a single season were not uncommon.

As a result of this strategy, which was entirely directed towards the control of *H. armigera* (Anon., 1971; Anon., 1976), a much more serious pest, *Bemisia tabaci*, developed. According to a CIBA-GEIGY report (Anon., 1971), the most important pest in the Gezira in the 1970/1971 season was *H. armigera*, and that after the first week of November, the incidence of all pests was low and without economic importance. That was the reason why both CIBA-GEIGY and Montedison emphasized the *H. armigera* question in their research proposals. However, despite the highly advanced pest control techniques claimed to be employed by these and other spraying contractors, the whitefly has become the major pest of cotton. In addition, frequent applications of split doses of a chemical such as Nuvacron, which was known to have poor activity against some Lepidoptera (El Tayeb, 1977) could create future pest control problems (El Bashir, 1986b).

The participants discussed in some depth the package deal system of pest control. The consensus was that the system seems to offer an easy and relatively efficient way of pesticide application; however, it had serious inherent weaknesses which are bound to jeopardize future crop protection programmes. These include the complete dependence of the grower on a contractor who is to provide the pesticide and apply it on a profit/loss basis. Often, the practices used in the package deal areas do not follow the recommendations of official government committees such as the Pests and Diseases Committee. Other weakenesses were the continuous use of a limited number of proprietory chemicals, perpetuation of over-reliance on pesticides as the primary method of pest control, elimination of commercial competition in the purchase and application of pesticides, weakening of local technical capabilities to carry out an effective pest control programme, lack of guarantee on cotton quality and yield and the non-separation of commercial and research interests. In the light of these drawbacks, it was recommended that the system should be critically reviewed with the intention of replacing it with a more ecologically based and environmentally sound pest control approach (Anon., 1986; El Bashir et al., 1986).

The Symposium also reviewed various aspects of IPC by observing and discussing results from different countries. Considering the economic and environmental benefits, it was recommended that every effort should be made to develop and apply IPC in the Sudan on cotton and the rotational crops. Activities should include:

- Exploration of current knowledge on the reduction of pest incidence, e.g., early clean-up of crop residues;
- Adaptive research on matters such as biological control, varietal resistance, sampling methods, pest and disease forecasting, crop loss assessments;
- Development of an effective extension delivery system which is to be closely related to research centres (Anon., 1986).

Inter-Country Project on Integrated Pest Control

The FAO/UNEP Cooperative Global Programme on Development and Application of Integrated Pest Control (IPC) was established in 1974 by the FAO/UNEP Panel of IPC Experts who recommended a setup of two IPC Regional

Stations, one in Latin America and one for south and southeast Asia. Top priority was given to rice and cotton. It was realized that cotton had played an important role in the economy of most developing countries in the last 50 years and that it was the major source of hard currency. Cotton harbours, however, more than 150 insect species, some of them causing serious crop losses. Throughout the world, cotton received and still receives more pesticide applications than any other crop. The number of sprays in many cotton growing countries have varied between 7 and 18, especially in Africa and Latin America. The Inter-Country Programme for IPC in Latin America was initiated by FAO and funded by UNDP in Nicaragua in June 1976.

In 1975, the FAO global coordinator for the IPC programme informed the Ministers of Agriculture in the Sudan, Egypt, Ethiopia, Somalia, Uganda, Kenya and Tanzania that FAO intended to select a cotton growing country in northeastern Africa as the main base for the African Regional IPC programme.

The FAO/UNEP IPC consultation mission on cotton pests visited Egypt, Sudan, Ethiopia, Uganda and Tanzania in 1976. The mission nominated the Sudan as the most suitable country because of the vital importance of cotton for the well being of the Sudanese people and because of the seriousness of crop losses caused by insect pests. Other factors influencing this choice were the severity of the economic and environmental impact of increased use of chemical insecticides, availability of facilities for field trials in well-developed research stations with a long tradition of cotton crop protection management, high standard of crop management and wide range of agro-ecological conditions and technologies used in cotton production under irrigation and rains. The authorities of the Central Ministry of Agriculture, the Agricultural Research Corporation (ARC) and other agricultural institutions and organizations had also expressed interest in the establishment of this project in the Sudan.

The first proposal was finalized in October 1976 by the FAO/UNEP global programme coordinator and the Sudanese authorities. The title of the project was "The African Inter-country programme for the development and application of integrated pest control (IPC) in cotton growing" and was based at the Gezira Research Station, Wad Medani, hosting both regional and national IPC activities.

The financial funds of US$150,000 from FAO/UNEP were planned to cover IPM project preparation and activities in the African region. Because some changes in the first project draft were made in February 1978 to provide a better reflection of Sudanese need and also to take into account FAO and donor requirements, the IPM regional activity was suspended and limited to the initial Sudan inter-country project phase as from February 1978 to April 1979. At this stage, the name of the project was "Development and Application of IPC on Cotton in the Sudan". Funds from the Sudan Government of LS 708,700 were considered as a local component to cover salaries for staff, drivers and casual workers; land preparation; fuel for the IPM experimental area. Funds from the donor (the Netherlands Government through FAO) amounted to US$ 991,300 and were for recruitment of expatriate experts for development of IPM, purchase of field research vehicles and equipment, training activities and operational costs.

Dr K.G. Eveleens, IPC specialist, was nominated by FAO/UNDP and endorsed by the Sudanese authorities; he took up his assignment at the Gezira Research Station of the Agricultural Research Corporation (ARC), Wad Medani, in February 1978 as a team leader. Dr Asim A. Abdelrahman, senior research entomologist of the ARC was his national counterpart (Table 1). However, when the Sudan country project began at the end of 1979, in concurrence with the temporary suspension of UNEP funding for regional activities, the regional programme leader was transferred to a field trial programme relating to the establishment of criteria for proper timing of initiation of insecticidal spraying in early season. The FAO/UNEP Panel of IPC Experts closely monitored developments on IPC by the new programme in the Sudan. In October 1978, Dr El Tigani M. El Amin, National Coordinator for Entomology Research, ARC, was invited to visit the FAO Headquarters in Rome to discuss recommendations of the eighth meeting of FAO/UNEP Panel of Experts on IPC held in Rome 4–8 September 1978. There was a possibility of holding the next meeting of the Panel in December 1979 in the Sudan; also on the agenda was extension of the IPC project in Sudan with financial support from the Netherlands.

The Panel noted with satisfaction that the IPC project in the Sudan under leadership of Dr K.G. Eveleens had already started to investigate the status of cotton pest problems and the establishment of research priorities for the implementation of an effective IPC programme (FAO, 1979). The request for the project's extension had been presented by Dr L. Brader, Chief, Plant Protection Service, FAO, Rome and Dr El Tigani M. El Amin to H.E. Ambassador of the Netherlands in Rome in October 1978. In November 1979, the project title was changed to "The Development and Application of Integrated Pest Control in Cotton and Rotation Food Crops" (GCP/SUD/025/NET) as an FAO executed project in the Global Programme on Integrated Pest Control and financed by the Directorate-General for International Cooperation of the Netherlands, Ministry of Foreign Affairs from its International Research Fund.

Table 1. Staff of the IPC project on cotton in the Sudan, Phase I, 1979–1983

Name	Function	Starting	Ending
Dr K.G. Eveleens	Team Leader	1.2.1978	15.7.1982
Dr O.S. Bindra	Host plant resistance expert	11.8.1980	15.7.1982
Mr R.V. Van Gent	Assoc. expert, Biological Control	23.3.1981	May 1983
Mr D.W. Sippel	Assoc. expert, Host Plant Resistance	13.10.1982	July 1983
International Consultations			
Dr L. Brader	FAO Global IPM Programme Coordinator, Rome	20.11.1976	25.11.1976
Dr L. Brader	Chief, FAO Plant Protection Service, Rome	9.1.1981	19.1.1981
Dr O.G. Beingolea	Expert, Biological Control and IPM study areas	18.10.1981	2.11.1981
National Counterparts (ARC)			
Dr Asim A. Abdelrahman	Senior Research Entomologist and Team Leader Counterpart	1.2.1978 1.2.1978	15.7.1982 31.10.1996
Dr Hassan Khalifa	Senior Cotton Breeder, Host Plant Resistance Specialist	15.10.1980	15.7.1982
Dr Ahmed Nasr Balla	Senior Research Entomologist, IPM Specialist	1.8.1981	1983
National Coordinators (ARC), Gezira and Rahad Scheme			
Prof El Tigani M. El Amin	National Coordinator, Entomology Research and Senior Research Entomologist	1.2.1978	1983
Dr Osman I. Gameel	Head, Entomology, GRS Senior Research Entomologist	1.2.1978	1983
Dr N.M.Nasr Eldin	Director, Crop Protection, Gezira Scheme; Senior Field Entomologist	1.5.1978	1983
Dr Musa A. Ahmed	Senior Research Entomologist and Taxonomist; Head, Insect Museum, ARC	1.2.1978	1983
Mr Galal H. Osman	Deputy Director, Crop Protection, Gezira Scheme and Senior Field Entomologist	1.8.1983	1983
Mr A.A. Talab	Director, Crop Protection, Rahad and Senior Field Entomologist	15.9.1978	1983
Mr H. Abbas Eltom	Director, Plant Protection, Ministry of Agriculture, Khartoum; Senior Field Entomologist		

FAO/UNEP Meeting on Sudanese Cotton Production Crisis, December 1979

The meeting discussed the results of the strategy of the FAO IPC project. Cotton production in the Sudan was in the crisis phase and rapidly approaching disaster phase where the produced cotton would not sell on the world market because of the stickiness of lint which could not be processed in modern textile mills. The field data indicated that rapidly developing strains of whiteflies were resistant to OP insecticides. For example, monocrotophos formerly provided effective control of the whitefly, but in 1977–1978 whiteflies were out of control in fields that had been sprayed as many as 11 times with this insecticide. This indicated that the whitefly population had concentrated the genes that confer resistance to monocrotophos.

The Panel addressed a number of questions: Could whitefly outbreaks be avoided? Could jassid and *Helicoverpa* sprays be manipulated so as to conserve parasites and predators of the whitefly? Could planting dates be altered so as to reduce the need for *Helicoverpa* or jassid sprays? Could the choice of insecticides and dosages be restricted to selective compounds that do the least damage to pest natural enemies? Could broadcast sprays be avoided so that only infected fields are treated? It was recommended that first sprays be delayed as long as possible and that they should be applied only when absolutely necessary based on the presence of an economically damaging infestation because that the first spray does the most damage to pest natural enemies and commits the manager to a season using a sequence of sprays (Anon., 1979). Suggestions were to undertake long-term research on resistant varieties, biological control, cultural practices, host manipulation and the judicious use of chemicals.

FAO/ARC IPC Project

Identification of Factors Responsible for Crisis

The first workplan of the IPC project in the Sudan included the following:

- Rotational cropping system in relation to pest incidence on cotton;
- Treatment at the threshold level of the cotton insect pests;
- Insect scouting system versus the traditional method of insect pest controls on cotton;
- Evaluation of the significance of natural biological control agents and the effects on these by insecticidal chemicals;
- Plant growth pattern in relation to the injury caused by insect pests;
- Possibilities for using pest resistant varieties.

Field work started in the 1978/1979 growing season on 45 feddans in the Gezira Experimental Farm, Gezira Scheme (Seed Farm, Barakat) and Rahad Agricultural Corporation. Each study area was divided into three components: untreated with pesticides; currently used methods of cotton pest control and integrated pest control approach. The trials helped to identify factors responsible for the crisis in cotton production. They emphasized that in spite of the FAO/UNEP Panel warning that the cotton production crisis phase was rapidly approaching the disaster phase, developments in the year elapsed had done little to brighten the picture. Yields in the 1979/1980 season in the Gezira, the oldest and largest production scheme, turned out to be the lowest in sixteen years, and provisional estimates for the 1980/1981 season indicated even worse harvests (Eveleens and El Amin, 1981). They observed that complex interacting factors, socioeconomical as well as technical, were responsible for the crisis. The increasing failure of currently applied chemical insecticide treatments to provide effective crop protection resulted in a treadmill of more and more sprays being applied with less and less results. The principal pest incriminated in this development was the cotton whitefly, *Bemisia tabaci* [Genn]. The chronic outbreak of this pest not only adversely affected plant growth and development but also resulted in contamination of lint by honey dew secretion which increasingly detracted from the export value of Sudanese cotton, especially medium-staple varieties.

In a special meeting held in January 1981 to formulate cotton crop protection strategies for the 1981/1982 season, the Ministry of Agriculture reported that expenditures incurred for purchase and application of chemicals for crop protection in the 1980/1981 season had risen to US$65 million which represents approximately one-fourth of the yield returns (Table 2). In spite of this increasing outlay, whitefly infestations were as severe as ever. Dissatisfaction with this situation led to the adoption of important changes in crop protection policies, namely, abolition of DDT or DDT containing mixtures and discontinuation of the package deal arrangements on crop spraying with agro-chemical companies. Both decisions entailed significant changes from the established practice.

Table 2. Purchase of pesticides by Sudan

Years	US$Million
1980/1981	65
Av. 1990/1991	40
Av. 1992–1995	12

Exclusion of DDT

Until the 1980/1981 season, DDT was the most commonly applied insecticide on irrigated cotton in Sudan, usually in combination with other compounds in such popular insecticidal mixtures as DDT/dimethoate, Torbidan (methylparathion/DDT/toxaphene). DDT being a cheap and effective control agent for *(H. armigera)* and cotton jassid, its usage had persisted notwithstanding strong evidence of outbreak inducing action on whitefly in Sudan and elsewhere. Because of developments in the 1970s, with whitefly as a cotton pest eclipsing both bollworm and jassid, the opinion had gained ground that this disadvantage of DDT had come to outweigh its advantages. As to the substitutes for DDT for bollworm and jassid control, the schemes increased the use of endosulfan as well as some pyrethroid compounds like cypermethrin (Ripcord) and decamethrin (Decis).

Termination of the Package Deal

The package deal was a contractual agreement between the management of a crop-growing corporation and a pesticide producing company. Since the inception of the package deal in the 1971/1972 cotton growing season with an allocation of 5,000 feddans in the Gezira scheme, the areas under package deal contract rapidly increased to a maximum in the 1978/1979 season, when almost half of the Gezira and substantial portions of other schemes were covered. In the years since, dissatisfaction with the standard of whitefly control in the package deal areas grew rapidly and resulted in the decision to abolish the system altogether from the 1981/1982 season (FAO, 1983). The forced termination of the package deal occurred not more than ten years after its introduction in the Sudan.This was a striking example of how a strategy, which had been developed on a solid base of scientific research, could precipitate into failure in a short time.

The end of the package deal has had some consequences for the development of institutional crop protection expertise. Responsibilities for crop protection in the areas, formerly under package deal contract have returned to the previous crop protection units of the schemes. During the time of operation of the package deal, however, such crop protection apparatus suffered eutrophication in those areas where commercial company staff had taken over responsibility for pest control. Considerable efforts had to be made to bring about the necessary restoration of these crop protection units.

Project Field Activities

First field experiments were directed to establishing of criteria for proper timing of initiation of insecticidal spraying in early season; field observations on natural biological control of the cotton whitefly; host plant resistance breeding; and modification of cultural control practices such as observing the effect of selected agronomic practices—amount of nitrogen, crop density and the timing of the termination of watering on the population dynamic of the whitefly on cotton (Eveleens and Abdelrahman, 1979; FAO, 1983).

Dr Eveleens left the Project on 15 July 1982. The work was continued by the Sudanese counterparts and new experts (Table 1).

Dr O.S. Bindra, Host Plant Resistant Expert, joined the IPM project in August 1980 and left the Sudan in July 1982. His national counterpart was Dr Hassan Khalifa, Senior Cotton Breeder and National Coordinator for Cotton Research. Their programme of work and area of engagement for 1980/1982 included observations of natural biological control of the cotton whitefly (*Bemisia tabaci*); observations of pest incidence, breeding lines and selection for resistance in different long and short cotton varieties; establishment of cotton pilot area to execute research objectives on various components of IPM.

The contribution of the international and national staff in formulating an IPC strategy for cotton indicated that the economic threshold level (ETL) for whitefly, an important pest in cotton in Sudan, could be increased without causing a decrease in quality of cotton lint. Most studies of plant resistance to whitefly showed that resistance was conferred by two factors, low leaf-hair density and leaf shapes, which led to the selection and release of the variety Sudac-K. Related developments during this period were the withdrawal of DDT and DDT mixtures from the Sudan and the abolition of the package deal starting with the 1981/1982 cotton season.

Dr O.S. Bindra left the Project in July 1982. Donor support from the International Research Budget and allocated for the initiating phase of research activities ended in October 1982. The project work was continued by the national counterparts.

The project activities were reviewed by Prof. V. Delucchi representing the FAO and Mr L. Razoux Schulz representing the Netherlands Government. The Mission acknowledged significant progress made in the Sudan in initiating IPC activities on cotton and recommended extension of the Project for the second phase.

The activities of the second phase concentrated on preparation of an inventory of natural enemies of the key cotton pests; development of biological control strategies for American bollworm, aphids and whitefly; analysis of the cotton ecosystem; and organization of large-scale demonstrations in commercial fields to show that less pesticide could be used without yield reduction.

Third phase achievements were revision of ETLs through large-scale field tests in the cotton production scheme; improving the role of biological control in cotton crop protection; and initiation of research and demonstration activities for food crops and cotton rotation.

During all phases, training was an important project component; both local training courses and international training (fellowships, study tours) were organized. The main activity was the organization of workshops on IPM for different target groups. Extension activities were initiated in Phase II and began to play a major role in Phase III with the aim of familiarizing advisers, farmers and women with the principles of IPM.

Tripartite evaluation of Phase III and formation of Phase IV were done in February 1992. The Evaluation Mission noted the significant achievements made by the project, especially in better scientific understanding of the cotton agro-ecosystem resulting in improved biological control through importations and augmentation of natural enemies and reduced pesticide use. New ETLs resulted in higher profits and fewer health and environmental risks. The Mission emphasized the increased awareness and appreciation for IPM by farmers, scheme managers, researchers and policy makers. They recommended that this successful project be extended into a fourth phase, targeted towards the development of IPM for vegetables (where pesticide misuse and risks for health and environment are large), with a minor part of the inputs to be spent on IPM on cotton and wheat.

The recommendation was approved by the FAO and the donor, and the project entered its fourth phase in January 1993 for three years with a substantial shift from cotton to vegetables and cereals. The new project title is "Development and Application of Integrated Pest Management in Vegetables, Wheat and Cotton."

All phases of the project have been funded through generous grants from the Netherlands Government. The budget allocation was US$1 million for the first phase, US$1.4 million for the second phase, US$2.9 million for the third phase, and about US$3 million for the fourth phase. This continuous support from the Netherlands and international organizations such as FAO, UNEP and UNDP demonstrates the importance of the IPM project, through which substantial improvements in agricultural production, protection of the environment and quality of life are envisaged.

Summary

The first phase of the project started during the crisis in cotton plant protection and production in the Sudan. The field data collected in the 1978 and 1979 seasons had supported Prof. El Sayed El Bashir's criticism on package deal arrangements and numerous objections expressed by Sudanese entomologists to using DDT in cotton control expressed during the symposium on "Crop Pest Management in the Sudan", February 1978, Khartoum. Both the package deal and use of DDT were abolished in 1981.

Further successful expansion of the project into the present full scale cooperative activities embracing hundreds of national researchers, extensionists, field agronomists and entomologists working together with the international IPM experts has been achieved through various favourable factors such as long-term continuous support by the donor. It has been recently realized that an appropriate time frame is needed for proper implementation of a sound IPM strategy. In the past, most donor financed IPM projects had ceased too quickly. There was acceptance of the IPM approach by researchers, scheme managers and national policy makers in the Sudan, and there was provision of technical expertise first by the FAO/UNEP Panel of Experts in IPC followed by recruitment of international IPM experts and regular backstopping missions from the FAO Plant Protection Services.

Cotton Pest Resistance in the Sudan: Status Quo

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Pest resistance to pesticides has now been widely spread, particularly in the developed countries and in some of the developing countries. The development of resistance to modern organic insecticides has attracted much attention (Whittermore, 1973; Oppenoorth and Welling, 1976). This phenomenon may be said to occur when a pest can no longer be controlled by a treatment that was previously effective. The pest is not usually immune, for it can still be killed, if enough chemical is applied (Johnes and Johnes, 1984). The phenomenon whereby an insect population becomes resistant to two or more chemically distinct insecticides as a result of selection by one insecticide only is called *cross-resistance* (Bettini et al., 1970; Whittermore, 1973). The term *multiple-resistance* is used to denote simultaneous resistance of the pest to two or more insecticides as a result of successive simultaneous exposure to the same insecticide, due to the presence of several different mechanisms (Bettini et al., 1970).

The issue of the development of resistance to insecticides was covered by Bettini et al. (1970), Brown and Pal (1971), and Sawicki (1983). The mechanism of resistance to insecticides was covered by Hassal (1982), Bull (1982) and Georghiou and Taylor (1986). The following authors discussed the issue of genetics of resistance: Crow (1957), Bettini et al. (1970), Brown and Pal (1971) and Plapp (1986). Leeper et al. (1986) and Brent (1986) dealt with the issue of monitoring and managing resistance and, finally, Sawicki (1983) suggested some more permanent solutions for management of resistance to pesticides.

The introduction of cotton spraying started in 1945/1946 in the Gezira Scheme (Osman and Balla, 1985). Prior to 1963 an average of one spray per season or less was applied, mainly against the jassids (*Jacobiasca lybica* [de Berg]) and to some extent the whiteflies (WF) (*Bemisia tabaci* [Genn.]) and the flea beetles (FB) (*Podagrica puncticollis* [Weise.]). After the outbreak of the American bollworm (ABW) (*Helicoverpa armigera* [Hub.]) in 1963, the high infestation of WF and the relative abundance of the cotton aphids (CA) (*Aphis gossypii* [Glov.]), the number of sprays has gradually increased.

About 28 insecticides and various compatible combinations are registered for use on cotton, and 17 insecticides are used to control WF. Of these, the most widely used is Torbidan (Toxaphene + methyl parathion), endosulfan, dimethoate, monocrotophos as ECs and ULVs (Ahmed, 1984; Abdeldaffie, 1984). Since the early 1960s, the WF was controlled with one or two sprays of dimethoate or endrin applied to cotton in the Gezira (Gameel, 1969; Eltayeb et al., 1986).

In the Sudan, insecticides approved for the control of cotton WF are dimethoate, dicrotophos, chlorpyrifos, quinalphos, endosulfan, formothion, aldicarb, phosphamidon, phenthoate, monocrotophos, methomyl, malathion and dichlorvos. These insecticides are used either alone or as mixtures (Elamin et al., 1980). In addition, the following chemicals, alone or in mixtures, were later recommended: Danitol-S 20 EC, CGA 106630-50 SC, Thiodan 50 EC + Triazophos 40 EC, Ekatin WF 35 + Danitol-S 50 EC, Danitol-S 50 EC + Curacron 400 EC, Endophos 32/16 EC, Thimulone 25/20 EC, Chlorpyrifos + Endosulfan, Thiocyclan hydrogen oxalate, Cypermethrin + Profenophos methyl ULV, Lambda Cyhalothrin, Pirimiphos methyl ULV, Baythoid/Morestan and several other compounds (Gameel and Hassan, 1989);

The resistance phenomenon was studied in the Sudan in four major cotton pests: *Bemisa tabaci, Aphis gossypii, Earias insulana* (Boisd.) and *Podogrica puncticollis.*

Cotton Whitefly (*Bemisia tabaci*)

The resistance of *B. tabaci* to insecticides in the Sudan was studied in season 1981/1982 as compared with a standard susceptible strain. The Sudanese field strain proved to be highly resistant to dimethoate and monocrotophos; moderately resistant to dicrotophos and quinalphos and slightly resistant to DDT, endosulfan and profenophos (Dittrich and Ernst, 1983).

Ahmed (1984) and Abdeldaffie (1984) studied the resistance to some commonly used insecticides belonging to different groups, viz. organochlorines, OPs, carbamates, pyrethroids and formamidines in the Gezira Scheme. Ahmed et al., (1987) found that the strain collected from Barakat is highly resistant to dimethoate and endosulfan and; moderately resistant to amitraz when compared to those of the dead-season WF. The resistance ratio (RR) obtained for the adults and nymphs of the Barakat population were as follows: dimethoate, 454x and 257x; endosulfan, 364x and 5x; dimethoate/endosulfan mixture, 10x and 7x; methomyl, 8x for both; amitraz, 6x and 2x; and amitraz/endosulfan mixture, 5x and 3x, respectively. The adults of the dead-season population showed lower levels of resistance to amitraz (7x), amitraz/endosulfan mixture (3x) and endosulfan (3x). Their nymphs showed moderate resistance levels to dimethoate (25x), amitraz (8x), and dimethoate/endosolfan mixture (3x).

Abdeldaffie (1984) found the RR of the Barakat population for adults and nymphs to chlorfenvinphos/endosulfan mixtures, 5x and 2.28x; deltamethrin, 25x and 4.43x; deltamethrin/endosulfan mixture, 2.5x and 2.68x, respectively.

According to Yassin (1987), endosulfan proved to be more toxic to *B. tabaci* than chlorpyrifos, and endosulfan/chlorpyrifos mixtures were more toxic than chlorpyrifos alone. His results confirmed that the mixture demonstrated additive effects at the LC50 level and a potentiation effect at the LC90 level. El Zubair (1990) studied the pattern of resistance in three WF populations when exposed to specific chemicals, viz. dimethoate, endosulfan, deltamethrin, profenophos and amitraz. The first population was collected from Tayba Block (Gezira Scheme) during the period February–March. The second population was collected from the same location but during the period October–January. The third was collected from the University of Gezira farm (Wad Medani) during the period July–August. The first population (i.e., the dead-season population) showed moderate level of resistance, and endosulfan was the most efficient, followed by deltamethrin; dimethoate proved to be the weakest of the three. The October–January population (the cotton-season population) proved to be the most resistant of the three populations; deltamethrin proved to be the most efficient, followed by endosulfan; again, dimethoate was very weak. The third population (no history of insecticide use) was the most susceptible of the three populations, especially to endosulfan, followed by deltamethrin, dimethoate and profenophos.

Assad (1990) studied the effects of some insecticides on *B. tabaci* control and development of resistance. The chemicals tested in the field and the laboratory were endosulfan, deltamethrin and chlorpyrifos. The field was sprayed with the specific chemical three times in season 1989/1989, and five times in season 1989/1990. The field study revealed that endosulfan and deltamethrin were the most effective treatments. However, none of the chemicals dropped the WF population below the then adopted ETL (i.e., 200 adults/100 L). The bioassay tests revealed:

- The endosulfan population developed high levels of resistance to deltamethrin after three endosulfan sprays (RR from 3.17x to 30.4x) to chlorpyrifos (from 1.5x to 15.7x) and to endosulfan itself (from 1.7x to 30.4x).
- Resistance of the deltamethrin population to endosulfan and chlorpyrifos had risen after three deltamethrin field sprays: for endosulfan from 2.4x to 5.9x, for chlorpyrifos from 2.0x to 6x and for deltamethrin from 3.4x to 14.8x.
- The chlorpyrifos population showed high level of resistance to deltamethrin (from 2.9 to19.0x) and moderate levels to endosulfan (from 1.6 to 5.9x) and chlorpyrifos itself (from 1.8 to 7.1x) after three chlorpyrifos field sprays.

Generally, the resistance to deltamethrin in both endosulfan and chlorpyrifos populations was greater than that of endosulfan and chlorpyrifos. Alajwa (1995) after studying the results obtained by Assad (1990) carefully designed experiments to test the efficacy of six regimes, each consisting of three chemicals (endosulfan, deltamethrin and chlorpyrifos) and four sprays. The chemical sprayed as a first spray was also reused as a fourth spray. The other two insecticides exchanged positions in each regime. Samples of the WF population in each regime were taken following each spray for bioassay using the three insecticides to test LD50, LD90, RR, slope, LD50 ratio (RR). The results indicated the following:

- The use of insecticides from different chemical groups in each regime reflected high efficacy in controlling the pest, lowered the WF population below the ETL and increased the susceptibility of the pest; this helps in increasing the life span of the chemicals compared to the continuous use of the same chemical in each spray.
- The chemical should not be re-sprayed within the same season.
- Some insecticides show low LD50s (i.e. susceptible insect); however, the same chemical, or the same population shows high LD90s. Therefore, RR should be the real measure for the population resistance, i.e. the LD50 alone is a misleading measure.
- Deltamethrin as a third spray, after endosulfan or chlorpyrifos or vice-versa, effected good results concerning the susceptibility of the pest.
- It is recommended to use chlorpyrifos after endosulfan or after deltamethrin/endosulfan or endosulfan/deltamethrin. This practice improved the performance of chlorpyrifos compared to its field performance as a first or second spray, following deltamethrin.
- Endosulfan has its effect on the performance of the other two insecticides, i.e. it improves their field performances. However, endosulfan itself will not be affected by either of the two chemicals.

- The best regime is endosulfan/chlorpyrifos/deltamethrin. This regime makes the population highly susceptible.

Cotton Aphid

The cotton aphid (*Aphis gossypii*) used to be a late-season pest and cause light damage in cotton fields. It has gained importance since 1987. Severe infestations throughout the season were observed. Despite the heavy use of a wide array of insecticides, the gravity of the aphid problem has increased in recent years. Some investigations associate this with the successful control and removal of the competitive *B. tabaci* and *J. lybica* and the suppression of the natural enemies through the use of the broad-spectrum and persistent insecticides. However, resistance to insecticides cannot be ignored.

The resistance to insecticides of three Sudanese strains of *A. gossypii* collected from cotton fields in the Gezira scheme over three seasons (1988, 1989 and 1990) was studied. When compared with a known susceptible strain, the aphids were found to be resistant to the eight tested insecticides, viz. fenvalerate, deltamethrin, methidathion, dimethoate, pirimicarb, methomyl, endosulfan and gamma-BHC. A steady increase of resistance level over the three successive seasons was observed for all insecticides, except for methidathion and methomyl, where a rapid increase of resistance level was noted in the second season, and for fenvalerate, where the highest resistance factors was shown in the first season and remained steady throughout the three seasons. The same authors assayed aphid hormogenate for carboxylesterase activity. No enhancement of this class of enzyme(s) was detected, and thus it was not a cause of resistance in this species. The kinetics of the inhibition process, using pirimicarb, showed high 150 values for the Sudanese strains. Resistance was caused by a modified Ache, which had a reduced affinity and poor carbamoylation ability for pirimicarb. The authors concluded that:

- Sudanese aphid in the Gezira Scheme have developed resistance to some insecticides used directly for aphid control or to insecticides used to control other pests.
- The resistance phenomenon should be considered as one of the important factors responsible for aphid resurgence in recent years, and it should be considered when designing pest control strategies.
- Resistance can spread to unexposed neighbouring aphid populations infesting melon and cucumber.
- Considerable resistance is inevitable in cotton aphid populations continuously exposed to regular and repeated applications of insecticides.

The revision of ETLs for cotton aphids and subsequently the selection thresholds, moderation in insecticide treatments and use of selective chemicals to help non-chemical PM techniques in the scheme was recommended.

Mohamed et al. (1993) tested five insecticides (viz. amitraz, chlorpyrifos, dimethoate, endosulfan and fenvalerate) and three mixtures (i.e. endosulfan + amitraz, endosulfan + chlorpyrifos and endosulfan + dimethoate) on *A. gossypii* which was collected from unsprayed cotton fields in the University of Gezira farm, Wad Medani. The LC50s (ppm) obtained were as follows: Amitraz (770.4), chlorpyrifos (79.7), dimethoate (160.2), endosulfan (113.3), fenvalerate (153.9), endosulfan + amitraz (49), endosulfan + chlorpyrifos (15.9), and endosulfan + dimethoate (42.3 ppm). The authors concluded that *A. gossypii* was relatively tolerant to most tested insecticides and recommended the following chemicals for aphid control: chlorpyrifos, endosulfan, dimethoate and amitraz in descending order. Fenvalerate exhibited a relatively low level of activity and ranked sixth in the order of efficiency. This result is supported by Cauquil (1981) who reported that pyrethroids have a low level of activity against leaf pests, especially *A. gossypii*.

Spiny Bollworm

In the Sudan, the spiny bollworm (SBW) (*Earias insulana*) was reported as an important pest of cotton as early as 1908 in Zeidab scheme (King, 1908). Now it occurs in all cotton growing areas (Eltayeb, 1976).

There are three clearly defined generations of SBW on cotton during the season (Eltayeb, 1970). The direct control of the SBW by the use of insecticides proved to be difficult, except where applications every 10 days are made as it spends very little time wandering about on the cotton plant before it attacks the plant (Ripper and George, 1965). Eltayeb (1976) stated that the strategy in SBW control depends primarily on Sevin (carbaryl) + Anthio (formothion) and endosulfan. In 1967, Azodrin + DDT ULV, Torbidan ULV, Nuvacron ULV and Dursban (Chlorpyrifos) ULV were recommended and approved for use.

Azer (1984) studied the susceptibility of *E. insulana* to DDT, endosulfan and cypermethrin through four generations of larval selection. He determined the sublethal doses and studied their effects on the fecundity and egg fertility. Spiny bollworm began to develop resistance to these insecticides in the third and fourth generations. The LC50s of DDT, endosulfan and cypermethrin in F4 were 1.9, 2.0 and 3 x that of F1, respectively. The larvae were extremely susceptible to cypermethrin (0.00010, 0.00011, 0.00015 and 0.00025 mg/larva, for F1, F2, F3 and F4, respectively), followed by DDT (0.0013, 0.0015, 0.0018 and 0.00025 mg/larva, following the same order), and endosulfan (0.0046, 0.0052, 0.0064 and 0.0095 mg/larva, respectively). There was no apparent effect of the sublethal doses on fecundity of F1. In the fourth generation, the egg-laying was reduced by 31.8, 27.0 and 21.0% for DDT, endosulfan and cypermethrin, respectively. The percentage of egg hatching was not affected after four generations of larval selection.

Mohamed et al. (1993) tested the previously mentioned insecticides (which were tested on aphids) and reported the following LD50s (mg/g body weight): amitraz (716.3), chlorpyrifos (2.41), dimethoate (2.3), endosulfan (0.97), fenvalerate (0.073), endosulfan + amitraz (103.6), endosulfan + chlorpyrifos (0.78) and endosulfan + dimethoate (0.28). The authors recommended the following chemicals in a descending order, for the control of the SBW: fenvalerate, endosulfan, dimethoate or chlorpyrifos.

Cotton Flea Beetle

Mohamed et al. (1993) studied the effects of the above mentioned chemicals on the susceptibility of cotton flea beetle (*Podagrica puncticollis*) adults. The LD50s (mg/g) obtained were as follows: amitraz (305.9), chlorpyrifos (6.4), dimethoate (5.8), endosulfan (25.3), fenvalerate (18.8), endosulfan + amitraz (94), endosulfan + chlorpyrifos (3.5) and endosulfan + dimethoate (3.19 mg/g). For this beetle control, the authors recommended dimethoate, chlorpyrifos, fenvalerate or endosulfan. Mixtures should be avoided for the time being so as to minimize the selection pressure.

Conclusions

- The four tested cotton pests proved to be moderately to highly resistant to all tested chemical groups.
- Broad-spectrum insecticides should be avoided.
- Endosulfan seems to potentiate the activities of all the other chemicals (i.e. it causes lower LD50s); in other words, it makes the population more susceptible.
- Mixtures should be avoided, if individual chemicals can do the job.
- Any individual chemical should not be used more than once within the season, whether for controlling a specific pest or a pest-complex, alone or in mixtures.
- Natural enemies should be given a chance to build-up during the season. This can only be achieved by adopting proper and accurate sampling procedures; adopting proper, accurate and dynamic ETLs; proper understanding of the biology and ecology of the natural enemies and their hosts; using selective chemicals; using insecticides selectively, i.e. when and where needed. Dimethoate seems to have lost its effect, especially on WF. Dimethoate should be stopped for a few seasons after which the chemical will regain part of its potency.

** This is a contributory paper.*

The Impact of the FAO/ARC Integrated Pest Management Project on Vegetables, Wheat and Cotton in the Sudan

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The FAO/ARC Project on the Development and Application of Integrated Pest Management in Vegetables, Wheat and Cotton (Phase IV, 1993–1996) is a continuation of the previous three phases of the project entitled "Development and Application of Integrated Pest Control in Cotton and Rotational Crops in the Sudan" signed in 1979 between the Food and Agriculture Organization of the United Nations as the executing agency and the Ministry of Agriculture and Forestry through the Agricultural Research Corporation (ARC) as the implementing agency (Eveleens, 1983; Abdelrahman and Munir, 1989; Stam et al., 1994).

In its fourth phase, the FAO/ARC IPM Project initiated activities on developing, implementing and validating IPM on vegetables where pesticides were commonly used in a very inappropriate manner with regard to the types of chemicals used, dosage rates, application methods or safety procedures. Professors Siddig A. Siddig and Nasr Eldin Sharaf El Din reviewed vegetable production and insect pest status and their control in 1990 and presented their frightening conclusions in the FAO consultancy report on the vegetable plant protection practices in central Sudan (Siddig and Sharaf El Din, 1990). The survey clearly pointed out serious losses in yields of vegetable crops resulting from insect pests and diseases and to an extremely irrational use of insecticides by ignorant farmers. Farmers used to apply any available insecticide to control pests, sometimes fungicides to control insect pests. Most of them were aware of using action thresholds or proper dose of insecticides for spraying and safety periods. Without any exception, all vegetable farmers mixed one tin (of tomato sauce) of any liquid insecticide irrespective of its type and percentage or active ingredient with one *safeha* (4 gallons) of water. Some farmers were still using twigs of branches instead of a knapsack sprayer which resulted in poor coverage of plants and loss of insecticides (Siddig and Sharaf El Din, 1990).

All interviewed farmers had used several insecticides; 78% of them used unrecommended insecticides and 10% used unknown insecticides. The survey also revealed other problematic aspects relating to the sources of insecticides used by farmers and the source of information related to them. Of the 48 farmers interviewed, 86% reported that they got their insecticides from unqualified village merchants who purchased different agricultural inputs compared to 10% who got them from the Plant Protection Division. As for the source of information, 83% reported that they asked the village merchant; 43% the extension service, 19% the neighbouring farmer and only 5% asked the Plant Protection Division. Farmers were completely ignorant of the safety period after the last spraying of the crop; most of them did not wait more than one week and quite a large number of them reported that they waited for only 1 or 2 days and then they marketed their sprayed crops (Siddig and Sharaf El Din, 1990).

The Government of the Sudan, the Netherland government as a donor and the Food and Agriculture Organization have acknowledged the need to improve plant protection practices on vegetables and approved Phase IV of the FAO/ARC IPM Project in 1993 for three years.

The development objectives of the IPM project were to establish a self-sustaining institutional capacity to foster sustainable agriculture, the well-being of the farming community and the protection of the environment. The immediate objectives of the project were to establish IPM as a standard practice of cotton production, and to introduce IPM as a viable alternative to conventional wheat and vegetable production methods by strengthening the capacity of the ARC to develop and disseminate IPM strategies for vegetables, wheat and cotton; and strengthening the capacity of the extension services, particularly in the central Region and the Rahad and Gezira Schemes, to cooperate with the ARC and to disseminate IPM programmes among the farming community. The following outputs were expected from the Project:

- Development and implementation of IPM strategies available for major vegetable crops;
- Development and implementation of IPM strategy for wheat;
- Expansion and further improvement of IPM strategy for cotton;
- Extension programmes for vegetables, wheat and cotton IPM;
- Preparation and dissemination of information materials to increase awareness of and support for IPM among senior decision-

makers in government, scheme management and extension services;

- Training of farmers, extensionists and plant protection specialists in IPM on vegetable, wheat and cotton; and
- Organization of MSc and PhD level fellowships for IPM-related studies and of study tours to other IPM projects and programmes in developed as well as developing countries.

Achievements

The FAO/ARC IPM Project in the Sudan seeks to consolidate the achievements of the Green Revolution (when inputs are available and cheap) but to remove its negative consequences by reducing the cost of production and helping the farmers become better managers. It seeks to incorporate natural processes into farming and to reduce off-farm inputs leading to a more profitable and efficient production and to better human and environmental health.

During the first three phases of the IPM project in the Sudan, the main thrust was to develop and introduce IPM in cotton, particularly, through the use of raised ETLs for the four main insect pests. This approach did not involve major extension activities since pest monitoring, decision making and pest control operations are executed by the schemes (Gezira and Rahad) and not by farmers. The same could be said for wheat IPM. However, with the shift in the fourth project phase from cotton and wheat to vegetable IPM, the project had to change its approach because in vegetable crops, all pest control operations are carried out by farmers. This means that farmers need to be trained in pest and natural enemy recognition and monitoring, understanding of pest damage crop loss relationships and pest control operations, including the use of pesticides. Moreover, very few technical options were available for vegetable IPM. This situation has obliged the Project to develop a new strategy for IPM development on vegetables (Schulten, 1994).

Vegetable IPM and Farmer Field Schools

The first vegetable IPM strategies suitable for the Sudanese vegetable farmers were formulated during two national workshops—Integrated Vegetable Crop Management in the Sudan: Present status and future alternatives, 5–7 December 1993 (Dabrowski, 1994) and Control Methods of Broomrape, *Orobanche* in the Sudan, 13 August 1995 (Dabrowski and Hamdoun, 1995). H. E. Prof. Ahmed Ali Geneif, the Minister of Agriculture, Natural Resources and Animal Wealth, participated in the first workshop; he had given his strong support for IPM as government policy for involvement and empowerment of farmers.

The role of cultural practices, plant resistance and crop rotation in producing "healthy" vegetables as the base of integrated vegetable management has always been highlighted (Baudoin, 1994). Various activities concerning farmers, researchers, extensionists and the government in implementing IPM on vegetables were discussed in depth to formulate a network of various institutions involved in IPM development, validation and implementation in the Sudan (Schulten, 1994).

Additional modifications of IPM options were made based on critical analysis of farmers' current knowledge, attitudes, production and protection methods of vegetable crops (KAP survey, December 1993–February 1994) and on regular pest surveys on 140 vegetable farms (Faki et al., 1994; Dabrowski et al.,1994a). IPM recommendations on the control of *Orobanche* parasitic weed on tomatoes were formulated by the First National Workshop on Control Methods of Broomrape, *Orobanche* in the Sudan, 13 August 1995 (Dabrowski and Hamdoun, 1995).

In developing a new implementation strategy for vegetable IPM in the Sudan, the Project has drawn on the experiences of other FAO IPM projects, particularly in southeast Asia, and has adopted the IPM Farmer Field School (FFS) approach (Kenmore, 1991; Matteson, 1992; van de Fliert, 1993). In this approach, on-farm research is integrated with extension: farmers were trained in IPM by validating technical options for pest control at farm level. The results of FFS were analyzed to provide feedback in the process of IPM technology development. This new approach was developed with close collaboration between farmers, IPM Project staff, ARC researchers, extensionists, horticultural agronomists and plant protectionists of Khartoum and Gezira States and Gezira and Rahad schemes (Dabrowski et al., 1994b; see also, Alsaffar et al., this volume). Between 1993 and 1996, 46 IPM Farmer Field Schools (FFS) were established in central Sudan. Farmers were trained in the recognition of pests and beneficial insects and on the safe use of pesticides. Proper cultural practices were demonstrated on the IPM fields, and the farmers discussed the development of their crops.

The following IPM options were validated in Farmer Field Schools:

- Replacing regular preventive spraying by curative application based on pest appearance on the crop and better knowledge of crop/pest interaction. Action thresholds indicating the maximum pest population that can be tolerated at a particular time and place without resulting in an economic loss in yield have been developed and validated for onion thrips (*Thrips tabaci*) on onion—20–25 thrips/plant—and 1–2 adult cotton jassids on eggplant (Tables 1–3);

Table 1. IPM options for tomato (modified after Dabrowski et al., 1994b)

General

1. Avoid overlapping between seasons
2. Sanitation measures
   - removal of crop residues, disposal of volunteer plants, burning chaff stack is useful to control, e.g., American bollworm
   - do not grow seedlings near the previous season crop
   - do not grow tomato close to okra (a vital symptomless host of Tomato Yellow Leaf Curl Virus, TYLCV)
3. Rotation
4. Khareef season cultivation shows lower TYLCV incidence
5. Old tomato crops should be destroyed soon after harvesting

Specific

1. Seed dressing with systemic fungicide triadimenol to reduce the number of regular sprayings with foliar fungicides against the powdery mildew infections (especially important for the winter growing season)
2. Planting high yielding and tolerant tomato varieties to TYLCV as Peto 86 (Peto-seed of Sluis and Groot); Strain B of known origin (e.g., California Seed Co. and Pop Vriend); Giha recently registered by the Gezira University, Fiona F, (TYLCV) (Sluis and Groot); new heat and TYLCV tolerant advanced lines are under final on-farm testing by breeders from the Gezira University
3. Production of 3–4-week-old seedlings under low insect-proof netting restricting vector *(Bemisia tabaci)* infestation
4. Sowing/transplanting in well prepared soil, followed by proper cultural practices and regular irrigation
   Optimal watering intervals and nitrogen fertilization to minimize the blossom end rot of fruits (an excess of nitrogen rate and long watering intervals are highly conducive to the disease)
5. Plant border rows of pigeon pea, which are good for natural enemies and give protection
6. Intercropping with the following plants:
   - winter crop: fenugreek or coriander, as non-host for *Bemisia* and TYLCV; these plants are also favourable for natural enemies and repellant for whitefly
   - summer crop: lubia bean; pigeon pea as *Bemisia* trap crops, non-hosts to TYLCV and hot and dry wind-breaks
7. Removal of weeds, potential alternative hosts of TYLCV:
   Acalypha indica *Datura stramonium*
   Hibiscus ficulneus *Solanum dubium*
8. Chemical control against the vector, *Bemisia tabaci*, especially during early seedling stages on seedbeds with pyrethroids at recommended doses
9. Mixing mineral/organic oils with low doses of insecticides or using single oils; natural oils are toxic to both eggs and larvae and repellent to adults for 7 days
10. Insecticide treatment against the whitefly should be stopped at the fruit setting (later TYLCV infections have little effect on tomato yield)

Table 2. IPM options for onion

1. Proper preparation of seedbed
2. Pre-watering before sowing and transplanting; regular irrigation in 7–10-day intervals
3. Early sowing in July/August, transplanting in September/October so that the crop is well established before thrips develop; thrips infestation increases between January and March; seedlings transplanted in December and January are still small when the thrips' infestation develops rapidly soon after transplanting
4. Transplanting into rows (in light basin soils, 20 cm between rows and 10 cm in the row or in heavy soils 60 cm between ridges and 5–10 cm between plants) improves hand weeding
5. Optimal dose of fertilizers and regular weeding
6. Regular irrigation in 7–10-day intervals after transplanting significantly reduces thrips population
7. Chemical treatment only above 20 thrips/plant as the economic threshold level; however, strong plants and frequency of natural enemies such as *Chrysoperla*, spiders, *Orius and Campylomma* bugs and coccinellid or anthicid beetles can tolerate short lasting infestations up to 50 thrips or more/plant
8. Elimination of regular preventive (prophylactic) spraying by training of farmers in recognition of the onion thrips and their damage level on plants
9. Restriction of using Lannate (first class toxicity) insecticide for other less toxic insecticides as Malathion and Cidial (phenthoate) recommended by the Pests and Diseases Committee
10. Frequent sprayings have proved to be a waste of money; thrips peaks usually occur early in February; after the middle of February pesticide applications are useless, since the crop transferred in September/October is normally maturing then
11. Well grown crops with presence of natural enemies will often not need pesticide applications

- Elimination of the sources of infestation by applying sanitary measures; removing alternative hosts and elimination of overlapping growing of susceptible crops between seasons;
- Modification of cultural practices by intercropping tomato and onion with insect repellent coriander and fenugreek; optimal irrigation intervals to reduce onion infestation by onion thrips or blossom end rot and

Table 3. IPM options for eggplant (Dabrowski Z. T., Nafisa. E. Ahmed, Yasir G. A. Bashir, Mamoun B. Mohamed and Gaafar A. El Zorgani, unpublished)

Nursery

1. Proper selection of seedbed location

   The eggplant nursery should be located where members of Solanaceae family such as tomato, pepper or potato have not been grown and not be located close to the presently growing eggplant crop; wrong selection of nursery site may lead to heavy infestation of seedlings by the root-knot nematodes (Moloidogyne) or wilt caused by soil-borne fungi of *Pythium* or *Rhizoctomia solami*
2. To secure production of healthy seedlings, the seedbed should have good drainage, not be compacted and have organic material well decomposed. Do not provide excessive irrigation in nursery as heavy clay soil and excess watering at sowing and seedling stage of growth cause the pre-and post-emergence damping off of seedlings
3. Sow seeds singly in rows in raised flat beds (Mastaba)
4. Seed dressing with the following fungicides: Captan at rate 3 g/kg seeds, or Dayton at 6 g/kg seed
5. Inspect seedbed regularly for damage caused by grasshopper, cricket and cutworm; cricket and cutworm damage roots below the soil surface or cut stems of seedlings at night; use poisoned bait to control them as soon as first symptoms of their damage are found

   Prepare a bait as follows: 1 kg bran; 20 g Sevin 85% WP insecticide and 40 g sugar (optional); mix the components with a clean stick in a container, slowly adding just enough water to moisten the mixture to make it hold together so that it is easier to handle; spread the bait around the base of plants or along the plants rows; one kg of the bait is enough to treat about 100 m^2
6. Occasionally the grey blister beetle attacks young eggplant seedlings; can be controlled, with other insects, by spraying Sevin 85% WP (26 g powder mixed with water for 100 m^2 of nursery); some farmers powder seedlings with burnt ashes of sesame or banana leaves for protection
7. Some farmers grow eggplant seedlings in covered nurseries by using light cotton covers to protect seedlings or placing cartons at the sides and thatches at the top against cricket and grasshopper
8. A few days before transplanting, spray seedlings with one recommended insecticide if damage by jassids, the tinged bug or grey blister beetle occurred; young seedlings are susceptible to leaf feeding insects; spray if av. 0.5 jassid found per leaf (Action Threshold for eggplant seedling stage)
9. Seedlings produced in open or closed nursery should be hardened before transplanting to the permanent place by withholding water, by widening the irrigation interval or by subjecting the plants produced in the closed nursery to increasing duration of exposure to direct sunlight during mornings and afternoons

Permanent Field

1. Proper pre-planting irrigation secures good establishment for seedlings in the permanent field and development of strong, healthy plants tolerating insect and disease attack; proper watering is done through irrigation in a slow rate to fill up the soil cracks, repel soil insects and raise soil humidity level
2. On the day of transplanting, the nursery is irrigated lightly to ease pulling of the seedlings with minimal breakage of roots
3. Transplanting should be done in the afternoon to give the shocked transplants 12 hours of night to recuperate at lower moisture loss due to lower transpiration
4. In areas of regular eggplant damage by the stemborer (*Euzophera* sp.), a single application of Furadan 10%G, in dose 1 g per hole
5. After transplanting, a light irrigation is necessary, followed by frequent irrigation twice a week

   Properly watering eggplants increases their tolerance to insect damages; during the main growing season, irrigation frequency and water quantity depend on soil and weather conditions, not exceeding 5–7-day intervals during hot spells and 7–10 days during cool periods
6. Eggplant should be kept clean of weeds, especially during the first two months; later, the crop produces a strong vegetable cover, reducing weed development

   Eggplant nutritional requirements are met by using 80 kg N per ha for optimal plant growth and production of fruits; half is given on the third week after transplanting and the second half one month later
7. Do not spray with insecticides as a preventive control method against cotton jassids, aphids, whitefly or tinged bug; use insecticides only as curative treatment at a pest occurrence in the field; as a rule, try to avoid using broad spectrum insecticides toxic to natural enemies
8. Monitor regularly pest occurrence in the field by inspecting one leaf per plant on 30 plants selected diagonally or at random for cotton jassid, aphid and tinged bug; inspect randomly 30 flower buds for damage by the eggplant bud-worm
9. If av. 1–2 jassid feed per leaf (Action Threshold after transplanting), spray with one of the recommended insecticides (Anthio 25% EC; Folimat 80% EC; Malathion 57% EC) or with neem seed water extract (1 kg of seed powder per 40 l water); spraying with sesame oil or cotton oil (3% of water emulsion with 0.05% of liquid soup as detergent); avoid using recommended Azodrin 55.2% WSC as a highly toxic insecticide

   Recommended Sevin and other insecticides of broad spectrum action can eliminate natural enemies in eggplant, causing resurgence of aphid and spider mite
10. In areas of regular and heavy infestation by bud worm, Sevin 35% WP spraying is recommended by the Pest and Diseases Committee; if treatment is done during the fruiting period, a 5-day waiting period (withholding) should be obeyed; the fruit borer (*Daraba laisalis*) will also be controlled by this treatment; Folimat 80% EC recommended against aphids and jassids will control both pests; waiting period for Folimat 80% EC is also 5 days
11. Eggplant heavily sprayed with broad spectrum insecticides are often covered by sooty (black) mould developed on the honey dew produced by aphid; more field observations are needed on natural enemies on eggplant

Fusarium wilt on tomatoes; optimal fertilization (dose, location and time of application);

- Enhancement of natural enemies by growing pigeon pea borders serving as refugee places for beneficial insects escaping sprayed tomato fields;
- Growing of insect/disease tolerant and resistant cultivars (Tables 4 and 5). Insect resistant cultivars of onion and eggplant were validated in the FFS and showed an insect damage tolerance. Newly released tomato varieties resistant to Tomato Yellow Leaf Curl Virus by ARC and Gezira University (Sennar 1, Sennar 2; Giha) showed superiority in comparison to TYLCV tolerant Strain B cultivar commonly grown in central Sudan; 4 kg seeds of Giha cultivar resistant to TYLCV were multiplied in cooperation with Gezira University for wide adoption tests in FFS;
- Reduction of numerous fungicide sprayings on tomato crop by seed dressing with Baytan (6 g/kg seeds);
- Using biopesticides, neem seed and leaf extracts and sesame and cotton oils, against cotton jassids and cotton whitefly (Tables 1–3);
- Control of the broomrape, *Orobanche* parasitic weed, by soil solarization and cultural practices.

Since 1995, qualitative data on the production and economic impact of IPM options were collected on farmers' fields managed by researchers (on-farm research) and in eight Pilot Field Schools where IPM techniques were tested with full farmer participation. The research built a close partnership between ARC and university researchers, field extensionists and farmers. Results of IPM farm validation were analyzed jointly by researchers, extensionists and farmers, and the needs for additional on-station or/and on-farm research to develop new IPM options were identified. Recommended IPM options were carefully tailored to the specific local production and socioeconomic factors, such as soil conditions, availability of irrigation water, rotation system, preference for on- or off-season crops; experience of farmers and their willingness to make changes (Fig. 1; see also, Ahmed Salih, this volume).

Table 4. Tomato host plant resistance to TYLCV variety trial Darwish area, 1993/1994 growing season (Merghani K. Ahmed and Z. T. Dabrowski, unpublished)

Variety	Yield (t/fed.)
Pearson Improved	7.9
Peto 86 (Peto Seed Co.)	5.4
Peto 86 (Sluis and Groot)	4.9
Strain B (Peto Seed Co.)	6.4
Strain B (Pop Vriend)	7.2
Fiona F_1 (TYLCV resistant)	18.9
Cristian F1	15.1
Carpy F1	16.0
Jackal F1	15.5
Fiona F_2	5.01
SDL 47	8.8
SDL 28	6.8

The economic impact of introducing IPM recommendations such as planting in optimal period reducing pest infestations, implementing proper cultural practices and using only the recommended safe pesticides as curative treatment has also depended on the farmer's own experience in growing vegetables. The impact was much more visible in a group of farmers whose own experience and knowledge were inadequate for producing a good crop. We have noticed the existence of two distinct groups of vegetable farmers in central Sudan: the "advanced" farmers growing vegetables for a long period and already using (or over-using) mineral fertilizers, pesticides, improved cultivars; and the "new" farmers who were attracted by the high prices of some vegetables and have only recently shifted from field crops to vegetable production.

The economic evaluation of tomato and onion IPM options implemented by farmers showed the superiority of IPM packages over farmers' traditional practices. School farmers incurred higher cost on purchasing recommended

Table 5. Comparison of yield of Fiona F_1 TYLCV resistant hybrid with commonly grown Strain B in farmer's field in two locations in the 1993/1994 winter growing season (Merghani K. Ahmed and Z. T. Dabrowski, unpublished)

Location	Variety	Seeding date	Transpl. date	Area	Yield (t/fed.)
Darwish	Fiona F_1 TYLCV Res.	16.11.1993	19.12.1993	1 feddan	15.87
	Strain B (Peto Seed)	16.11.1993	19.12.1993	$\frac{1}{4}$ feddan	6.54
Hantoub	Fiona F_1 TYLCV Res.	16.11.1993	22.12.1993	$\frac{1}{2}$ feddan	24.73
	Strain B (Peto Seed)	16.11.1993	22.12.1993	$\frac{1}{8}$ feddan	8.32

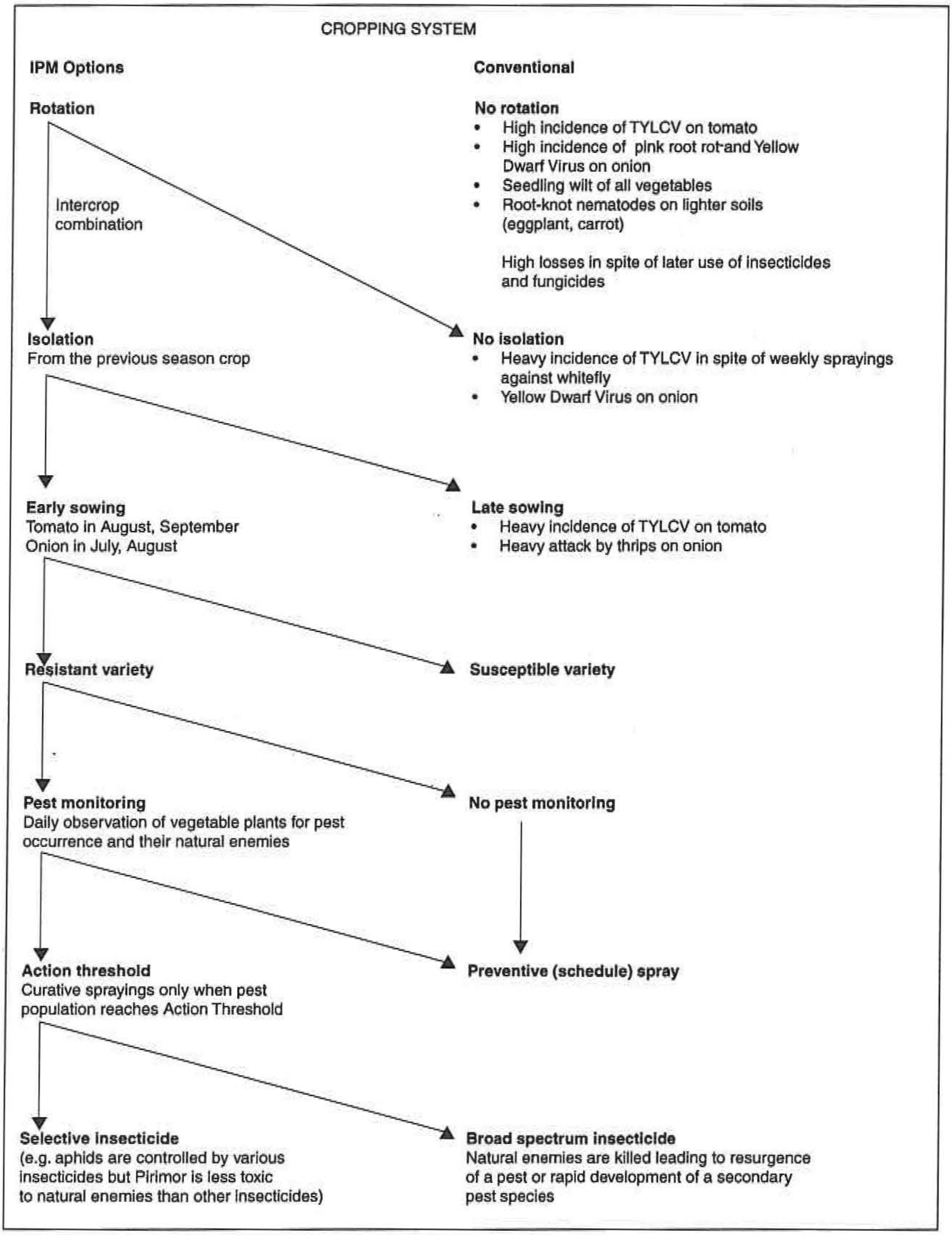

Fig. 1. A decision tree showing a sequence and range of control options available for protection of some major crops in the Sudan

varieties, land weeding and other cultural practices (planting pest repelling plants); however, they spent 25–50% less on pest control

Wheat IPM

The IPM principles were formulated based on on-station and on-farm research on new ETLs, improved scouting procedure and monitoring a role of natural enemies. Two large-scale field experiments of 1,320 feddans were carried out each season between 1993 and 1996. The quantitative relations between wheat aphids and the occurrence of various groups of natural enemies (*Chrysoperla; Coccinellids*; larvae of syrphids and spiders) were established for decision making on spraying.

A new ETL based on the percentage of plant infestation by aphids and degree of infestation (a size of aphid colony: 1–10, 11–29 and large colonies more than 29 aphids per plant) was validated on station and large-scale field experiments showing that at the presently used monitoring technique, 60–80% of infested plants had only simple aphids and small colonies. New recommendations on decision making for wheat aphid spraying were presented to the Pest and Disease Committee in 1996 for approval. The proposed Action Threshold maintains 35% of infested tillers, but only medium/large size wheat aphid colonies should be counted for calculating the percentage of tiller's infestation by aphids. Decision for spraying should be made only in the absence of natural enemies.

In the Gezira scheme, 2.1 sprays were carried out in the 1991/1992 season, 1.7 in 1992/1993, 1.03 in 1994/1995 and only 0.52 in 1995/1996. Fields of wheat in the IPM Farmer Field Schools were unsprayed in the 1995/1996 season with higher yield than harvested by non-participating farmers. On average, 35 to 40% fewer areas were sprayed in the 1994/1995 season when individual numbers (90-feddan fields) were monitored. With a total area of 392,690 feddans under wheat in the 1994/1995 season and potential savings of 35% on unsprayed areas, there was a saving of 514,029,240 Sudanese pounds (the cost of insecticide application on one feddan was equal to 3,740 Sudanese pounds in the 1995 season).

Wheat is not sprayed in the Rahad scheme, and the natural enemies population is continuously increasing due to significant reduction of cotton spraying since the 1993/1994 growing season.

Cotton IPM

Significant progress on cotton IPM was achieved by the FAO/ARC IPM Project in the first three phases. ETLs for the four major cotton pests were developed and tested in large-scale commercial farmer fields in Gezira and Rahad schemes and approved by the National Pests and Diseases Committee on 14 July 1991. They have, since then, been adopted by all cotton growing areas in the Sudan (Stam et al., 1994; Abdelrahman et al., 1995a).

In Phase IV, which is mainly devoted to vegetables, some limited work on cotton was continued in two fields. This included evaluation of selective application of insecticides only on cotton plots which reached the ETLs. The results indicated that some saving in spraying could be attained and better grades of cotton could be obtained. Secondly, the impact of the new ETLs on populations of natural enemies in the cotton ecosystem was annually monitored in both Gezira and Rahad schemes.

The cotton IPM concept had demonstrated its value. The Mid-Term Review Mission evaluated the FAO/ARC IPM Project impact in 1994 and wrote the following:

> Raised ETLs for the chemical control of four key insect pests in cotton and one key pest in wheat were implemented in the Gezira and Rahad schemes. As a result, the number of sprays in the Gezira scheme had dropped from 5–6 in 1980s to 4.9 in 1993 to 3 in 1994 in cotton and from 1.7 to 0.3 in wheat. This means a saving of approximately, 2.6×10^6 US$ in cotton and 1.3×10^6 US$ in wheat (calculation using the 1994 cotton and wheat areas and current exchange rate). In the Rahad scheme, the number of sprays in cotton was reduced from 4.6 in 1993 to 3.1 in 1994. This means a saving of 0.7×10^6 US$. The total donor contribution to the FAO/ARC project amounted to 8.3×10^6 US$ for the four respective project phases from 1979 to 1996. From this data it can be concluded that the donor contribution to the project is less than the savings in pesticides of two years of IPM implementation in cotton and wheat in the Gezira and Rahad schemes. (Saad Abbadi et al., 1994)

The cotton quality also improved as shown by the increase in the percentage of the higher lint grades which mean higher prices for the farmer. One of the obvious merits of the adopted IPM package is the significant control of the stickiness-causing species, the whitefly and aphids. Fibre stickiness is one of the major factors reducing cotton grades in Sudan (Abdelrahman et al., 1995a).

The reduction of insecticide applications on cotton also had a positive impact on the promotion of the role of the natural enemies in the other crops of the rotation, i.e., wheat and vegetables. Wheat in the Gezira was usually given two sprays against aphids per season. The number of sprays on wheat has dropped from 1.7 in 1992/1993 to 0.5 in 1995/1996. Wheat in Rahad received no spraying since its introduction in the Rahad scheme in 1992/1993 coincided with the adoption of the cotton IPM recommendations (Fig. 2). The reduced number of insecticide sprays in the Sudan also had an environmental and health impact. Generally, one-third of the amount of insecticides applied annually on irrigated cotton has been saved through the adoption of IPM recommendations.

Extension, Training and Communication Activities

Integrated Pest Management (IPM) is not a technology and is therefore not something that can be transferred using conventional approaches. Instead, it is a process—ideally a catalyst supported by extensionists, plant protection services and researchers—that engages farmers in experimential learning and dynamic local research that continuously reshape solutions to problems. These problems, as perceived and defined by farmers within their local ecological context, knit farmers, extension agents, plant protectionists and research workers into the IPM implementing groups. This approach automatically leads to a new perception of research and extension. Research can no longer be seen as an outsider's activity which attempts to optimize the value of externally defined inputs and externally verified knowledge. Similarly, extension moves away from traditional models, for example, those embedded in diffusion theory, and moves towards the robust principle of putting farmers first. When the fundamental role of farmers as owners and implementors of IPM is recognized, it focuses on the effects of research, extension and other external activities in a way that leads to successful IPM (Chambers, 1992; Schulten, 1994; Dabrowski et al., 1994b).

This new approach was first taught to extensionists, researchers and other cooperators of the FAO/ARC IPM Project in 1993. Training and extension activities were then directed to help the farmers, extensionists, researchers, plant protectionists and agronomists upgrade their knowledge and skills to be able to plan, execute and follow up the IPM programme. These were carried out in close collaboration with the ARC, Rahad Agricultural Corporation, Gezira scheme and the Health, Horticulture, Plant Protection and Extension Department of the Ministry of Agriculture of Gezira and Khartoum States.

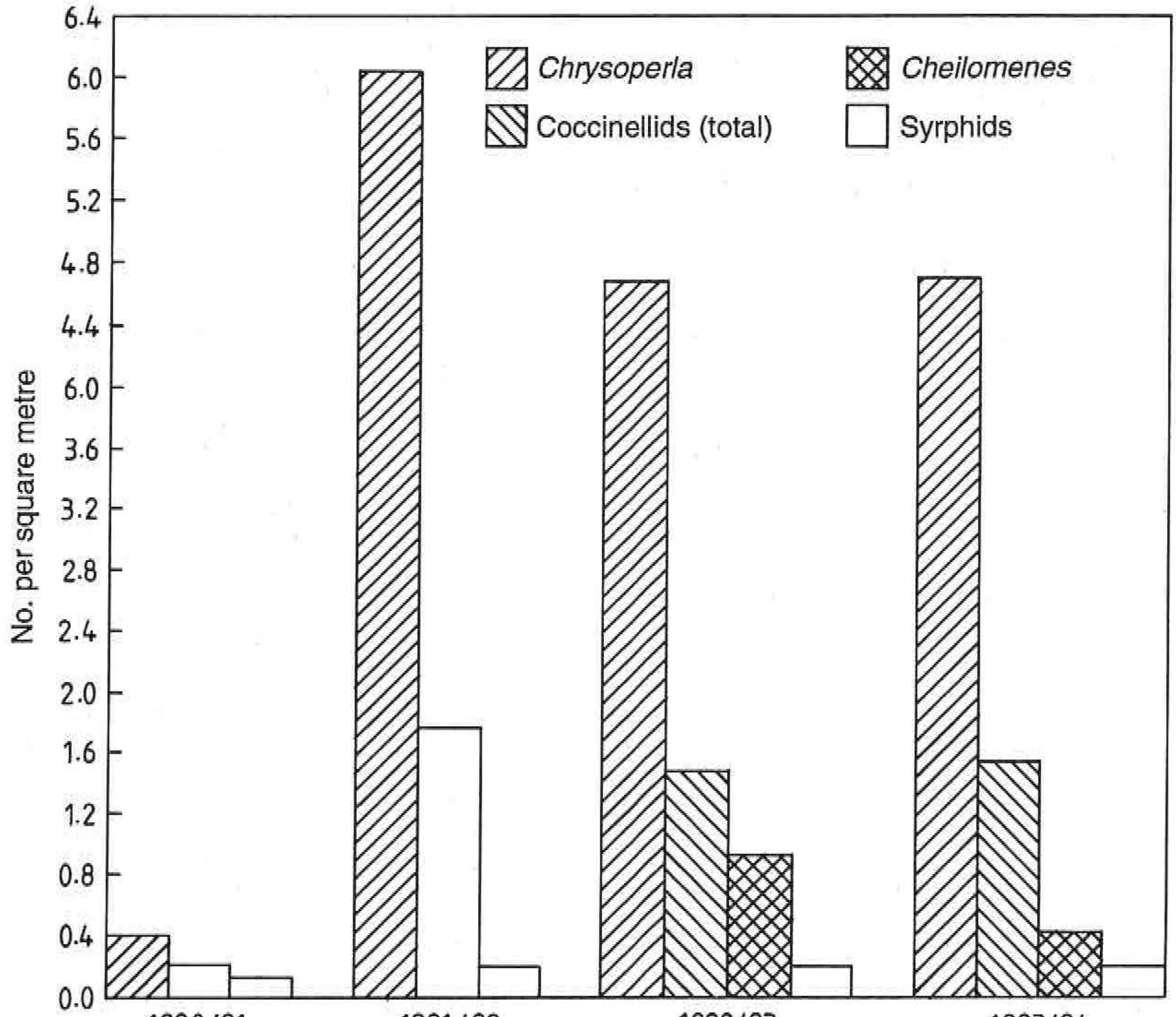

Fig. 2. Comparison of average number of various groups of natural enemies occurring on wheat in four growing seasons in the Rahad scheme (by courtesy of Dr Hassan O. Kannan, unpublished)

A national workshop on the Role of Agricultural Extension in IPM was organized for 19–21 September 1994 to exchange views and discuss mechanisms, organization and other institutional arrangements related to the effectiveness of agricultural extension in transferring the IPM principles in the Sudan. The specific objectives of the workshop were to:

- Review the capabilities of the national agricultural extension and training services in serving the farmer community;
- Identify farmers' needs for effective IPM transfer;
- Review the role of extension in IPM development in the Sudan and other countries;
- Develop realistic recommendations for more effective extension work in the Sudan.

An average of over 70 people participated in the various working sessions. The discussions were very informative and targeted to improve the current and future efforts in IPM programme design and implementation. The conclusions and recommendations highlighted the role of government institutions and farmers' organizations in IPM adoption and reallocation of resources for application of IPM principles and practices. The main recommendations could be summarized as follows:

- Legislative measures to adopt IPM as a national policy for plant protection;
- Progressive removal of subsidies on pesticides;
- Finding sources of investment in the agricultural sector at low interest rates;
- Decentralization of services for farmers;
- Merging of research and extension services in a single institution;
- Reorientation of research programmes to solve the real problems faced by the farming communities with focus on IPM practices;
- More resources to be allocated to research, extension and training on IPM;
- Intensive involvement of farmers' organizations in diffusing IPM principles and practices;
- More assistance on the part of international organizations and donor agencies to support IPM programmes in the Sudan.

Forty six IPM Farmer Field Schools as a model of participatory research and extension have been established since October 1993 (Table 6). The school activities included weekly meetings in the field throughout the whole growing season with a group of 15–20 farmers (the groups increased late in the season to 25–35 farmers). In this approach, on-farm research is integrated with extension: farmers are trained in weekly training sessions and by validating technical options for pest control at farm level. The first eight model FFSs were established in the 1993/1994 season in the Gezira and Rahad schemes and Gezira State. In the 1994/1995 season, fourteen FFSs with 258 farmers were organized in Khartoum and Sennar State in addition to Gezira and Rahad schemes and Gezira State; 26 FFSs (including five Rural Women Schools) were established in 1995/1996 (see other reports in this publication).

Participation of vegetable farmers in the IPM FFSs positively affected farmer knowledge, attitudes and practices related to IPM implementation, i.e., the percentage of farmers who could identify vegetable pests and beneficial insects increased after training from 53% in Gezira State, 40% in Gezira scheme and 40% in Rahad scheme to 74%, 75% and 70%, respectively.

Training for Leadership in IPM Development and Implementation

Training was an important project component which included local training courses, workshops and conferences and international training (MSc/PhD fellowships, study tours, international group training courses). Nominees of the ARC, the Ministry of Agriculture, Gezira State, and the large agriculture schemes (Gezira, Rahad) participated (see Tables 7–9). The importance of establishing the in-country higher degree

Table 6. Numbers of beneficiaries trained by the FAO/ARC IPM Project, 1993–1996 period

	Numbers of trained beneficiaries				
Beneficiaries	1993	1994	1995	1996	Total
Cadre	586	346	428	266	1,626
Farmers (general sessions field days)	2,161	625	264	230	3,280
Farmers in the IPM Farmer Field Schools	108	140	221	448	917
Rural women	842	50	515	252	1,659
Students	2,071	146	284	80	2,581

Explanations: Training sessions financed by the FAO/ARC IPM Project and organized by other institutions with IPM project staff teaching are both included.

Table 7. Overseas PhD/MSc degree training programmes–FAO/ARC IPM Project (Phase III/IV)

Name	Period	Degree programme	Present activities
Samira Abu Elgasim Mohamed	8.90–4.91 (returned)	MSc, Crop Protection, Wageningen Agricultural University, the Netherlands	ARC/ICARDA project, pests of legumes
Ahmed Abdelgadir Elsiddig	6.90–8.92 (returned)	MSc, Plant Breeding, Oregon State University, USA	ARC/ICARDA project, resistance wheat breeding to aphids
Elginaid Ibrahim Hamadain	12.89 Continue	PhD, Agricultural Entomology, Mississippi State University, USA	
Ahmed Hassan Mohamed	4.90–1.96 (returned)	PhD, Biological Control, Colorado State University, USA	IPM on vegetables
Ahmed Mohamed Mustafa	8.91–6.94 (returned)	PhD, Plant Breeding, University of Newcastle upon-Tyne, UK	ARC/Cotton resistance breeding
Abdalla Hassan Mohamed	6.93 Continue	MSc, Weed Science, Purdue University, USA	
Mohamed Izzeldin Mahgoub	9.93 Continue	MSc, Agricultural extension, Mississippi University, USA	
Anas Ahmed Fadl Elmula	8.94–1.96 (returned)	MSc, Applied Entomology, Wageningen Agricultural University, the Netherlands	Biological control of cotton pests
Nafisa Hassan Baldo	9.94–1.96 (returned)	MSc, Virology, Wageningen Agricultural University, the Netherlands	

Table 8. Junior research grants (in-country degree training)

Name / Nominating institution	Period	Project title	Place
Hassan Elawad Elkhider Plant Protection, Rahad scheme	12.91–12.94	*Chrysopa* spp. of central Sudan, biology, seasonal abundance and susceptibility to insecticides	Gezira University
Sampson Akoi-Binyason ARC Abu Na'ama research station	1.94–12.96	Comparison of three methods of establishing ETLs for selected insect pests on eggplant and onion	University of Khartoum
Kamal A. Mohamed ARC Hudaiba research station	7.94–12.95	Importance, cultural control of weeds in wheat crops in northern Sudan	University of Khartoum
Nadir H. Saadabi Extension services, Gezira State	8.94–6.95	Adoption rate and economic return of IPM implementation by various groups of farmers	Gezira University
Nasr Eldin Khairi Abdalla ARC/Gezira research station	7.95–6.97	Validation of cultural practices to control *Orobanche*	Gezira University
Iman Basher Abdalla ARC/Gezira research station	7.95–6.97	Impact of major predators on wheat aphid populations in Gezira	Gezira University

programme in human resource development and institution building should be emphasized. Junior researchers selected research projects closely related and relevant to the IPM project's objectives and priorities (Table 8). Their thesis projects are jointly supervised by Khartoum and Gezira University academics, the ARC researchers and the FAO international staff. The inter-institutional formal and informal cooperation and interaction have been strengthened. Payment of registration fee (much lower than for overseas institutions) brings much-needed financial support to the universities.

In-service Training of Practitioners

At first, training and extension activities were aimed at creating general public awareness about the benefits of IPM through mass extension activities (e.g., meetings with large numbers of farmers and students' groups). Since January 1993, totals of 1,626 cadres (extensionists, horticulturists, entomologists, plant protectionists), 3,280 farmers, 1,654 rural women, 2,581 students and IPM project technicians were trained during in-service courses in IPM (Table 6). The training activities concentrated on the participatory approach used

Table 9. Study tours organized by the FAO/ARC IPM Project (Phase IV) since January 1993

Name, Institution	Period	Destination
Yousif Gadallah	12–25/9/1993	Reading University, UK
Nafisa E. Ahmed ARC Plant Pathology Department	28/7 – 6/8/1993	Montreal, Quebec, Canada
Saud M. Saad Eldin, Extension, Gezira State	22/8 – 3/9/1993	Bangkok, Thailand
Musa Abdalla Ahmed Taxonomist, ARC Insect Museum	4 –25/9/1993	Mombasa, Kenya; Department of Entomology, National Museums of Kenya, Nairobi
Abdalla Musa Abdalla and Izeldin Mohamed Ali Senior technicians, FAO/ARC IPM Project	27/7 – 15/10/1993	International Institute of Biological Control, Rawalpindi, Pakistan
Mirghani Khogali Ahmed ARC-Horticulture Department	11–27/1/1994	Egypt and Jordan
Nadir Hussein Saadabi Extensionist, Gezira State	29/11–18/12/1993	International Centre for Agro-Forestry, Nairobi; Kenya Agricultural Research Institution; Institute of Horticulture, Thika; International Centre of Insect Physiology and Ecology, Duduville, Nairobi, Kenya
Hassan O. Kannan Entomologist, ARC Rahad station	28/5 – 2/6/1994	Wageningen Intl. Agric. Centre & Agric. University, the Netherlands
Mamoun Basher Mohamed ARC Rahad station	28/5 – 6/6/1994	Wageningen Intl. Agric. Centre & Agric. University, the Netherlands
Osman Elshaikh Tayallah Head, Plant Protection, Rahad scheme	28/5 – 6/6/1994	Wageningen Intl. Agric. Centre
Abdel Azim Bannaga Head, Plant Protection, Gezira State	28/5 – 6/6/1994	Wageningen Intl. Agric. Centre
Asim A. A. Rahman National Project Director, FAO/ARC IPM Project	28/10 – 10/11/1994	Nairobi, Kenya: ICIPE; Thika Horticulture Research Institute
Nasr Eldin Sharaf Eldin National Coordinator, Entomology, ARC	28/10–10/11/1994	Niaro Agric. Research Station, Nakuru, Kenya
A. Magid Yassin Virologist, ARC	27/11– 2/12/1994	Morocco; Fayoum, Egypt
Mohamed Ali Hashim Extensionist, Gezira scheme and Awad Idress Mohamed Extensionist, Rahad scheme	7–17/2/1995	Zimbabwe
Asim A. A. Rahman National Project Director, FAO/ARC IPM Project	9–12/7/1995	Wageningen Agric. University, the Netherlands
Abdelgadir Bushara Entomologist, ARC	8–19/1/1996	UK
Eltayeb M. El Allam Entomologist, Gezira scheme	29/1– 5/2/1996	Egypt

in FFSs and a wide range of IPM subjects (Table 10). Joint training courses for field inspectors organized with the management of the Gezira scheme indicated an increased awareness of the large agricultural schemes in wide implementation of IPM principles.

Preparation of Extension and Training Materials

The main effort was to provide farmers with simple, easy and understandable advice on proper cultural practices in vegetable production and protection. Numerous brochures, posters, field manuals, video films and training manuals were published. Others are in the final preparation stage and should be printed before the project termination (Table 11).

Establishing New Institutional Links

The development of an effective model for the development and implementation of IPM in vegetable crops involved institutional issues

Table 10. In-service training courses and workshops organized by the FAO/ARC IPM Project GCP/SUD/025/NET since January 1993

No.	Title	Date	Duration	Audience
1.	IPM training course	7 –10/2/1993	4 days	59 extensionists and inspectors
2.	IPM training course	13–28/1/1993	2 months	18 project members
3.	Training course on operation, maintenance and safety measures of knapsack sprays	7–8/9/1993	2 days	14 extensionists and inspectors
4.	IPM training course	18–30/9/1993	13 days	54 extensionists and inspectors
5.	Training	18/10/1993	1 day	20 extensionists + 67 farmers
6.	KAP survey training	4/11/1993	1 day	19 cadres
7.	Training course on operation, maintenance and safety measures of knapsack sprayers	22–23/11/1993	2 days	20 extensionists and technicians
8.	National workshop on integrated vegetable production	5 –7/12/1993	3 days	101 cadre + 23 farmers
9.	IPM training course	19–24/3/1994	1 week	49 entomologists
10.	IPM GTZ training course on vegetables	26–29/3/1994	4 days	26 extensionists
11.	Extension staff training course	1/5–22/6/1994	2 months	5 cadres
12.	Annual review and planning workshop	26–27/7/1994	2 days	79 policy makers, researchers SMSs
13.	National workshop on the role of agricultural extension in IPM	19–21/9/1994	3 days	42 extensionists and researchers
14.	IPM/FFS orientation day	30/10/1994	1 day	47 FFS cadres
15.	Training course on vegetable IPM	15–16/11/1994	2 days	49 FFS cadres, SMS and researchers
16.	IPM workshop	11–15/3/1995	5 days	53 extensionists, SMSs and researchers
17.	Biological control training course	18–25/5/1995	8 days	20 IPM staff
18.	Annual review and planning meeting	25–28/6/1995	4 days	75 researchers, SMSs, policy makers and extensionists
19.	Workshop on control of *Orobanche*	13/8/1995	1 day	46 researchers, SMSs and extensionists
20.	IPM workshop	20–24/8/1995	5 days	40 extension and SMSs
21.	Biological control workshop	29–30/10/1995	2 days	45 IPM FFS trainers
22.	Workshop for Gezira and Rahad schemes	10–14/12/95	5 days	48 inspectors
23.	Workshop	16–21/12/1995	6 days	48 inspectors
24.	Vegetable diseases workshop	26–28/12/1995	3 days	38 IPM FFS trainers
25.	Workshop	7–11/1/1996	5 days	75 inspectors
26.	Workshop	14–18/1/1996	5 days	73 inspectors
27.	Workshop	3–7/8/1996	5 days	50 inspectors
28.	Group training on biology, ecology and control of nematods in the Sudan	26/3/1996	1 day	20 cadres
29.	IPM agricultural extension workshop	23–25/4/1996	3 days	8 extensionists and farmers
30.	Annual review and planning workshop	10–12/6/1996	3 days	95 researchers, extensionists, plant protectionist; cotton, wheat and vegetable agronomists
Total				1,435 trainees

related to the organization of the participatory approach in technology development and implementation. Prior to 1993, the majority of experiments on plant protection of vegetables had been on research stations and concentrated on the effect of selected insecticides on individual pests or N,P fertilizers on yield and varietal trials.

The establishment of the IPM FFSs shifted the researcher's involvement to on-farm research managed by both researchers and participating farmers. FAO/ARC IPM Project staff in cooperation with vegetable agronomists, entomologists and plant pathologists of the Shambat, Gezira, Rahad, Sennar and Abu

Na'ama research stations of the Agricultural Research Station established IPM development and validation fields in the FFS network. On-farm research is more difficult to manage, requires access to transport and is more exposed to unpredictable risks, but it is more related to actual production conditions.

The FFS approach has stimulated closer integration of researchers from the ARC and universities with extension services and field plant protection staff. Collaboration was strengthened and expanded with the University of Gezira's project on Plant Protection of Vegetables financed by the Government of France. Selected heat tolerant and TYLCV resistant/tolerant tomato varieties were jointly validated under farmer field conditions and the first 4 kg of seeds of resistant cultivars were produced in the 1995/1996 growing season for wide adoption experiments.

The management and field staff of the Integrated Services for Vegetable and Fruit Farmers (ISVFF) were involved from the beginning in the project activities on vegetable IPM. Senior staff participated and presented IPM relevant papers during the national workshops organized by the IPM project, and the senior IPM project staff lectured on vegetable IPM and biological control during regular ISVFF annual training courses. Field extensionists and plant protectionists of the ISVFF were invited for further advanced training courses, and some were involved in establishing IPM FFS.

Close cooperation in IPM group training and supervision of the MSc/PhD candidates, nominated and sponsored by the IPM Project with the University of Khartoum, Gezira and Sennar University, was expanded from the traditional links with the Department of Plant Protection to the Departments of Horticulture and Agricultural Extension. The FFS approach is now included in the curriculum for the agricultural extensionists at the University of Gezira.

Working contacts have been established with farmers' unions of the Gezira and Rahad schemes and the Vegetable Growers' Union of the Gezira State through joint planning and appraisal of the IPM FFSs.

The IPM project provided technical support through discussions and lectures during group training courses organized by other FAO/ARC/UNDP/IFAD projects coordinated from El Obeid (SUD/88/022) or Kosti (IFAD). Two IPM trained researchers in participatory research and training were requested to be transferred to an on-farm research project (FAO/UNDP/ARC) in El Obeid and the White Nile project for agricultural development (IFAD/ARC) in Kosti to implement FFSs in their areas.

The IPM methodology on reducing unnecessary pesticide treatments and formulation of environmentally acceptable strategies of pest control has been accepted by the ARC researchers involved in the ICARDA coordinated Nile Valley Project on Cool Season Crops (financed to 1995 by the Netherlands government). A joint paper on wheat IPM, based on achievements of both programmes, was presented during the Crop Health Conference, Future of IPM in Crop Health and Sustainable Agriculture, IPM and Environment, 21–24 March 1994 Fayoum, Egypt.

The IPM project has taken the initiative in strengthening relations with the International Centre of Insect Physiology and Ecology (ICIPE), Kenya, in human resource development and preparation and publishing of training and extension materials. Five counterparts visited selected programmes of the ICIPE (Social Science Interference Unit, Biological Control, Chemical Ecology), and an ARC entomologist participated in the two-week course on Biological Control of Cereal Stemborers.

Through the 1993 visit of the Extension and Training Expert and his counterpart to the FAO/IPM Project on rice in Thailand and Indonesia, the exchange of information on recent IPM developments in South-East Asia was established. The FFS approach is presently used as a basic mechanism in vegetable farmers' training in the Sudan.

Awareness and More Sustainable Agriculture

The IPM Steering Committee, chaired by the State Minister or Under-Secretary of the Federal Ministry of Agriculture, Animal Wealth and Natural Resources and composed of general managers of the Gezira, Rahad and New Halfa schemes; directors of ARC and Plant Protection Horticulture and Extension Directorates and heads of the Plant Protection Departments of Khartoum and Gezira Universities in addition to the senior IPM project staff have facilitated direct dissemination of IPM achievements among policy makers in the Sudan. The committee meets twice a year to review and provide guidance for strategic planning of IPM activities in the Sudan, e.g., Mr Osman Abdel Shakour Mohamed, General Manager, the Rahad scheme announced, during the committee meeting in February 1994, that the scheme made substantial savings on lower pesticide use after implementing IPM on cotton. He confirmed that the average number of sprayings was reduced from 4.5 in the 1992/1993 to 3.1 in the 1993/1994 season on 53,444 feddans of cotton.

The IPM principles on relaying of plant protection on natural enemies, regular monitoring and using ETLs are commonly accepted by the policy makers in the Sudan.

Prof. Ahmed Ali Geneif, the Minister of Agriculture, Animal Wealth and Natural Resources

Table 11. List of training and extension materials produced by the FAO/ARC IPM Project, 1993–1996

No.	Title	Authors	Year	Language	Pages	Copies
1.	The effect of improved cultural practices on vegetable pests	Alsaffar S.M. and M. Ezzeldin	1993	Arabic	12	500
2.	Basic cultural practices for main vegetable crops: tomato, onion, okra and eggplant	Mirghani Khogali	1993	Arabic	22	500
3.	FAO/ARC IPM project development (brochure)	Asim A. Abdelrahman and A. Alsaffar	1993	Arabic	6	1,000
4.	IPM wall calendar 1994	IPM project staff	1994	Arabic/English	6	1,000
5.	IPM pocket calendar 1994	IPM project staff	1994	Arabic/English	1	3,000
6.	Operation and maintenance of knapsack sprayers	M. Ezzeldin Mahgoub	1994	Arabic	12	10,000
7.	Field manual on farmer's friends, natural enemies	B. Munir	1993	Arabic	34	500
8.	Pamphlet on vegetable insects	Dieya Eldin Alagwah	1994	Arabic	38	500
9.	Pamphlet on safe use of pesticides	F. Alagabani and Ahmed Alsaffar	1994	Arabic	6	500
10.	Identification of main vegetable pests and farmer friends	Saud M. Saad Eldin	1994	Arabic	46	500
11.	Integrated vegetable crop management in the Sudan	Z. T. Dabrowski (ed.) and 15 counterparts	1994	English	71	500
12.	IPM Farmers Field Schools	Ahmed Alsaffar	1995	Arabic	99	1,000
13.	Workshop on the role of agricultural extension in IPM	IPM project staff and 12 counterparts	1995	Arabic	70	500
14.	Field guide on evaluation of pest and disease infestation on tomato and onion	Nafisa Elmahi, Z. T. Dabrowski and A/Magid Yassin	1995	Arabic	8	50
15.	Participatory approach in IPM FFSs	Ahmed Alsaffar	1996	Arabic	17	500
16.	Identification of farmers' problems and priorities	Ahmed Alsaffar	1996	Arabic	12	500
17.	Textbook on vegetable production in central Sudan	Mamoun Basher	1996	Arabic	104	500
18.	Challenges in plant protection	Z. T. Dabrowski and El Tigani M. Elamin	1996	Arabic	18	50
19.	Broomrape-Halouk (*Orobanche* spp.) in the Sudan	Z. T. Dabrowski and Abdalla Hamdoun (eds.) and 10 counterparts	1996	English	70	500
20.	Poster on Broomrape-Halouk control (in press)	Z. T. Dabrowski and Nasr Eldin Khairi	1996	Arabic	100x40 cm	2,000
21.	Lecture notes on IPM, part 1	IPM project staff and counterparts	1996	Arabic	82	500
22.	Biological control in FFSs	C. M. Beije and Eltigani M. El Amin	1996	Arabic	13	100
23.	IPM on cotton in the Sudan	Asim A. Abdelrahman	1996	Arabic	16	500
24.	Using *Bacillus thuringiensis* in transgenic plants	Ahmed H. Mohamed	1996	Arabic	6	100
25.	Development of rural women schools in the Sudan	Hala Abdel Rahim	1996	Arabic	11	100
26.	Main natural enemies of insect pests in central Sudan	C. M. Beije	1996	Arabic	100x40 cm	3,000
27.	(Poster in preparation) Manual on IPM of vegetable pests in the Sudan	Z. T. Dabrowski	1996	Arabic	74	500

presented the achievements of the IPM project in the Sudan during the General Assembly of the Arab Organization of the Agricultural Development in Tunisia in December 1995 and made a recommendation to establish an IPM regional development project. The recommendation was endorsed by the Assembly, and the FAO Regional Office in Cairo was requested to coordinate the activities. The office requested access to the project document on the Intercountry Programme for the Validation and Implementation of the Integrated Pest Management in Cotton, Vegetables and Cereals in the Horn of Africa prepared by GCP/SUD/025/NET project (1995, 36 pp.).

Lessons Learnt

The experiences and achievements of FAO/ARC IPM Project GCP/SUD/025/NET should serve as the model for other countries in Africa. Of critical importance was the identification of 'real' farmer problems by collecting baseline information on the ecology of pests and their natural enemies, the relationship between pest occurrence and yield losses and the effect of cultural practices on pests and natural enemies in designing IPM strategies.

The farmer is the key person in IPM implementation and Farmer Field Schools. Top-down systems concentrating on delivering inputs like resistant varieties and pesticides or simple messages like uni-dimensional thresholds fail to help farmers understand the concepts and field indicators of biological control. Unless farmers understand biological control, they cannot derive maximum benefit from other inputs. Adoption of the IPM FFSs in developing and implementing vegetable IPM in central Sudan led to the integration of participatory research and extension.

The economic impact of the wide implementation of cotton IPM was demonstrated by all irrigated agriculture schemes in the Sudan; in addition, there was a synergistic effect on the government of the Sudan through involvement of policy makers in the IPM National Steering Committee, creating environmentally friendly policies related to plant protection decisions and increasing their support for more sustainable agriculture.

Inter-disciplinary collaboration was strengthened between agriculture research, extension, agriculture production schemes, universities and farmers' unions in developing and implementing IPM on cotton, wheat and vegetables. The following institutions and organizations are involved in the IPM activities: Agricultural Research Corporation, extension departments of Gezira, Khartoum and Sennar States and the Gezira and Rahad schemes, University of Khartoum and the University of Gezira, Farmers' Union at the Rahad and Gezira schemes and the Vegetable and Fruit Growers' Union, Gezira State. The human capacity of these participating institutions was also increased through MSc/PhD degree programmes, study tours, individual advanced training in selected IPM areas, group training courses and by involving more than a hundred field staff in participatory research and training of farmers.

Vegetable farmers have recognized the innovative and effective methods of the FFSs which have addressed pressing production problems in four regions in central Sudan. Farmers of the Gezira and Rahad schemes, and Gezira and Sennar States are requesting their respective authorities to establish an FFS in each village.

Finally, there has been a synergistic effect on research developing plant protection recommendations for other crops and programmes not included in the FAO/ARC IPM Project (e.g., Nile Valley Project on Cool Season Crops coordinated by ICARDA; the White Nile Irrigation Scheme Rehabilitation financed by the International Fund for Agricultural Development in Darfur and Khartoum States and an on-farm research project sponsored by UNDP/FAO/ARC, El Obeid).

3 Participatory Approach in IPM

The Need for Farmer Field Schools in the Sudan

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Maunder (1973) defined agricultural extension as 'a system of service which assists farm people, through educational procedures, in implementing methods and techniques, increasing production efficiency and income, bettering their levels of living, and lifting the social and educational standards of rural life.' Agricultural extension could be broadly defined to include any non-formal education system which serves rural people, with primarily agricultural subjects.

The function of agricultural extension is to enhance learning among rural people so that they can feed themselves and others. The approach is the essence of an agricultural extension system. Each system also has organizational structure, leadership, personnel, equipment, facilities, a programme with good objectives, methods for implementation and linkage with others as well as its particular clientele. Therefore, the approach is the style of action within a system. It emphasizes the philosophy of the system and stimulates and guides various aspects of it. There are commonalities among all approaches: All employ non-formal education procedures, have content related to agriculture and seek to improve the standard of living of rural people.

Whether the agricultural extension systems are centralized or uncentralized, whether their strategy is technology transfer or enhancement of rural life, there are several approaches which have been used. Over the years, practice has shown that certain approaches are more effective than others under particular circumstances.

Why Participation

The participatory approach in agricultural extension assumes that farming people have much experience and wisdom regarding production of food from their land, but their levels of living could be improved by learning more of what is known outside. It further assumes that effective extension cannot be achieved without the active participation of the farmers themselves, as well as of research and related services, that there is a reinforcing effect in group learning and group action and that extension efficiency is gained by focusing on important points based on expressed needs of farmers and by reaching more small farmers through their groups/organizations instead of through individualized approaches. The purpose is to increase production and consumption and enhance the quality of life of rural people.

Programme planning is controlled locally, often by such groups as farmers' associations. Where these associations do not exist, extension staff assist to form them. Priorities vary greatly from place to place and from time to time within a country. Resources required tend to be less than with other approaches, and a high proportion may be provided locally. Implementation is through group meetings, with field training, demonstrations, individual and group visits, and local sharing of appropriate technologies. Success is measured through the numbers of farmers actively participating and benefitting, as well as by continuity of local extension organizations.

Recognizing the right to organize, the International Labour Organization (ILO) calls on governments "To develop on a voluntary basis free organizations/active encouragement of rural people organization" and recommends that they be independent and voluntary in character. The World Conference on Agrarian Reform and Rural Development (WCARRD) held in Rome in 1979 identified the reason why the development efforts on poverty were having little impact on poverty, because of the lack of active participation of the people in programme planning and extension. Hence the WCARRD declared that participation by rural people in the institution that governs their lives is a basic human right. If rural development is to realize its potential, disadvantaged rural people are to be organized and actively involved in designing practices and programmes and in controlling social and economic institutions.

FAO started implementation of the participatory approach in the 1970s and found out that the most effective means for achieving farmers' objectives are small demonstration and informal groups, cooperatives, organizations and FFSs. FAO believes that the participatory approach will be an essential part of any strategy to meet the 1990s challenges (FAO, 1988; Schulten, 1989; FAO, 1990 a,b).

Conventional rural development strategies tend to see development as a series of technical transfers aimed at boosting production and generating wealth. Conventional projects usually target medium- to large-scale "progressive" producers, hoping that improvement will extend to more "backward" rural groups. However, this approach often leads to concentration of resources, marginalization of small farmers and increasing landlessness. The basic fault in the conventional approach is that the rural poor are rarely consulted in planning or given an active role in development activities. This is because the poor have no organizational structure to represent their interests. Isolated and often exploited, they lack the means to gain greater access to resources, and to prevent the imposition of unworkable programmes for technologies. The lesson is clear: unless the rural poor are given the means to participate fully in development, they will continue to be excluded from its benefits. This realization is provoking new interest in an alternative rural development strategy: people's participation through organizations controlled and financed by the poor.

Several Advantages of the Participatory Approach

The FAO People's Participation Programme (PPP) has demonstrated that participation is possible when the poor form small self-help groups that allow them to pool resources in pursuit of their own objectives. For governments and development agencies, people's participation through small groups offers several advantages. The participatory approach constitutes a receiving system that reduces the delivery cost of government services. With greater access to services, the poor become more receptive to new technologies and ideas, and they achieve higher levels of production and income. Their contribution to project planning and implementation represents savings that reduce project costs. The small group environment is ideal for the diffusion of collective decision making and leadership skills. Participation can lead to the establishment of a network of self-sustaining rural organizations.

The Need for IPM FFSs

The central element in the participatory approach is the formation of self-help groups of the rural poor as the first step in a long-term institution building process. Groups are founded around activities designed to satisfy the priority needs of the intended participants (Alsaffar, 1996). Hence, there is a need for IPM FFSs in the Sudan because they aim at creating movement which will make it possible for farmers to gain control over their lives; in this context knowledge, skills, positive attitudes and interaction are the core of improvement. Soon farmers become experts (Schulten, 1989 and 1994; Chambers, 1992; Dabrowski et al., 1994a).

Weekly field training sessions focus on work, interaction and empowerment domains (Alsaffar and Saadabi, 1996). These use a participatory approach in carrying out activities and training. There is active learners' participation so that their objectives are associated with work, interaction and self-reliance.

FFSs are excellent instruments in reaching farmers' groups. They are creative and realistic in implementing extension and IPM philosophy, principles and practices.They also strengthen linkages and interaction among farmers, researchers, specialists, managers and extensionists at various levels. In addition, they help in reducing cost, effort and time in motivating farmers to improve their lives; they create a healthy environment which encourages farmers and their trainers to be democratic and humanistic so that they can work together to challenge main constraints. As a result, farmers become more organized, cooperative, independent, open minded and communicative in expressing their needs and experiences. Farmers are motivated to actively participate in rural development.

In future, FFSs graduates can offer practical models to other farmers and encourage them to establish their own schools. This could lead to the establishment of a network of self-sustaining rural organizations; there could be a core of cooperatives and other farmers' organizations to train group members. The FFS is a source of information in each village. It promotes farmers to become "experts" in line with IPM principles; proper farmer's decisions are at the base of IPM.

Summary

One basic function of agricultural extension is to enhance learning among rural people (men, women and youth) so that they have control over their lives. The traditional agricultural extension strategy tends to see development as a series of technology transfers aimed at increasing production and incomes. Therefore, most agricultural extension approaches consider and deal with rural people as objects. The main fault in the conventional approaches is that the rural people (especially the poor) are seldom consulted, or given a chance for active roles in development activities. This is due to the fact that most rural people don't have economical or political power; they are isolated and don't have organizations to represent their needs and constraints. Unless farmers are given means to participate fully in controlling their lives, no real and sustainable development can be expected.

The first humanistic, scientific and practical step towards helping farmers participate in improving their lives is to train, motivate and help them in establishing IPM FFSs, where they could learn how to actively participate in

controlling their lives; where researchers, extensionists, specialists, managers and farmers interact and enable farmers to gain more knowledge, skills and positive attitudes as well as become effective communicators able to solve problems. In these schools, farmers learn how to organize their time, resources and effort; how to observe their fields; how learning can change their lives; how it increases their confidence in themselves and their experience and how to open their eyes and minds.

The participatory approach is the essence of the IPM FFSs; they are educational means for other social, political and economical organizations. They are the means for creating awareness and faith among rural people. In this way, science, work, challenges, and organization achieve a better life for rural people.

IPM Farmer Field Schools and Rural Women's Schools: Present and Future

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The success of IPM Farmer Field Schools (FFS) in some Asian countries encouraged its introduction to other developing countries (Kenmore, 1991). In 1993, Sudan became the first African country to apply the system, modify it to suit the socio-economic structure of the rural community, evaluate it and present it as a model that can easily be assimilated and adopted by small farmers in the rest of the Sudan and other parts of Africa (Dabrowski et al., 1994a and b).

Present Status

The adoption of IPM FFSs was preceded by preliminary observations, primary evaluations and intensive surveys to identify the nature and extent of the constraints facing vegetable growers (Faki et al., 1994; and Dabrowski et al., 1994a). Accordingly, the organizational structure of the schools was formed and duties specified. Researchers and extensionists were invited to prepare their programmes for research, demonstrations and training; work logistics were made adequately available.

During the first season, six FFSs were established, and by the 1995/1996 season, the number grew to 26 with 448 members, six RWSs with 163 members and seven pilot FFS. Over a hundred employees were involved in managing, supervising and monitoring the schools. Realizing the need for up-to-date information, curriculum was prepared and about 35 different publications were issued and distributed. Moreover, the flow and exchange of knowledge and information continued through field days, visits, technical tours, workshops and seminars in which various groups participated.

The IPM FFS is a group of 20–30 farmers meeting once a week under a tree next to their fields to be trained in knowledge, skills and attitudes so as to become more effective communicators who depend on themselves to solve their problems (Alsaffar, 1994, 1995, 1996; Alsaffar and Saadabi, 1996).

The system aims at helping the farmers, through active participation in various school activities and especially in the learning process, to become experts in their fields (Alsaffar, 1996). Weekly field training sessions are organized at each school on a fixed day, time and place. The trainer(s) meets with the farmers under a tree next to the fields to discuss the training subject for that week. Participants go to the field to observe the crops and cultural practices and to collect samples of insects and infected plants. Then they return to the shade to discuss what they saw, learnt and collected. The trainers summarize the topic and with the farmers discuss and select the topic for the next week. Each school organizer (extensionist or plant protectionist) has an IPM FFS guide for carrying out activities as well as previous participation in various workshops and courses which would have provided basic knowledge and skills to apply the participatory approach and run the school successfully.

There are 20–30 farmers selected for each school. Some of them have experience in vegetable production and they were willing to cooperate in learning and teaching others as well as participating in different school activities. The farmers in each school were divided into 4–6 groups headed by farmers' leaders.

The main aim of the IPM FFS is to help the farmers to become experts in their fields; therefore, their training in FFSs has been directed to improve work efficiency, interaction and empowerment. It is expected that FFSs will train members to become self-dependent in challenging their production problems and organizing their efforts to improve income.

Table 1 gives training details and other activities in Gezira State, Rahad and Gezira schemes during 1995/1996 season. The overall attendance of farmers was 68% during field sessions with 74, 78 and 51 in Gezira State, Gezira and Rahad schemes, respectively. The farmers' acceptance of the IPM FFS idea and practices was very high. However, their attendance was not as high as expected due to their strong commitment to social, economic and personal affairs; involvement in various agricultural and other activities and the unavailability and/or high cost of production inputs: seeds, fertilization, fuel, water and pesticides. The FFS system is still considered a new approach which needs more time and effort to show an effect on farmers and cadres.

Pilot Farmer Field Schools (PFFSs) were implemented for the first time in the Sudan during the 1995/1996 season. Seven PFFSs were established; one for wheat and cotton and five for vegetable production. Each school was

Table 1. Locations, dates, trainers and training activities during 1995/1996

School names and locations	Type of FFS	Date	No.	Weekly field training: Trainers	Specialization	Sessions	Other activities: N	DP	FD	OFR
A. Gezira State										
Fadasi	Veg	11.95	25	Ghazi G.Alsid El Rayah Abu Agla	Ext.	20	1	1	–	–
Abu Frua	Pilot	11.95	25	Faisal Nur Eldin	Ext.	10	4	–	–	2
Ganib	Veg	11.95	25	Huda Ali/Nagat Nasaf Mohamed	Ext.	22	2	2	–	–
Rufa'a	Veg	12.95	25	Elfadil A/Mutalab	Ext.	20	2	2	–	–
Um Dagarsi	Pilot	10.95	30	Yousif AlHag	Ext.	28	4	2	–	2
Elkasamber	Veg	11.95	20	Nagwa Mohamed Mohamed Ismail	Ext.	20	2	2	–	–
Gundal	Veg	11.95	25	Al Tayeb A/Alla	Ext.	22	2	2	–	–
Faris	Veg	11.95	25	Ahmed Marghani	Ext.	10	4	2	1	2
Hantoub	Pilot	12.95	25	Samia Ahmed	Ext.	3	2	–	–	2
B. Gezira Scheme										
Wad El Hindi	Veg	9.95	25	Mohamed Ali ElTayeb Alallam	Ext.	28	2	2	–	2
Wad Nouman	Veg	9.95	22	Khalifa Ibrahim Faisal Abu-Naib	Ext.	28	2	2	–	–
Bashkar	Veg. pilot	9.95	24	A/alla M.Osman Hamad A/Rahim	Ext. Ent.	24	2	8	–	8
Gadelein	Veg	11.95	21	Mustafa Mohamed	Ent.	3	–	–	–	–
Abdel Hakam	Wheat pilot	11.95	20	Al Tayib Alalam Yassir G.Alsid	Ent. Ext.	14	–	–	–	–
Wad el Magdi	Veg	11.95	20	Babiker Hamad Galal Ibnout	Ext. Ent.	2	–	–	–	–
Wad El Ataya	Veg	9. 94	20	Khalifa Ibrahim Faisal Abu Nayib	Ext. Ent.	8	1	2	–	–
Wad El Naeim	Veg	9. 94	2,131	Mohed A.Hashim Eltayeb El Allam	Ext. Ent.	8	1	2	–	–
C. Rahad FFSs										
Village 38	Cotton pilot	10.95	31	Salah Abdin Alla M.Ahmed	Ext. Ent.	12	–	–	1	–
Village 23	Veg. pilot	10.94	20	Mustafa A.Mustafa Mubarak Aboush	Ext. Ent.	22	–	–	–	5
Village 19	Veg	11.95	20	Moawia Barakat Awad Elhag	Ext. Ent.	22	–	2	1	1
Village 11	Veg	11.95	23	Omer Elgasim Siddig Ibrahim	Ext. Ent.	NA	2	2	NA	NA
Village 41	Veg	1. 96	20	Awad Khair Alla A/Azeem A/Ghani	Ext. Ent.	NA	NA	NA	NA	NA
Village 9	Veg	12.95	16	Elamin Elbeshir	Ext.	NA	NA	NA	NA	NA
D. Khartoum State										
El- Remaila	Veg		23	A/Elghani M.Gibreel Tagelsir M.Habeeb	Ent. Ext.	13	3	3	–	–
Gamoeiya	Veg	11.95	27	Al Tayib Suliman Yassir G.Alsid	Ext.	NA	2	3	–	–
Soba FF Sagdi	Veg	11.95	20	Idris Osman Idris Galal Ibnout	Ext.	NA	2	2	1	–
Total: 26			1,498		43	339	40	41	4	24

Explanations: Ext - Extensionist; Ent - Entomologist; N - Nurseries; DP - Demonstration plots; FD - Field days; OFR- On-farm research; NA = Not available supervised by an ARC researcher and school organizer. The IPM PFFSs aimed at validation of IPM options. In the Pilot FFS, 4–5 farmers selected IPM techniques to use on part of their land next to their current practices; they had technical assistance from the IPM specialist and extensionist responsible for the school. The IPM specialist collected and analyzed the necessary data. The activities included cost and benefit analyses of the new techniques in comparison with existing techniques. Table 2 shows the number of Pilot FFSs, locations, dates of establishment, organizer and specialist names, weekly field training, number of nurseries, demonstration plots and on-farm trials during the 1995/1996 growing season (see other papers in this volume).

IPM Rural Women Schools(RWSs) in the Sudan were implemented for the first time during the 1995/1996 season. Five RWSs were established in Gezira State and one in Gezira scheme with 213 and 24 members, respectively (Table 3). RWSs aim at enabling rural women to realize the effect of pesticides on human lives and the environment; encourage people to use less pesticides; recognize the main IPM elements and objectives, the main diseases and how to protect their families and nutritional value of food; preserve food; cooperate with others to improve their lives; use the participatory approach in carrying out school activities; participate in rural development activity; establish small home gardens; train other women and spread the ideas of the IPM RWSs and their usefulness in the community.

Future Project

The implementation of the philosophy and concept of the IPM FFSs and RWSs in the Sudan has been a successful experience, through which it is confirmed that the participatory approach is a useful and effective instrument for the improvement of rural knowledge, attitude and skills. People were inspired to be more confident, self reliant and interactive. As a result, school members became more aware of their problems and well prepared to present and discuss them with the authorities.

Impressed by the success achieved by government officials, farmers' unions and observers have on different occasions expressed their satisfaction with the FFS impact and requested the continuation of these activities in their areas. They also promised to offer moral and financial support.

RWS set up was extensively discussed by evaluating an impact of FFS. It is neccessary to consider Sudan's previous experience with

Table 2. Activities of the IPM Pilot Farmer Field Schools in1995/96

Location	Date	Organizer	Specialist	No.of farmers	Training sessions		Nurseries				On-farm trials				Evaluation
					No.	% attendance	Tomato	Performance	Onion	Performance	Tomato	Performance	Onion	Performance	
Gezira State															
Faris	Oct.	A.Mirghani	Dr A. Salih	25	18	62	2	V.Good	5	V.Good	–	–	5	V.Good	V.Good
Um Dagarsi	Oct.	Y.Elhag	Prof Al Amin M.	35	26	95	2	V.Good	2	V.Good	6	V.Good	3	V.Good	V.Good
Abu Frua	Oct.	F.Nur Eldin	Prof M. Bashier	26	8	65	2	Moderate	2	Moderate	4	Week	2	Moderate	Closed
Hantoub	Jan.	S.Ahmed	Dr A. Hassan	20	2	–	1	V.Good	1	V.Good	1	Moderate	–	–	Closed
Gezira Scheme															
Bashkar	Sep.	Abdalla M.Osman	Dr N.El Mahi	30	24	65	–	–	2	V.Good	6	V.Good	2	V.Good	V.Good
A/Hakam	Nov.	ElTayeb Alalam	Yassir G.Elsid	22	14	76	–	–	–	–	–	–	–	–	V.Good
Rahad Scheme															
Village 23	Oct.	Mustafa Ali	Dr H.Omer	20	27	57	–	–	–	–	3	V.Good	1	V.Good	Good
Village 38	Oct.	Salah Abdin	Dr Asim Ali	31	11	50	–	–	–	–	–	–	–	–	Good
Total 8				209	130	67	7		12		20		13		

Table 3. Rural Women Schools in Gezira State and Scheme, 1995

Location	Date	Organizer	No. RW	Weekly field training session No.	%	Home gardens	Evaluation
Gezira State							
Fadasi	July	Safia Eljack	38	34	77	3	V. Good
Elsadaga	Oct.	Howida Ali	25	32	85	4	Good
Elkasamber	Nov.	Nagwa Mohamed	40	27	100	2	Good
Abu Sugra	Oct.	Manal Mohamed	75	32	94	4	V. Good
Hantoub	Oct.	Howida Ali	35	28	73	2	Good
Gezira Scheme							
Elsoriba	Sept.	Badria Hassan	24	30	73	3	V. Good
Total 6			237	183	83.7	18	

foreign financed projects which collapsed soon after the termination of the international assistance. Also, the sustainability of IPM FFSs or RWSs requires a strong will and determination, a high degree of coordination and sufficient funds. With this perception about the prospects and future of IPM FFSs and RWSs, area coordinators designed and submitted work plans in which the main guidelines and essential prerequisites for the effective continuation of the schools were embodied. The managerial, financial and technical aspects of the workplan are hereby outlined.

IPM Research and Training Centre (IPM RTC)

To maintain and perpetuate the role of the IPM RTC as a research and training body at this transitional stage, it is necessary to define clearly its position, status, finance and mandate as an affiliate to ARC and supervised by it. However, the fact that the IPM RTC has practised its activities in a special way to achieve specific goals justifies the continuation of the present setup. Some of the organizational changes proposed are:

- Forming a board of trustees with a broad representation to be fully responsible for running the Centre as an IPM institution;
- Implementing and strengthening the existing organizational structure of the IPM FFSs and RWSs to include women at the coordinator level;
- Securing a high degree of external and internal coordination and interaction between the centre and other institutions.

With this structure, the role of the IPM RTC will be to establish a good link between the IPM RTC and the local, regional and international organizations to obtain finance and back-up services; coordinate activities with the different sectors to make use of the services offered by them which can be of benefit to IPM programme; prepare, publish and distribute school curricula and any other relevant scientific material; provide facilities and training materials for the IPM FFSs and RWSs; organize and conduct training courses, workshops, seminars, technical tours and prepare work plans as well as supervise, monitor and evaluate the ongoing programmes.

IPM FFS Organizational Structure

The existing organizational structure shall be implemented, strengthened and revised from time to time when and where necessary (Table 4). To serve the set objectives and conduct the duties and responsibilities outlined, the degree of liaison required between the different categories involved in the IPM programme should be clearly specified and strictly adhered to. The proposed structure comes under the following hierarchy:

- IPM Steering Committee responsible for the implementation of IPM concept at the national level;
- IPM Planning and Supervision Committee responsible for the implementation of IPM concept and programmes at the local level;
- Coordination Committee provides a forum for planning, monitoring and evaluating IPM FFSs and RWSs in present and future sites;
- School organizers supervise schools, conduct training and make the necessary arrangements for school activities;
- Members fully committed to IPM options by their participation, interaction, willingness to train others and team work.

Role of Governmental Bodies

At the ministerial level, IPM was declared a national policy. In this context the Ministry of Agriculture, agricultural schemes, research

Table 4. IPM FFS structure, membership and activities (as recommended by Schulten and Meerman, 1995)

Membership		Responsibilities
IPM planning and supervision team ARC Head at Horticulture	IPM CTA IPM NPD IPM E,T Expert IPM Biological Expert ARC DG Deputy	1. Approval of FFS plans, locations, numbers, committees, responsibilities, structures and costs 2. Preparation of FFS programme, incentives, inputs, fuel and transportation 3. Participate in field visits for supervision and problem solving 4. Approval of FFS final reports
IPM FFS coordination committee	IPM P & S Team FFS coordinators Technical officers Horticulturist Protectionist Pathologist Agricultural managers	1. Call for meetings 2. Programme preparation and follow up for FFSs 3. Exchange experiences and opinions among members on programme planning, supervision and execution
FFS area coordination team	Coordinator Entomologist Pathologist Horticulturist Extension Farmers' representative	1. Plan FFS programmes and supervision of their execution 2. Data collection, monitoring and evaluation of FFSs 3. Making available requirements and coordinate different concerned services
FFS organizer	Extensionist or Horticulturist or Entomologist	1. Conduct weekly meeting field sessions 2. Ensure that data are collected 3. Request the FFS area coordinator for assistance 4. Prepare monthly report for FFS area coordinator describing the activities undertaken, farmers' views on the IPM options and suggestions, further improvement and a listing of data collected 5. Responsible for organization and execution of all IPM FFS activities
FFS Members	20 selected farmers who are willing and ready to learn and apply IPM principles	1. Attend weekly/monthly FFS sessions 2. Involved in all FFS activities 3. Learn IPM practices and teach others 4. Apply IPM principles

centres, federal and regional offices of agricultural departments can use this declaration (Schulten, 1994). Various steps can be taken to implement IPM concepts. The rehabilitation of the existing agricultural services centres in the Central Region link them with IPM FFSs and RWSs activities. IPM units should be established in departments such as plant protection, horticulture and extension; their responsibilities and areas of coordination should be defined. Active participation of government officials who, by virtue of their posts, are represented in the different IPM Committees and hold key positions in the organizational structure should be encouraged. Facilities should be availed for conducting IPM activities.

Role of Farmers' and Women's Organizations

Farmers' unions can be very effective and influential in promoting IPM FFSs and RWSs and in improving the quality of life of the rural people. Activating the existing unions and forming new ones is highly important and urgent. Bringing farmers together to face their common issues and interests is a merit that deserves to be worked for seriously. It goes without saying that organizations are more capable and officially delegated to present and express the views of members than individuals. Being an official, recognized entity, an organization can have access to the authorities and is in a better position to exert pressure and obtain some rights and concessions to their membership.

Unions should encourage rural people to form their own organizations and associations at the farm and village level. This will facilitate contacts and ensure the interaction process between them and governmental bodies. Area coordinators and school organizers offer their help in this respect. The fact that rural people are disassociated made them victims for a well- organized network of brokers and mediators who control the market of inputs and outputs to their favour.

Farmers and women as representatives of their respective organizations or associations in the different committees will help in monitoring, supervising and evaluating the schools, and women will get some training in managerial skills and administrative guidelines.

Financial Aspects

During the project cycle which lasted for three years, funds for IPM FFS and RWS were secured from FAO and the Netherlands Government. The establishment of the IPM RTC and over 30 schools benefitted over 600 members. These concerned people are determined to tap all the possible services to seek adequate finance for the IPM FFSs and RWSs. Proponents of the IPM FFS concept advocate that capital investment, human resources and other efforts should not be wasted or lost; any investment in education is sound, pays off and deserves all possible support; with good management and rational utilization of resources, appreciable accomplishments can be made. With this understanding, different agencies can play their role. This includes the IPM RTC, through its contacts and links with the national, regional and international organizations. Government bodies can allocate a portion of the taxes and dues levied on farmers to finance IPM FFSs and provide operating budgets and other logistics for school activities. Farmers' unions can make direct donations from their treasury, subscriptions from farmers and contributions from the rural people.

For farmers and women to be self-reliant, self-employed or self-financed some effort should be made to secure reasonable funds to be invested in their training. This can be done through fundraising projects such as exhibitions, fairs, book sales and recreational activities; by seeking the backup of village leaders or non-resident citizens living inside the country or abroad and by encouraging on-farm, off-farm and non-farm activities in form of small and medium investments that will increase the family income and its contribution to the schools. Organizing women into associations boosts their moral and motivate them. Since RWSs provide a good base for integrated socioeconomic development of the community, many donors will be interested in supporting them. In addition, national banks were recently directed to give poor families' projects top priority in their credit policy. This puts RWSs at a privilege as far as financing is concerned.

Technical Aspects

Weekly field training sessions are considered the backbone of the IPM FFSs and RWSs where farmers participate actively in the learning and teaching process. School curriculum ought to be well-prepared, periodically revised and updated with the farmers to match their needs and aspirations. The subjects and topics covered should be comprehensive, covering all areas of interest to the farmer, women and rural people. Keeping school members aware of the latest innovations in the field of IPM broadens their minds and improves their attitudes towards new ideas. A regular flow of publications and other training materials should continue, otherwise trainers and trainees will be bored. Copies of the various publications should be kept in the different agricultural centres and offices, libraries and personal bookshelves where farmers can consult and retrieve the information needed.

Farmers are known to be reluctant, skeptical and slow in adopting new technologies, but they are quick in imitating others or in applying a new material input. However, once the new technology is well grasped and successfully implemented, it dominates over traditional ones. IPM members who have benefitted from training, increased their knowledge, improved their skills or changed their attitudes while applying IPM options are in a better position to help others by passing information, explaining and demonstrating recommended packages to them. Recruiting such farmers as trainers is time-, effort-and cost-saving and will avail more training opportunities. However, trainers should be well selected and provided with the basic means and tools that help them work properly. Trainers should always be in contact with subject matter specialists, organizers, school members and agencies to guarantee the smooth running of training. Civil servants such as medical assistants or teachers working in villages may be invited to participate in training farmers in any area of importance to the programme.

In selecting farmers for a school and preparing curriculum, certain parameters need to be observed. These include types of crops grown and animals kept, main potentials and problems of the area, age group of the farmers and their education level and production relations under which farmers work. Harmony among trainees makes training easy, interaction and participation better. Some trainees might have some special skills and experiences which should be rewarded, encouraged and disseminated.

Rural women are very much concerned about family welfare and are eager for learning. Being relatively isolated from on-farm activities, they also need some leisure time. At the village level there are many problems pertaining to environmental health, nutrition and child care that can be addressed. These include handicrafts, food processing, knitting and many other off-farm activities.

The implementation of IPM FFSs in 1993 and the present recommendation for their continuation in the future came as a result of close monitoring and proper evaluation. To improve the performance of schools and obtain the educational and economical benefits envisaged, such efforts should continue in the future. Monitoring and evaluation should receive the attention of all categories as important components of the training curriculum and school programmes. Farmers need to know about bookkeeping, how to record important events and report about their crops so that the final evaluation will be based on certified factors. All activities should be checked with all the precision possible and any recommendations or advice should be implemented immediately. Farmers' participation in monitoring and evaluation is essential.

Rural Development Through IPM FFS and RWS

One of the main merits of the IPM Project is that it has extended its spectrum of activities to include the socioeconomic dimensions of rural life. This means that in the future, FFSs and RWSs will function as cultural centres concerned about the improvement and development of the community through consistent educational means and efforts.

Through this approach, a variety of projects, such as crop and animal production, rural industries, waste disposal and improved ovens, can be developed, in which various members of the community—men, women and youth—can participate. The advantages of such an approach are obvious. The participatory approach is practised and adopted. Rural people can develop independence and confidence, being more capable to coordinate and collaborate with others. They can define their objectives and activities; they are well-prepared to mobilize and utilize their human, material and monetary resources in a rational way. Finally, rural people are motivated to develop simple lending and borrowing systems for better management of money.

Farmer Field Schools in the Gezira Scheme

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Since the establishment of the FAO/ARC IPM Project in the Sudan in 1979, the Gezira scheme has been involved in the testing of research findings and validation of IPM options. In 1989, the technology validation phase started with the objective of helping farmers to maximize their returns at minimum cost and protect citizen health and the environment by reducing pesticides and introducing IPM on cotton. The Project together with the Sudan Gezira Board (SGB) Extension Department organized numerous intensive training courses for scheme staff. The Sudan Gezira Scheme (SGS) had the lion's share of these courses, and almost all extensionists, entomologists and field inspectors participated in the group training. This has enabled the Gezira scheme to train farmers in eight specialized workshops. Three senior entomologists and extensionists also participated in individual study tours to leading IPM projects in the Netherlands, Zimbabwe and Egypt. The Farmer Field Schools concentrated on identification of insect pests, mode of action and proper application of insecticides in 1993 as a joint effort of the extension and protection departments of the SGB. The FAO/ARC IPM Project has provided coordination through FFS Coordinating Committee technical back-stopping, training, extension materials and partial financial support.

IPM Extension and Training Activities

The IPM Farmer Field Schools were chosen as an IPM extension and training model. Two field schools were established in the 1993/1994 season in two groups: the Centre and Messalamia in the Gezira scheme. Thirty-five vegetable farmers were selected and exposed to an extensive extension training programme conducted by the FAO/ARC IPM staff and extension and entomology staff of the SGB. The main objectives of this training were identification of pests and diseases on vegetables, selection and application of pesticides, use of knapsack and other sprayers and safety measures during spraying.

Extension methods included general meetings, panel and group discussions, workshops, demonstrations, visits, tours, presentation of posters, leaflets and magazines. The results obtained were encouraging, especially in the Centre Group where farmers were very interested and the trainers were well-prepared to run the FFS. This was witnessed by the technical review mission which visited the Centre Group and acknowledged the high quality of work done there. The 1993 experience was used to implement the idea of FFS as a system for training farmers and dissemination of IPM options for the major vegetable crops, onion and tomato.

IPM Farmer Field Schools in the Gezira Scheme

Farmer Field School activities became a part of the extension programme in the Gezira scheme in the 1994/1995 season with the objective of introducing farmers to topics that would enable them to be aware of the basic principles of IPM, farm management practices and the skills necessary to take right decisions regarding crop management and control of pests and diseases. The work started in September 1994 in three locations, the South, Centre and Messalamia groups. A team of specialists had been contracted

Table 1. Specific subjects covered during the weekly field training in the 1994/1995 season

Subjects
Introduction to IPM
Objectives of Farmer Field Schools
Production of tomato seedlings in tunnels
Agronomic practices—tomato
Agronomic practices—onion
Agronomic practices—okra
Agronomic practices—eggplants
Soil fertility and use of fertilizers
Whitefly biology, damages
Jassids biology, damages
Cutworm biology, damages
Leaf miner, biology, damages
American bollworm biology, damages
Aphids on vegetables
Thrips on onion
Powdery mildew on tomato
Powdery mildew on okra
Powdery mildew on eggplant
Types of sprayer and proper use
Safety measures for using insecticide
Use of mean extracts

in fields of extension, entomology and horticultural production to prepare a site-specific programme for the FFS on vegetable IPM.

Twenty farmers from adjacent villages were selected for each school to be involved in different FFS activities. Each group of five farmers was headed by a leader. The training was conducted every week in subjects which were chosen by the participating farmers themselves according to the specific conditions of their fields (see Table 1). A total number of 59 weekly training sessions were conducted, and the attendance of trainers and farmers was fairly good (Table 2). Onion and tomato nurseries were established to teach farmers how to produce healthy seedlings. Tomato nurseries maintained under local insect-proof netting failed due to high moisture during the rainy season which resulted in damping off disease of seedlings. IPM options were demonstrated in small plots which later served as sites for training based on adopting the principle of learning by doing. Five IPM demonstration plots were established, three in the South Group and two in the Centre Group.

Table 2. Training and attendance and trainers during the Sept. 1994–April 1995 season in FFSs, Gezira scheme

		Participation (%)			
Month	Sessions	Ext.	Ent.	Hort.	Farmers
South Group					
Sept.94	2	100	–	–	60
Oct.	3	100	25	75	65
Nov.	4	100	75	100	80
Dec.	4	100	50	75	70
Jan.	4	100	33	66	72
Feb.	2	100	50	100	55
March	2	100	100	100	48
April	4	100	100	75	63
Total	25	800	433	591	513
Average		100	54.1	73.8	64.1
Centre Group					
Sept.94	2	100	100	100	75
Oct.	2	100	50	50	75
Nov.	4	100	100	25	65
Dec.	3	100	100	100	80
Jan.	3	100	100	100	75
Feb.	2	–	100	100	70
March	1	100	100	100	55
April	3	100	100	66.6	65
Total	20	700	750	641.6	560
Average		87.5	93.8	80.2	70.0
Messalamia Group					
Nov. 94	3	100	32	100	66
Dec.	4	100	75	75	90
Jan.	2	100	100	50	77
Feb.	3	100	33	66	65
March	1	100	–	–	80
April	1	100	100	100	33
Total	14	600	340	391	411
Average		100	56.7	65.2	68.5

Three field days were held, two on onion IPM in South and Centre Groups. The third was a major one attended by the policy makers of the State Ministry of Agriculture, ARC and Gezira University and the general managers of the Gezira Board with the purpose of evaluating the FFS activities and the knowledge and attitudes of participating farmers on IPM. Technical field tours were organized three times a month to one of the schools, with a total of 15 tours during the season. The team members participated in the training sessions and allowed queries from farmers and trainers. They also offered advice regarding organization and methods of training.

The performance of the FFS as an extension method was very good with strong farmer participation and sharing of knowledge and support. Their knowledge about IPM increased, and they were able to make decisions on when and what insecticides to select. Farmers extensively discussed proper cultural practices that would reduce insect and disease incidence and the use of chemical insecticides and fungicides as the last weapon to control pests and diseases. They have reduced the high number of sprays, abandoned scheduled spraying and use neem extract instead of chemicals against store pests.

In the 1995/1996 season, six new FFSs were established. These included Wad Numan in the at South Group, Wad Elhindi and Elsourypa Rural Women School in the Centre Group, Bashkar in the Messalamia Group, Gad Elaeen in the Wad Habouba Group and Wad Elmagidy in the North Group. Old schools continued at Wad Elatya in the South Group and Wad Elnaiem in the Centre Group. The training started in all schools in September 1995; sessions were held once per week for the new schools and once per month for the old schools. The number of farmers varied from 19 to 32, and the attendance was fairly good. Gad Elaeen and Wad Elmagidy schools were terminated at the end of December due to water shortages that affected the growing of vegetables and the attendance of the selected farmers. Specific subjects varied from the previous season because of local conditions in the fields which were the main subject of training. High incidence of various insect pests was encountered. The major change in the 1995/1996 season was that the responsibility of running the FFS was transferred to one organizer, with other specialists or experts attending as needed.

Two SGB technical officers were assigned to support the school organizers in extension, entomology and pathology. They made 25 visits to the FFSs. In addition to visits, ten technical tours to the different FFSs were organized by a team consisting of an ARC researcher and representatives from the FAO/IPM Project and the Sudan Gezira Board.

The performance of the Farmer Field Schools was satisfactory. Training of the SGB staff selected as the FFS organizers was adequate to efficiently organize and administer the FFS activities. Participating farmers gained a considerable level of knowledge, and there was a positive change in proper use of chemicals and precautions taken for any hazards during application. Farmers developed a strong belief of the importance of adopting IPM technology; they are now able to manage their fields properly, make decisions regarding field practices, solve their own problems and interact with each other easily.

In general, all FFSs in Gezira Scheme have given positive and impressive results, and FFS methodology will be followed as a standard system for training farmers in all aspects of crop protection and production. The Scheme's management has realized the importance of IPM and has sponsored four training courses on IPM extension and training of farmers for its 250 field inspectors.

Farmer Field School Curriculum for Small-Scale Farmers in Gezira State

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The Extension Department of Gezira State is the first governmental institution in the Sudan to initiate the establishment of Farmer Field Schools as a model for extension activities after participation of its director in the FAO Global IPM Training Workshop organized 22 August to 3 September 1993 in Thailand. The model of Farmer Field Schools was demonstrated to workshop participants who gained first-hand experience in the rationale, methodology and new participatory techniques used by rice farmers in schools established in Thailand and other countries in southern Asia by various IPM projects coordi-nated by the Food and Agriculture Organization.

Before establishing FFSs in Gezira, various pieces of information relating to the production and protection of agricultural and horticultural crops was critically reviewed to develop the most relevant implementation strategy to the needs of the farmer community. Gezira State is considered the most important in the Sudan for agricultural production. It has an area of 27,549.2 km² (about 6.57 million feddans, less than 2% of the total area of the Sudan) and spreads between latitudes 13° 32'S and 15° 30'N and longitudes 32° 22' W and 34° 20' E. It is flat, with a gentle slope from south to north. The Blue Nile crosses the state from south to north. The climate determines the agricultural and horticultural production.

Gezira State is considered a dry zone with a short rainy season extending from June to October with annual rainfall of 100–300 mm. The highest monthly rainfall is received in August. Temperatures are generally high. The maximum temperature exceeds 40°C during April–May. The mean monthly temperature may reach 45°C during those months. The coolest month is December when the minimum temperature ranges from 14 to 18°C. The humidity is generally very low except for the rainy season. Winds are moderate; there are dry winds from the north during the winter, November to April, and humid winds from the south during May to October.

The Role of Agriculture in the Gezira State

Agriculture has been the most important sector of the economy and, therefore, is accorded continued priority; 80% of the population of 2.8 million is engaged in agriculture which contributes between 40 and 50% of GDP and about 65% of the total value of commodity exports, including cotton, groundnuts, sorghum, vegetable, fruits and livestock.

Of the total land area of 27.5 thousand km² (6.57 million feddans), there were an estimated 5.91 million feddans of cultivable land, of which some 4.0 million feddans were actually cultivated. About 62% of the cultivated area was under irrigation (Table 1) and contributed 60% of agriculture GDP with the balance of agricultural GDP deriving from livestock, traditional rainfed production and forestry. About 38% of the cultivated area was rainfed.

Mechanized rainfed farming, privately financed, is located south of Batana on about 500,000 feddans. Traditional rainfed production concentrates mainly in north and east Batana, west of Managil and south of Gezira on about 700,000 feddans. Intensive horticulture and livestock production by small-scale farmers is located on pump-irrigated land along the banks of the Nile on about 73,700 feddans.

The major crops presently grown are cotton, sorghum, groundnut and wheat in irrigated schemes (Gezira and Rahad projects); sorghum in rainfed areas; sugarcane in Guneid project; alfalfa, onion, tomato, okra, jew's mellow, purslane, cucurbits, watermelon, sweet potato, sweet and hot pepper, mango, citrus, banana and guava along the Nile rivers.

Sorghum is the principal crop in terms of area, occupying about 1.8 million feddans annually; 1.2 million feddans in rainfed areas and 600,000 feddans in irrigated areas. Winter crops are produced mainly under irrigation; they include wheat, winter vegetables, fruits and fodder crops (Table 1).

There are about 80,000 small-scale farmers in Gezira State; 50,000 in the rainfed area and 30,000 in the irrigated area. The small-scale farmers are owners (25%), shareholders (about 40%); tenants (about 35%). However, actual production is managed by only about 10% of the owners, 60% of the shareholders and 30% of the tenant.

In spite of the long tradition of Gezira farmers in cultivating irrigated crops along the Nile River or in large agricultural schemes irrigated by

Table 1. Average annual production of various crops by large irrigated schemes and small-scale farmers in Gezira State

	Cultivated area (feddans)		Average product		% of total yield	
Crop	Irrigation schemes	Small-scale farmers	Irrigation schemes	Small-scale farmers	Irrigation schemes	Small-scale farmers
Sorghum	600,000	1,200,000	378,000	324,000	54	46
Wheat	580,000	–	287,100	–	100	–
Groundnut	180,000	–	153,000	–	100	–
Vegetables	46,000	53,000	207,000	265,000	43	57
Fruits	4,000	10,000	8,000	40,000	16	84
Fodder crops	1,300	10,000	5,200	45,000	11	89

gravity, the State Ministry sees possibilities of further increasing food and cash crop production with the objective of attaining self-sufficiency in sorghum, wheat, fruits, vegetables and livestock and to provide a surplus for export, and to increase the production of export crops, particularly, cotton, groundnut, sorghum, vegetables and fruits in addition to providing raw materials for local industries.

Extension Department, State Ministry of Agriculture and Animal Wealth

The Extension Department is staffed with 40 male and 32 female extensionists; all of them are BSc degree holders, located in eleven remote extension centres. Each centre usually has an extension unit with one or two offices, a meeting room, accommodation for the extension agent, a main store (50–105 m²) for fertilizer and a small store (18–24 m²) for seed and agrochemicals. There is a plan to transform these centres to IPM centres for FFSs and Rural Women Schools (RWSs). In addition to these stations, there are four stations of integrated services for vegetable and fruit farmers. The Extension Department closely cooperates with the Plant Protection and Horticulture Departments in its field activities (Tables 2 and 3). All departments of the State Ministry are working together as one body through collaboration, cooperation and coordination. They also work closely with farmers' unions whose membership comprises all State communities concerned with production and marketing. Financially, the State Ministry of Agriculture is encouraging farmers and farmer unions to invest in seed production companies and vegetable and fruits export companies.

Table 2. The role of the Horticulture Department, Ministry of Agriculture and Animal Wealth, Gezira State

- Produce healthy seedlings of fruit trees, vegetables and ornamental plants in eight government nurseries
- Participate in the forestation of cities
- Introduce improved seeds and new varieties
- Estimate annual cultivated area and average yield of vegetable and fruit crops
- Make reports about marketing and handling of vegetable and fruit crops
- Participate in training of farmers on horticulture crop production and protection

Table 3. The role of the Plant Protection Department, Ministry of Agriculture and Animal Wealth, Gezira State

- Control national pests such as desert locust, rats and birds with major financial support from the Federal Government
- Control local pests on vegetables and fruit trees
- Supply farmers with sprayers and recommended pesticides
- Participate in training of farmers on pest biology, damage symptoms, control methods, selection of proper pesticides and safety measures

FFSs and RWSs in Gezira State

The 1995/1996 growing season was the third for IPM FFSs in Gezira State. Rural Women Schools (RWSs) were also organized for the first time.

Eight FFSs and five RWSs were established in comparison with two and seven FFSs in 1993/1994 and 1994/1995, respectively. In addition, four FFSs and four RWSs were established during the last two seasons outside the Contractual Service Agreement with the IPM Project using local resources responding to the State Government and the farmers' request. IPM options for tomato and onion were compared with farmers' practices. New IPM options were tested under field conditions with farmers' participation. These options were applied in on-farm trials and demonstration plots. Twenty-three different subjects were covered in FFSs and RWSs (Tables 4 and 5). The model of FFSs and RWSs in Gezira State is considered a successful one by all parameters and parties involved, and it encouraged the State Government and farmer unions to support the FFSs and RWSs financially. Last year, the total additional funding from FAO was about one million Sudanese pounds for guarantee of the sustainability.

Based on the last three years' experience, the FFS model in Gezira State will be expanded (execution and curriculum), assuring continuity and coordination of all concerned partners: ARC, the State Ministry of Agriculture and farmers' union.

Table 4. Number of Farmer Field School and Rural Women School activities in Gezira State

	1993/94	1994/95	1995/96
Normal FFSs	2	7	4
Pilot FFSs	–	–	4
RWSs	–	–	5
Selected farmers	57	140	221
Non-selected farmers	20	54	86
Selected women in RWSs	–	–	203
Non-selected women	–	–	52
Cadres managing and supervising the schools	8	16	16
Training subjects	21	24	29
Ave. farmer attendance	73.1%	82.4%	77%
Ave. women attendance	–	–	89%
Nurseries	–	5	24
IPM demonstration plots	–	1	8
On-farm trials	–	2	8
Field days	1	2	4
Weeks of training sessions	48	92	316
Technical tours	3	12	18
Home gardens	–	–	13

Table 5. Rural Women School topics, weekly training programme, 1995/1996, Gezira State

- RWS concept, aims
- IPM concept, elements and objectives
- Safe use of pesticides and other chemicals
- Cultural practices: planting, transplanting, weeding, harvesting for onion, okra, eggplants, cucumber, carrot, leafy-crops
- Identifying main pests and diseases of vegetables
- How to benefit from the surplus of vegetables and fruits
- Needle work and sewing to produce protective clothes
- Making use of locally available materials
- Nutrition
- Control of diarrhoeal diseases
- Water associated diseases
- First aid
- Supplementary nutrition for pregnant and lactating mothers
- Healthy environment

Farmer Field Schools in Sennar

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General Characteristics of Vegetable Production

Sennar is a specialized production area for vegetables and banana on the light soils along the Blue Nile River or on the heavy clay soil of the island. Prevailing agro-ecological conditions are favourable for vegetable and fruit production covering presently between 7,000 and 7,500 feddans, of which approximately 50% is devoted to vegetables. Tomato, onion, eggplant and okra are the leading vegetables grown, with tomato occupying 50–55% of the vegetable acreage and grown by 80–85% of the farmers. Onion covers 23% of cultivated area and is grown by 45% of the producers. Banana is the most important cultivated fruit, occupying the majority of the cultivated area (90%) devoted to fruit production. Saggi improved is the most common onion cultivar grown by 50% of the farmers, while Strain B (74% of farmers) and Peto 86 (16%) are the most common tomato varieties; 72% of the farmers grow Baladi and 18% Khartoumi okra cultivars. More than 85% of the farmers buy seed at local markets; 80–88% produce their own tomato seedlings and 90–95% their onion.

Onion is sown from July to December, while harvesting extends from December to May. Tomato sowing takes place almost all year round. Tomato harvest time usually ranges between November and July. Onion is competing with tomato as a return crop. Both are often grown as an off-season crop for better income irrespective of the cost of production. Other crops like eggplant, okra, cucurbits and leafy vegetables are becoming important. All are cultivated on the silt light soils of the Blue Nile bank or on central plain soils. The former land is often submerged at flooding period, and the Nile serves as a source of permanent irrigation while the latter depends mainly on underground water. The shortages of power sources (diesel and electricity) sometimes stand as a bottleneck in continuous irrigation; there are also difficulties in obtaining spare parts for pumps. Irrigation intervals range from 7 to 10 days, while the amount differed widely according to the crop.

Crop diversification has been adopted to avoid total crop failure and to improve economic stability. Widely fluctuating prices of produce make it obligatory for farmers to increase crop diversification.

Generally, farmers do not follow appropriate rotation, and, consequently, some fields are heavily attacked by root-knot nematodes on tomato and pink root rot on onion. The majority of farmers relying on chemical control. Repeated preventive chemical spraying in short intervals was often applied regardless of safety measures or safety periods during the harvest. Pesticides were applied by most farmers without special clothing. Farmer awareness of possible hazards during spraying was satisfactory, but their awareness of the recommended doses of pesticides was low.

Most of the farmers are tenants under contract or shareholders with the landlords. Their education level varies from illiterate to secondary school level, with few cases of landowners or individuals of higher education.

The Extension Department has lacked sufficient staff and facilities for their normal activities. Some farmers sometimes get extension services from the Sudanese-German Integrated Services for Vegetables (GTZ) through their office in Wad El Hadad, but most of farmers rely on their own experiences in the absence of extension for so many years. They have developed their own agricultural skills independent of technical scientific packages.

IPM FFSs were introduced in three villages to raise the skills of the farmers through close interaction with the school organizer and subject matter specialists who aimed at better understanding of production and protection requirements of vegetable crops and to increase farmers' awareness of pesticides used on vegetables.

In the absence of extension services at the State Ministry, cooperation with ARC projects of Blue Nile State was arranged by the scheme organizer to overcome difficulties. The nominated personnel participated in two specialized courses organized by the FAO/ARC IPM Project during the 1995/1996 season in Wad Medani.

Establishing Farmer Field Schools (FFS)

FFS derives its name from the origin of the activity directly from the field in a concept of learning by doing. The learning materials were either demonstrations, samples, materials or explanatory posters. Farmers had the choice of testing any package that satisfies their requirements and production system.

The area under FFS activities extended from Hag Abdalla to Sennar including Faris and Daim El Mashaikha (referred to below as Daim). The area belongs administratively to Gezira State, but technically it was supervised from Sennar. Three schools were held at Hag Abdalla, Faris and Daim from the third week of March through the first week of April 1995. The estimated cultivated area in the schools amounts to 250 feddans, mainly vegetables and orchards. Vegetables are the cash crop under continuous cultivation throughout the year, especially tomato in Faris and Daim. The school organizer visited the location under horticultural production in Sennar and provide advice for emerging problems.

One day a week was devoted to each school to handle day-to-day agricultural matters in a friendly forum with 20 selected farmers plus interested visitors. In most cases, a selected topic would be discussed and practically demonstrated whenever possible. The programme followed recommendations set up by the FFS coordinating committee (Table 1). Some *ad hoc* modifications were made to cover location specific problems such as:

- Cotton whitefly as the TYLCV vector and its relation to seasonal production of tomato;
- Root-knot nematode on tomato and its control methods;
- Pests of eggplant other than the cotton jassid or cotton aphid;
- Prevention methods in the control of pink root rot disease on onion;
- Factors affecting production costs of bananas due to high cost of weeding and proper management of banana plants.

Table 1. FFS curriculum in Sennar

• What is a Farmer Field School? Need for IPM fields
• Significance of agronomic/cultural practices in growing vegetables and in reducing pest damages
• Introduction to IPM; differences between IPM and conventional chemical pest control
• Identification of damage symptoms, biology of insect pests and diseases on tomato, onion, okra and eggplant (emphasis on whitefly as the vector of TYLCV on tomato, powdery mildew; pink root on onion and root knot nematodes)
• Identification of "Farmers' Friends" (natural enemies)—*Chrysoperla*, *Campylomma* and *Laius* Malachid beetle, spider
• Selection of recommended insecticide for a specific pest based on frequent field visits and pest monitoring
• Toxicity of pesticides: their effect on users, natural enemies and environment
• Safe use of pesticides, calibration of knapsack and spraying techniques, maintenance of sprayers
• Validation of IPM options through demonstration plots and regular weekly visits to IPM fields

Regular interaction between the FFS organizer, subject matter specialists and farmers paves the way towards an exchange of experience, but above all, it increases information and improves individuals, skills. Such experience cannot be assessed directly but can be revealed through the strong build-up of relations between professionals and farmers. The latter would maintain such relations only with confidence in and conviction for the concerned person. Such interaction can only be achieved through appropriate knowledge, high technical skills, participatory approaches and refresher courses. After two years of experience, a modified FFS curriculum was proposed for Sennar; it considered the specific local production needs and problems encountered by farmers (Table 2).

IPM Demonstration Fields in the 1994/1995 Season

In each school, two to four farmers volunteered to allocate part of a field or the whole field for IPM demonstrations in the 1994/1995 season. From the options available from the FAO/ARC IPM Project (Dabrowski et al., 1994a), farmers selected what was to be tested in their fields (Table 3). The emphasis was on proper cultural practices, rotation, sanitation and elimination of overlapping crops of the same species. Because of the intensive production of vegetables, especially off-season crops, the restriction of overlapping crops was the most difficult to introduce on a large scale. All farmers accepted the improved technique of preparing a seedbed for onion and tomato seedling production. They realized the importance of rotation in selecting a proper place for onion seedlings. Monitoring whitefly population in tomato by using sticky yellow traps was designed for an FFS discussion on sources of the TYLCV and the role played by whitefly. The field was also used to demonstrate the effect of curative spraying rather than weekly spraying.

A farmer field was selected randomly at Daim to monitor the whitefly population in correlation to TYLCV incidence for the 1994/1995 summer season. The seeds of Strain B variety were directly sown in the first week of March. All cultural practices were performed by the farmer, and the monitoring started four weeks after planting. Fourteen labels were numerated serially, and the sticky yellow traps were tied vertically by string on each label plate. They were arranged longitudinally in the field at five metres apart and adjusted to the plant height weekly. The traps were facing the wind direction, but they were set laterally to avoid glue reflection from

Table 2. The recommended curriculum of IPM Farmer Field School for Sennar

1. Objectives of FFS and basic information on IPM; short presentation of all available methods preventing occurrence of losses
2. Principles of growing healthy vegetables; proper agronomic practices; effect of cultural practices on pest management; tolerant/resistant cultivars; differences in varietal response to insects/diseases in onion, eggplant and tomato; farmers' views and past experience in the effect of intercropping of 2–3 vegetables (or vegetable-banana) on pests and diseases; effect of coriander and fenugreek on reduction of cotton whitefly and TYLCV in other FFSs
3. Differentiation between insect pests, nematodes and diseases and accordingly between insecticides and fungicides; characteristics of development, biology, migration or transmission of pests and diseases; hosts of plant viruses; role of insect vectors—host weeds as reservoir of virus of crop plants
4. Identification and control methods of vegetable insect pests on tomato, okra, onion and eggplant; field demonstration of various developmental stages of pests; using yellow sticky traps to show various insect species; onion thrips, cotton whitefly, American bollworm and leaf miner; eggplant pests: cotton jassid; tingid bug, eggplant budworm, eggplant fruit worm, eggplant stemborer and cotton aphid; cotton whitefly in TYLCV transmission; farmers' views on major pests; planting time of various vegetables and damages caused by insect pests; escape from insect infestation
5. Symptoms and economic importance of vegetable diseases in the area: TYLCV, powdery mildew, pink root rot, root-knot nematodes and viruses on cucurbits; field visits to identify various diseases
6. Non-chemical control methods of pests and diseases; identification of TYLCV alternative hosts (weeds); isolation between consecutive growing seasons of tomato; rotation and occurrence of pink root rot in farmers' fields; emphasis on proper selection of seedbed for production of onion seedlings
7. Spraying techniques, precautions and safety periods; safety measures and first aid; proper and safe preparation of insecticide for spraying; calibration of knapsack and spraying techniques; efficient spraying; maintenance of knapsack
8. Identification and importance of "Farmers' friends"—natural enemies of pests; major groups of beneficial insects; onion fields (rarely sprayed) and tomato crops (often sprayed) for demonstration of various groups of predators: *Chrysoperla* spp., *Campylomma* spp., *Laius* spp., spider and ant
9. Weed control as a major component of banana production improvement; densely planted banana suckers; use of green manure (alley cropping, agroforestry); improvement of banana crop management by allowing only three shoots per plant; proper pruning for growth of other shoots and development of quality fruit
10. Validation of IPM options on IPM demonstration plots/fields; various planting times to escape heavy damage by pests with higher market price of vegetables and banana during summer; modification of spacings, using ridges instead of flats; protecting tomato nurseries by using insect-proof nettings or intercropping with coriander and other crops; introducing other cash crops (e.g., green maize) in an area of heavy infection of tomatoes by TYLCV

direct sunlight. The trapped insects were counted at sunrise by farmers after 24 hours and later by the school organizer using hand lenses in the laboratory. The count stopped by the flowering stage of the tomato plants in the third week of May. The field received only one spray before the last count.

It was observed that the whitefly appeared only in low numbers during the 1994/1995 season (Fig. 1). However, in spite of the low density of the pest, the incidence of TYLCV amounted to 18% infection on the second week of May. The severity appeared in the last week of May due to the latent period of the virus. The incidence was almost 100% in that week, but the adjacent fields were found to be lower, although they did not receive more than two sprays (Fig. 1). Numbers of natural enemies such as predatory *Chrysoperla* spp., *Campylomma* sp. and *Laius* sp. (Malachid beetle) were observed on unsprayed tomato fields. Discussion with the FFS participants revealed that in spite of the high incidence of TYLCV affecting all tomato plants and reducing yield in the area, the farmers will continue to grow summer tomato crop due to its high market value.

Pilot Farmer Field Schools

The IPM Pilot Farmer Field Schools were established in the 1995/1996 season following the recommendations of the 1995 IPM Annual Review and Planning Mission to improve validation of the promising IPM techniques by farmers under field conditions. The idea was that in the Pilot FFSs, farmers would implement IPM techniques on parts of their land next to their current practices with technical assistance from the FFS team. One scientific coordinator was assigned to each IPM Pilot FFS to collect data and analyze the results. Data on cultural and plant protection practices on both IPM and non-IPM fields was collected in cooperation with the extensionist. Uniform scoring techniques on population density of major pests and infection level by diseases were used in all Pilot FFSs. The closest Pilot FFS to Sennar could only be established in Faris village in the 1995/1996 season.

Table 3. IPM options validated by FFS participants

Onion
- Rotation to reduce pink root disease
- Improved nursery on ridges to produce healthy seedlings
- Recommended fertilizer dose
- Planting seedlings in rows to reduce later cost of weedings
- Short irrigation intervals
- Spraying onion only after more than 3–4 thrips per leaf are noticed on most leaves (ETL established by researcher, 20 thrips/plant)

Tomato
- Proper selection of nursery location (rotation, isolation from present tomato crop)
- Growing heat/TYLCV tolerant cultivars
- Intercropping with coriander in nursery
- Sowing times to escape TYLCV infections
- Pre-watering before transplanting into permanent field
- Transplanting procedure and ridging
- Spacing between plants on ridges
- Irrigation intervals
- Optimal fertilization
- Inter-cropping with *Dolichos lablab* for whitefly attraction to alternative host and not to tomato plants
- Regular cleaning of the crop from weeds (alternative hosts of TYLCV)
- Judicious use of insecticides; obeying safety (withholding) periods
- Improving spraying techniques for better cover of leaves

Experimentation with Onion IPM Options

Four farmers were selected in two different locations in the Pilot FFSs. In both sites the soil structure was alluvial and the land received two heavy disc ploughs in an elapse interval period. Then it was levelled and divided into subplots manually. The size of each was in a range of 4.50 x 2.20 m as a plane-flat plot. Four subplots were prepared for IPM options versus others of the normal farmer practice. Three farmers accepted test-planting seedlings in rows and one farmer decided to plant in rows on ridges instead of flats as a normal practice.

In the IPM plots, the plants were grown in lines with 20 cm spacing between the rows and 10 cm within the row. Six-week-old seedlings of variety Saggi prepared in the farmer's nursery were transplanted early in the morning and irrigated directly in the second week of October 1995. Second irrigation was followed after 4 days and organized later at 7-day intervals. Before harvest the irrigation intervals were extended to 10 days.

In the IPM plot of the fourth farmer, ridges 70 cm broad were prepared manually. Growing onion on ridges was a recommended option in the field school. Four rows of seedlings were planted in lines of 10 cm spacing and 5 cm within the rows. These ridges were compared with the normal flat grown plots. All selected plots were fertilized with two sacs of urea at split dose in a 3-week interval starting from crop establishment. The fertilizer was buried in lines along the ridge and between the rows.

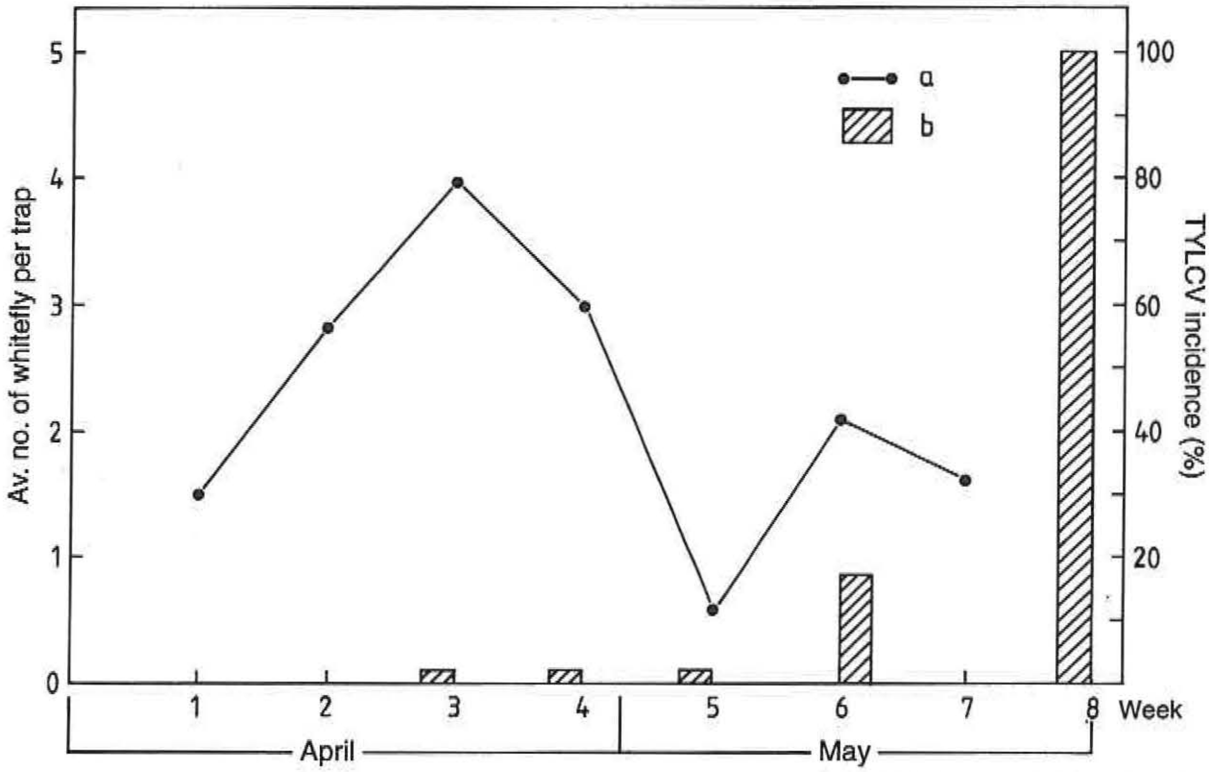

Fig. 1. Flight activity of cotton whitefly(a) and TYLCV incidence(b) in tomato fields in the 1994/1995 season, Daim El Mashaikha

In the traditional farmer plots, the seedlings were transplanted randomly at the maximum number in the plots in the early morning and irrigated directly. Water regime was similar to that of the IPM plots. Differences occurred in the amount, method and time of applied fertilizer. The IPM collaborative farmers used the same rate per feddan but in split doses. For the majority of farmers, there is no fixed time for application or interval, and application depends on the availability of the fertilizer. Until the end of the season, an average of 18 irrigations was recorded.

Weekly monitoring of the IPM and farmer practice fields by the FFS participants showed a low level of thrips infestation in all fields, even at the end of season when irrigation intervals were extended to 10 days or more (Table 4). Some onion fields under traditional practices showed heavy infection by dodder, parasitic weed, *Cuscuta campestris*. The plots planted according to farmers' practices had a larger number of smaller size bulbs than the IPM experimental plots. The yield did not show significant differences (Table 5). Onion planted on ridges by the fourth farmer exceeded those grown in flats (Field IV). The bulbs collected from all IPM plots showed uniformity in size, while those of traditional practices revealed a large variation.

Experimentation with Tomato IPM Options

Two IPM nurseries were established in the two sites adjacent to the farmers' one in the first week of January 1996 in a suitable location. Tomato seeds of variety Strain B were planted in a well-prepared flat plot. The seeds were treated with Captan at the rate of 3 g/kg and irrigated immediately. On the same sowing date, coriander was planted on tagnats (hedges) of the nursery as a repellent plant against whitefly. It could not be sown earlier due to a delay in land preparation and was not repeated in the field for the unfavourable conditions. Instead, *Dolichos lablab* was used to attract the insect. The cultivated land received only one disc plough and was prepared in ridges mechanically while levelling and plot division were done manually.

In the IPM experiment, 3–4 plots were prepared manually in ridges of 100–120 cm wide. After light irrigation 3 days earlier, 5-week-old tomato seedlings were transplanted on both sides of the ridge early in the morning at 40–50 cm spacing and irrigated directly. Seeds of *D. lablab* were planted on the same day on hedges between the plots. The cultural practices continued as recommended, e.g., irrigation at 4–5-day intervals, continuous cleaning and piling of soil on seedlings and fertilization with urea at the split dose at 3 weeks from transplanting using two sacs (100 kg) per feddan. Two chemical curative sprayings with Folimat were applied when the first whiteflies were found on plants, one after crop establishment and the other before flowering.

Farmers were either planting Peto 86 variety alone or mixed with Strain B. The age of transplanting seedlings varied between 4 and 7 weeks. Seedlings were planted on both sides of the ridge, maintaining 15 cm between plants and 60–80 cm between ridges. Pre-watering was not a prerequisite but it was followed by a fixed regime of 4–5-day interval.

During the experiment, farmers participated in observations counting whiteflies on tomato and *D.lablab*, monitoring the percentage of infection by TYLCV at fruit setting on the two fields and yield. The plants were checked weekly in the nursery and later in the field for whitefly occurrence. No incidence was observed in the former, while whitefly individuals were observed in the latter after 4 weeks from transplanting. The TYLCV incidence was relatively higher in farmer practice plots (5.5%) than in the IPM options (4.5%) in the same field of the first location, while it was 8% and 10.5% respectively, in the second location. The infection in the adjacent field was 27% and higher in the absence of chemical spraying or wrong selection of chemical. The third field was infected with nematodes, so observations were not taken in consideration.

Table 4. Mean number of onion thrips per plant on IPM plots and farmer practice fields at harvest (average of 20 plants)

	Locations		
Treatments	I	II	III
IPM fields	3.15	1.05	2.45
Farmer practice	3.50	2.50	3.25

Table 5. Average yield (t/feddan) of onion in the IPM pilot farms versus farmer practice in different fields

Treatments	Field I	Field II	Field III	Field IV
IPM component	11.633 NS	13.618 NS	13.810 NS	7.412 NS
Farmer practice	15.428	13.331	14.682	5.712
S.E. ±	1.19	1.05	6.50	2.17

The IPM plots finally yielded significantly higher than plots under traditional farmer practices (Fig. 2). The yield in the second field was lower due to severe disorders leading to a complete dry up of plants at the end of the season.

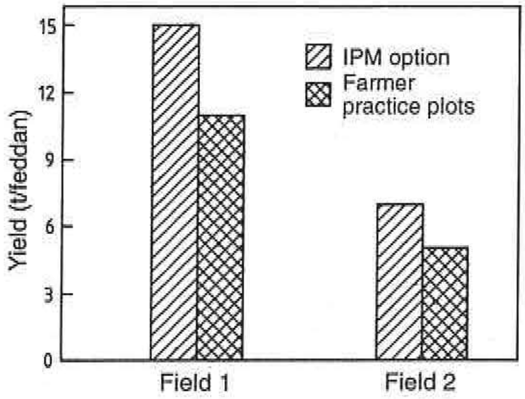

Fig. 2. Yield of tomato harvested in the IPM plots compared to farmer practice plots in Sennar in the 1995/1996 summer season

Conclusions

There was a good response from the farmer community towards FFSs and demand for extending their activities to other parts of Sennar. Some onion IPM options recommended by the IPM Project were already practised by Sennar farmers, e.g., early planting or the frequent and regular irrigation affecting pre-pupae of thrips in the soil. The onion crop of FFS participants as well as non-participating farmers was relatively free of severe damage by onion thrips. It should also be remembered that farmers' fields are located in a much more diversified environment than the fields in the Gezira and Rahad schemes. Large groups of fields are surrounded by trees, shrubs and other vegetation which probably enriched the population of natural enemies which are always observed in both onion and unsprayed tomato fields.

Farmers' knowledge of parasitic weeds; nematodes; biology and host plants of TYLCV; symptoms, biology, development and control of plant diseases is weak. Future FFSs should intensify training in these neglected areas. On the other hand, implementation of IPM options such as rotation is facing problems of intensive land use and specialized vegetable production. Future FFSs should consider diversification of vegetable production by introducing green maize, carrot or red beets (recently gaining high prices in cities).

Production of off-season tomato should be improved by the recent release by Gezira University of heat/TYLCV tolerant tomato varieties. Using healthy transplants in an improved technology (produced in soil compost clods; in mixtures of compost/clay/sugarcane residue bricks) grown under insect-proof nettings can also reduce losses by early infections by TYLCV. Organizers of FFSs located away from the IPM Research and Training Centre, ARC, Wad Medani need more extension and training publications, especially colour posters on symptoms, development and biology of plant pathogens. Even plant protection staff have problems with proper identification of major plant diseases, e.g., confusing symptoms of early blight of tomatoes caused by *Alternaria solani* with some uncommon symptoms of powdery mildew or symptoms of insecticide phytotoxicity on some varieties.

The FAO/ARC IPM Project FFSs in Sennar have influenced the Ministry of Agriculture and Animal Wealth to employ a dynamic extensionist, providing him with a reliable field vehicle and an operational budget to organize new Farmer Field Schools in Sennar.

Integration of IPM Options into Tomato Production by Farmer Field Schools in Central Sudan

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Of the various components of modern agriculture, IPM presents by far the most difficult challenge to traditional, small-scale farmers in the Third World as they make the transition to scientific farming. The demands of irrigation, chemical fertilizers and even standardized agricultural credit follow, more or less, understandably from the operations of traditional training and permit a considerable degree of self-instruction through experimentation (Goodell, 1984). In contrast, IPM requires the farmer to grasp a far more complex set of data, data which is often anything but self-evident, unitary and standard, or amenable to trial-and-error learning. IPM may call for tighter field-level organization (for synchronous planting, for instance); the cultural controls favoured by ecologically-minded entomologists, such as sanitation and post-harvest ploughing, laborious, hence expensive. IPM farmers must achieve greater discipline in fine-tuning their management practices: more precise and more frequent attention to pest identification, damage symptoms, timing and anticipated returns to costs incurred. Then, too, whereas generous credit and input subsidies encourage Third World farmers to adopt most components of the new technology of the green revolution (which sometimes were even free), in contrast, IPM urges farmers to question or even reject dole-out chemicals or pesticide-spraying services (Goodell, 1984).

Finally, from the farmers' perspective, IPM technology is sometimes counter-intuitive. Certain expensive chemicals turn out to be the cheapest when properly used; excessive pesticide use turns out to cause resurgence, secondary pest outbreaks and pesticide resistance; the proliferation of some insects turns out to benefit the crop. Thus, Third World farmers need exceptional incentive and intensive training to gain command over even the rudiments of IPM (Goodell, 1984).

The problem with the implementation of IPM principles and options was identified by a number of authors as a principle bottleneck limiting the progress of IPM worldwide, both in developing as well as in developed countries (Lincoln and Blair, 1977; Brader, 1980; Matteson et al., 1984; Wearing, 1988; Schulten, 1989). Some authors have also emphasized that the complexity of IPM could delay its adoption. This complexity also demands that considerable attention and resources should be devoted to the implementation process.

The situation of IPM implementation in the Sudan is not different from the rest of the world. The IPM concept was introduced in the Sudan in the 1980s by the FAO/ARC IPM Project to develop and introduce IPM in cotton; then in Phase IV, the project shifted emphasis to vegetable crops. It was decided to execute the IPM activities through IPM Farmers Field Schools (FFSs) developed first by the FAO IPM project in southeast Asia (Kenmore, 1991; Dabrowski et al. 1994a,b; Alsaffar et al. in this volume). The FAO/ARC IPM Project started to set a programme to implement IPM through FFSs first in the 1993 season in the Sudan.

The traditional extension approaches (transferring of the message and production packages from researchers to extensionists to farmers) dominate the agencies of the Ministry of Agriculture in the Sudan. The newly established IPM FFSs aim at helping farmers to become experts by gaining up-to-date information, acquiring positive attitudes towards IPM implementation and improving their skills. These aims are reached through participation by extensionists, researchers and farmers in naturally benefitting, active learning processes. In spite of the fact that this approach was new in the Sudan, it was fairly easily accepted by the extensionists, researchers and farmers.

The educational changes are, however, slow by their nature; it takes more than one season for the extensionists to master the approach and for the farmers to easily learn through it. The FAO/ARC IPM Project has realized that fact and started to train the extensionists in topics related to the new extension methodology and using techniques of participatory approach and audio visual aids (AVAs) suitable for field situations to meet the necessary changes that have occurred as a result of moving from traditional extension to a participatory approach.

This paper reports on the effects of weekly training in IPM FFSs which sought to change farmers' knowledge, attitudes and practices during the same season when the training took place and the adoption rate of the IPM options during the following season in two areas: Gezira scheme and along the Blue Nile banks (Gezira State).

Adoption Rate: Definition and Social Factors

Adoption rate is defined by Rogers (1983) as the relative speed with which an innovation is adopted by members of a social system. It is generally measured as the number of individuals who adopt a new idea in a specified period. So the rate of adoption is a numerical indicant of the steepness of the adoption curve for an innovation. Five characteristics of an innovation are essential for explaining its rate of adoption: the perception that the innovation is better than a traditional practice due to economic or social factors, compatibility with tradition and past experience, complexity, feasibility that the innovation can be tried/experimented on a limited basis and visibility of results.

Rural sociologists recognized early that essential differences among farmers can explain why they do not adopt innovations at the same time. Rogers (1983) used a time continuum to classify adopters into five categories based on their innovativeness, defined as the degree by which a farmer is relatively earlier in adopting compared to other members in the system. Because many human attributes (physical or psychological) are normally variable, he hypothesized that the time to learn a given task is also normally variable. Furthermore, he argued that substituting a social system for an individual also leads to a normal distribution, which in the cumulative form approximates the typical S-shaped diffusion curve. For that reason, Rogers (1983) used the standard normal distribution to define adopter categories.

Farmers in the first category are the "innovators". These individuals are characterized as venturesome and willing to assume the risk of using innovation; they experienced and learnt to adapt the innovation to local conditions. This category includes the first 2.5% of the adopters. The next 13.5% are the "early adopters". Farmers in this group play a key role in the diffusion process because they are well-respected by other farmers and exert a large degree of "opinion leadership". The next to adopt are the "early majority" which include 34% of the adopters. Farmers in this group deliberate for some time before adopting, waiting until sufficient experience has accumulated. Individuals in "late majority" group (34%) are skeptics who are not convinced until most of their peers have adopted. The last group to adopt, the "laggards" (16%), are attached to tradition and suspicious at innovation and of "change agents". The laggards adopt only when they are in certain that the innovation will not fail because they cannot afford failure due to their precarious economic condition (Rogers, 1983).

Methodology

The weekly training sessions in the FFSs established in the Gezira and Rahad schemes and along the Blue Nile banks (Gezira State) during the 1994/1995 growing season included a theoretical part related to vegetable production and protection with emphasis on non-chemical methods of preventing damage caused by insect pests and diseases. Demonstration plots were established by FFS participants to verify various IPM options on farmers' fields.

The study on the adoption rate of IPM option by the FFS participants was carried out during the next season (1995/96) following 6–7 months of training. The survey was restricted only to the Gezira scheme (FFSs in centre, southern and Messalamia groups) and FFSs established along the Blue Nile banks in Al Hag Abdalla, Fadasi and Abu Frua. A total of 120 farmers were trained in both areas.

The stratified random sample technique was used to select a representative sample. The farmers were divided into two strata according to their locations and mode of production. Sixty trained farmers were selected (30 from each area) out of 120, and 60 non-FFS participants (farmers who had never been trained) were chosen for comparison. The total number of interviewed farmers was 120. Data was collected by close-ended questionnaire. The questions were divided into two parts (Table 1, see end of paper). The first part addressed independent variables, i.e., socioeconomic characteristics and participation in FFSs.

The second part of the questionnaire was related to adoption of tomato IPM options presented in the FFS (Dabrowski, 1994; and this volume).

Data was recorded by independent staff (not the FFS organizer) through direct interviews of school participants and non-participants. Data was coded, fed to the PC and analyzed by SPSS. Frequencies and simple descriptive statistics were calculated for both farmer groups. Chi-square test was used to study the relationship between participation in FFSs, socioeconomic characteristics, farmers' knowledge and attitudes to recommended IPM options.

Integration of IPM Options into Tomato Production System

Pre-training and post-training evaluation of knowledge, attitude and IPM practices of the participants of the FFFs established in Central Sudan in the 1994/1995 season showed that after 6–7 months of training, there were positive changes related to the implementation of IPM principles. The percentage of farmers who could identify vegetable pests and beneficial insects rose from 53% in Gezira State FFSs and 40% in Gezira scheme FFSs to 74% and 75% after training, respectively (Fig. 1). More pesticides were used on tomato compared to onion in all FFSs in Gezira State or Gezira scheme in the pre- and post-training stages. However, FFS farmers succeeded in reducing pesticide applications in these two crops. The average number of sprayings on tomato in Gezira State was reduced from 11.1 to 9.3 sprays (reduced by 1.8 spray) and from 3.7 to 2.4 sprays on onion (reduced by 1.3 spray). In Gezira scheme, spraying on tomato was reduced from 9.8 to 8.4 sprays (reduced by 1.4 spray) and on onion from 2.7 to 1.9 (reduced by 0.8 spray). Implementation of some IPM options in the same season as training was different for some farmers in spite of their positive attitude to IPM. In general, farmers' attitudes after the FFS training became more positive towards reduction of pesticide applications; daily crop follow-up; recognition of insects; discontinuing spraying at fruit setting stage and further advanced training. The study also showed that the training in IPM FFSs for one season helped farmers improve their production and protection practices, i.e., cultural practices using recommended pesticides, correct dose and safety periods as well as safety measures during spraying.

In the 1995/1996 season, only adoption rate of selected tomato IPM options by partici-pants of the 1994/1995 FFSs was evaluated. It should be mentioned that some farmers not participating in the regular FFS training sessions in the 1994/1995 season could learn from their participating colleagues, visits to IPM demonstration plots or on-farms techniques.

Intercropping Coriander With Tomato

Thirty percent of FFS participants of the Blue Nile bank area ("Nile"farmers) grew tomato intercropped with coriander as compared to 7% of non-participating farmers (Fig. 2A). In the Gezira scheme, 35% of FFS participants intercropped coriander with tomato and none of the untrained farmers did.

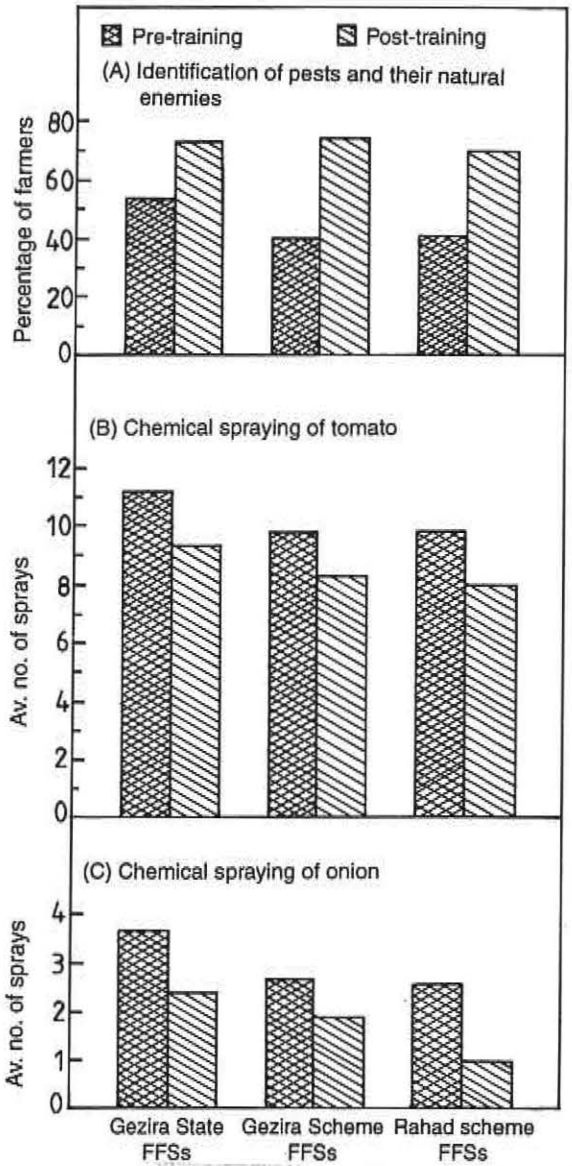

Fig. 1. Effect of FFS participatory training on IPM farmers' decisions in three regions, 1994/1995 growing season

Removal of Weeds as Potential Alternative Hosts of TYLCV

Most of the farmers do their regular weeding in the tomato crop, but they sometimes fail to remove weeds which are alternative hosts to Tomato Yellow Leaf Curl Virus. Some fields are covered by such weed species: *Acalypha indica, Datura stramonium* and *Hibiscus ficulneus.* Eighty percent of FFS participants in both Gezira scheme and along the Nile carefully removed TYLCV alternative hosts from their fields in the 1995/1996 season; however, 60% of Gezira non-participants and 47% of "Nile" farmers (Fig. 2B) removed the hosts.

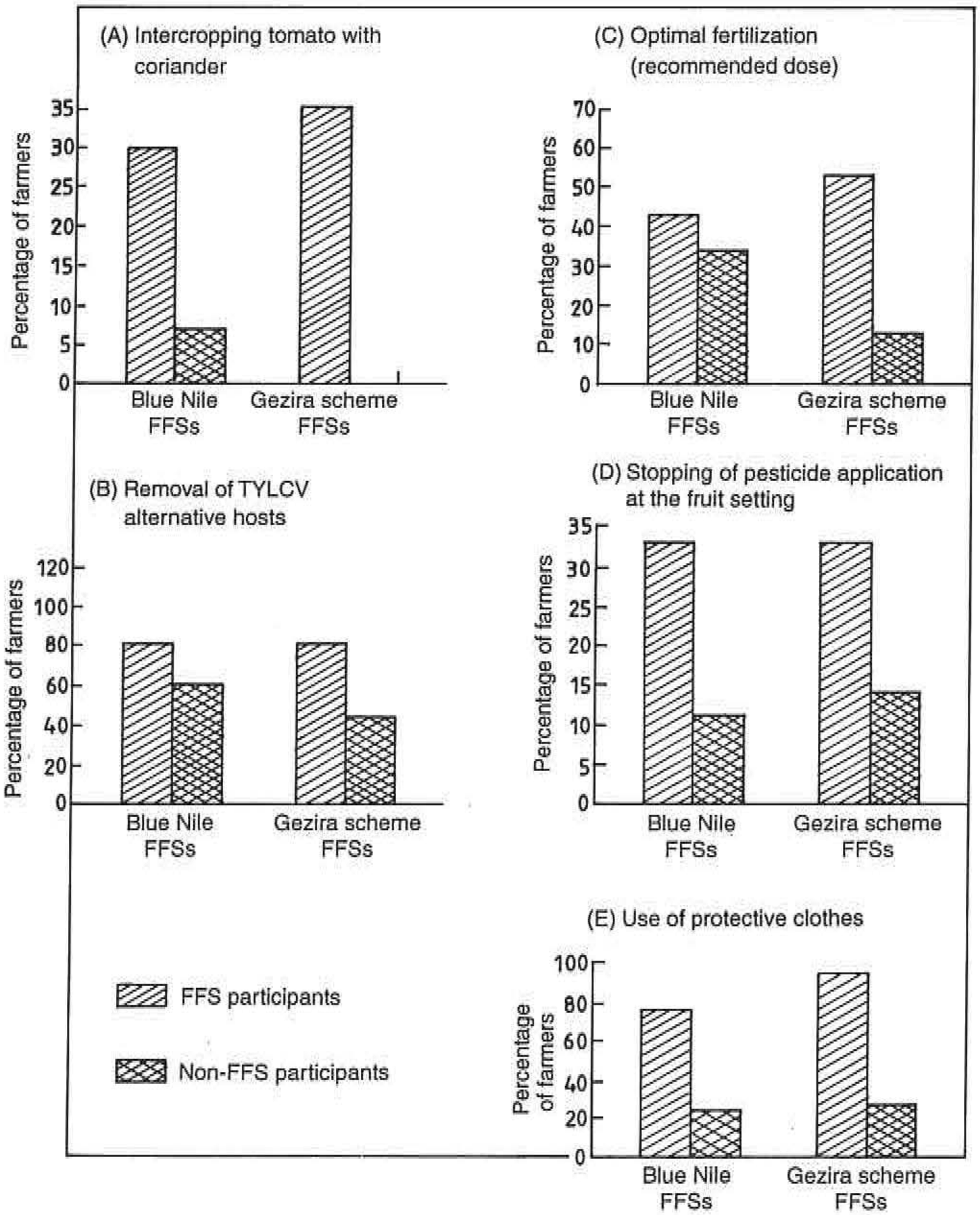

Fig. 2. Effect of FFS participatory training on IPM farmers' decisions in two regions,1995/1996 growing season

Application of Recommended Dose of Fertilizers

The recommended dose of urea is 80 kg/feddan. Some farmers were using excess dosage of nitrogen causing blossom end rot disease (see Nafisa and Wani, and Mamoun Beshir Mohamed in this volume). Between 43% of "Nile" farmers and 53% FFS participants of the Gezira scheme used the optimal dosage of urea in comparison to 33% and 13% of non-participating "Nile" and Gezira scheme farmers, respectively (Fig. 2C). The Chi-square test showed that the higher adoption of using optimal dose of urea was strongly associated with education level and the length of FFS training (attendance rate).

Along the Blue Nile bank, optimal fertilization was adopted by 43% of the FFS participants; 57% did not apply optimal doses. Thirty percent applied more than the recommended dose and 20% used less than the recommended dose. Seven percent did not apply any mineral fertilizer. Among the non-FFS participants, 33% used optimal fertilization and 67% did not; 37% of these applied higher doses and 20% lower doses than the recommended ones. Ten percent of farmers did not use any fertilization at all. The farmers who did not apply fertilizer were, however, aware of its positive effect on vegetables, but they could not afford to purchase them.

Of the FFS participants in the Gezira scheme, 53% applied an optimal dose and 47% did not; 33.5% applied a higher dose and 13.5% a lower dose than recommended. Only 13% of non-participating farmers applied optimal fertilization; 87% did not. Of those, 83.7% used more and 3.3% less than the recommended level.

Discontinuing Sprays at Fruit Setting Stage

It was shown by a number of authors that later spraying of tomato against cotton whitefly which transmits TYLCV to older tomato plants has little effect on yield. This option was adopted by 33% in both areas as compared to 11% for untrained farmers in the "Nile" area and 13% of the Gezira scheme (Fig. 2D). Because of American bollworm attacking fruits, most farmers still continue, preventively, to spray their tomato crop.

Curative Spraying Against Cotton Whitefly

FFS farmers as well as non-participating farmers were well aware of the whitefly's role as the TYLCV vector which can completely devastate their tomato crops. Their conventional practice was regular weekly preventive spraying. Untrained farmers of the "Nile" were spraying their tomato crop 12 times versus 5.2 sprays by the FFS participants (Table 2). The untrained Gezira scheme farmers sprayed 9.6 times versus 4.3 sprays by the FFS participants. The difference indicates 56.3% reduction of pesticide spraying between the "Nile" farmers and 55% for the Gezira scheme tomato growers trained in the 1994/1995 season in Farmer Field Schools.

Table 2. Average number of pesticide sprayings and tomato yield by FFS participants and non-participating farmers in Gezira scheme and along the Blue Nile banks 1994/95 season

Treatment	Blue Nile		Gezira scheme	
	FFS farmers	Non-FFS	FFS farmers	Non-FFS
Ave.no. sprays	5.24	12.0	4.3	9.58
Ave.yield (t/feddan)	6.7	5.5	7.18	4.6

The lower application of insecticides by FFS participants was mainly due to discontinuing spraying tomato plants at the fruit setting and implementation of other IPM options: removal of the alternative hosts of TYLCV; regular checking of their plants for whitefly; intercropping with coriander and better management of their field, increasing plant tolerance to pest damage. The increased number of insecticide sprays did not guarantee a higher yield of tomatoes (Table 2). The FFS participants, in addition to their better knowledge on general management of their crop, also knew when to spray and what chemical should be selected for specific pest or diseases.

Using Protective Clothes During Spraying

Protective clothes are used for legs, hands, face (especially eyes) and other parts of the human body during application of pesticides. The ideal protective clothes are not available for common farmers, and especially a labourer or shareholder. Trained farmers are overcoming this constraint by using locally made simple protective clothes or their old clothes. This recommendation was adopted by the majority of FFS trained farmers in both areas; 77% of the FFS "Nile" farmers used protective clothes as compared to only 23% of non-participating farmers (Fig. 2). The difference in the Gezira scheme varied from 97% for the FFS farmers and 27% for non-participating farmers.

Summary

Field data confirmed the efficiency of training in the Farmer Field Schools on proper crop management and curative use of pesticides rather than frequent preventive sprayings. The observed differences in the adoption rate of various IPM options in tomato crops are probably due to farmers' socioeconomic characteristics and previous experience in growing tomato in their own fields as well as on IPM demonstration plots during participation in FFS sessions.

A lower adoption rate of intercropping coriander with tomato is not surprising. Only in a specific growth stage does coriander have maximal repellent effect. The planting date of coriander should precede sowing tomato. It means bearing additional expenses on irrigation and weeding for a longer period. More economical evaluations of intercropping coriander with tomato are needed.

Major differences between FFS farmers and non-participating farmers in the number of sprays of tomato crops indicate that the FFS training programme has provided farmers with solid information on the curative use of specific pesticides against pest and/or disease actually occurring on the farmer's field.

To reduce the observed negative differences between various groups of farmers in the Gezira scheme and Nile Bank, the Farmer Field School model should be expanded to all villages in both areas. Only a few months separated the end of FFS training and the new 1995/1996 growing season. Probably the period was too short for disseminating IPM information to non-participants through FFS farmers. In any case, the school organizer should encourage the participating farmers to disseminate IPM information through various informal occasions or social gatherings.

The school organizers should also address the optimal use of mineral fertilizers. Numerous farmers have shown a tendency to apply higher doses of urea than recommended. More IPM demonstration fields should include farmers' experimentation on various levels of fertilization on plant growth, yield and occurrence of pests and diseases (see Nafisa Ahmed and Wani in this volume).

Table 1. Questionnaire used for measuring adoption rate of tomato IPM option by FFS participants in comparison to non-participating farmers

Farmer No. .... Date ....
Group/Region .... Village ....

Please answer the following questions. Mark (✓) on the paper for your answer.

1. Sex ☐ Male ☐ Female ☐
2. Age ☐ Years ☐
3. Educational level:
   Illiterate ☐ Khalwa ☐ Primary ☐
   Intermediate ☐ Secondary ☐ Beyond secondary ☐
4. Marital status:
   Single ☐ Married ☐ Divorced ☐
   Widowed ☐ Married more than one wife ☐
5. Mode of production:
   Nile pumps ☐ Underground water ☐
   Canal irrigation ☐
6. Production relationship:
   Shared cultivations ☐ Rent ☐ Farm owner ☐
   Hawasha owner ☐
7. Area cultivated by tomato this season:
   Less than one feddan ☐ 1–4 feddans ☐
   5–9 feddans ☐ 10 feddans or more ☐
8. Vegetable cultivated area:
   5 feddans or less ☐ 6–10 feddans ☐
   11–15 feddans ☐ 16 feddans or more ☐
9. Number of family members (including husband and wife/s):
   1–4 members ☐ 5–7 members ☐
   8 members or more ☐
10. Number of family members all season engaged in farm work:
    None ☐ 1–3 members ☐
    4–6 members ☐ 7 members or more ☐
11. For how many years have you been growing tomatoes?
    Less than one year ☐ 1–3 years ☐
    4–7 years ☐ 8–11 years ☐
12. For how many months did you participate in FFS training sessions during the 1994/1995 season?
    Did not participate ☐ Less than one month ☐
    1–2 months ☐ 3–4 months ☐
    5–6 months ☐ 7 months ☐
    The whole season (8 months) ☐

Table 1. Continued next page

Table 1. Continued

13. On average how many weekly training sessions did you attend per month?
Did not attend ☐ One session ☐
Two sessions ☐ Three sessions ☐ Four sessions ☐

14. For how many growing seasons did you participate in FFS weekly training sessions?
Did not participate ☐ One season ☐
Two seasons ☐ Three seasons ☐

15. Did you participate in the tomato IPM demonstration field?
Yes ☐ No ☐

16. Does the IPM field produce a better tomato crop than yours?
Yes ☐ No ☐

17. How did you prepare your tomato field this season?
Pre-irrigation, discing two times, mastaba formation using Abu vi ditcher ☐
Pre-irrigation then ridging 80 cm ☐
Discing one, levelling, then Abu vi ditcher ☐
Ridging 80 cm, ridge closure at end ☐
Deep ploughing, harrow discing, levelling, 120 cm mastaba formation, pre-transplanting ☐
Irrigation, hand tools finalization then transplanting ☐

18. Did you plant tomato this season close to the previous season tomato crop?
Yes ☐ No ☐
Distance to the previous crop ....

19. Did you plant your tomato close to one of the following crops?
Okra ☐ Eggplant ☐ None of the two ☐

20. What tomato cultivar(s) did you plant this season? ....

21. When did you plant your tomato crop this season?
Winter season ☐ Summer season ☐
Khareef season ☐

22. How did you plant your tomatoes this season?
Direct seeding ☐ Nursery ☐

23. If nursery, how did you prepare it?
Basins ☐ Ridges 80 cm ☐ Mastaba 120 cm ☐

24. How did you plant seeds on the nursery?
Broadcasting ☐ Planted in rows ☐

25. Did you grow a sole tomato crop or interplant with other plants?
None ☐ Beans ☐ Coriander ☐
Fenugreek ☐ Lubia beans ☐ Pigeon pea ☐

26. Interval period between field irrigation:
In winter .... days ☐
In summer .... days ☐

27. How did you water your tomato this season?
Light irrigation ☐ Medium ☐ Heavy ☐

Table 1. Continued next page

Table 1. Continued

28. How many urea sacks/feddan did you add to your tomato crop this season?
Did not add any ☐ Less than one sack ☐
One sack ☐ 2 sacks ☐
3 sacks ☐ 4 sacks ☐
More than 4 sacks ☐

29. What doses of urea did you use on your tomato this season (1995/1996)?
All in one dose—two weeks after transplanting ☐
Two doses; one two weeks after transplanting and the second just before transplanting ☐
More than two; one two weeks after transplanting; one just before flowering and continued fertilization after fruit setting ☐
Any other practice ☐ Mention it ....

30. What species of weeds did you remove from your field?
Um Imarat only ☐ Sakaran only ☐
Weika only ☐ Removing three above ☐
Orobanche ☐
Other weeds removed ....

31. When did you start spraying your tomato this season?
In nursery, after how many days .... How often ....
Apply pesticides only after transplanting ☐ Did not spray at all ☐

32. Did you spray regularly or when you first observed whitefly?
Regularly ☐ When I observed whitefly ☐
Others ....

33. What pesticides did you apply on tomatoes to control the following pests last season?

Pest	Pesticides	In nursery	In field	Dose/feddan	No.of sprays
Whitefly	....	....	....	....	....
American bollworm	....	....	....	....	....
Powdery mildew	....	....	....	....	....
Others	....	....	....	....	....

34. How many times did you apply insecticides on tomatoes before joining the Farmer Field School?
....

35. What insecticides did you prefer at that time (before training)? ....
....

36. What fungicides did you use on tomatoes before training (names)? ....
....
How many times did you spray? ....

Table 1. Continued next page

Table 1. Continued

37. How many times did you spray your tomato crop after training?
Insecticides ....
Fungicides ....

38. How many times did your neighbour spray his field last season? ....

39. Did you participate in the FFS?
Yes ☐ No ☐

40. When did you stop insecticide application for controlling whitefly?
Directly after transplanting ☐ Just before flowering ☐
At fruit setting stage ☐ Just before harvest ☐
Continuous spraying during harvesting ☐ Did not spray at all ☐

41. Did you use vegetable oil to spray tomatoes to control whitefly? (e.g., sesame oil or cotton seed oil).
I did not use any ☐ I used few times only ☐
I used regularly ☐
If not, why didn't you try ....

42. What do you wear during applying insecticides?
I don't wear special clothes; I use ordinary clothes ☐
Using special protective clothes; covering legs and nose ☐
Others (specify) ....

43. What was the yield of your tomato field last season (tins/feddan) ....

44. Why didn't you implement all IPM recommendations?
Too late learnt ☐
Too complicated ☐
Not given precise, clear recommendations during the training ☐
I have to test new recommendations on a small plot first ☐
IPM did not show good results on the IPM demonstration plots in the FFS ☐
Others (specify) ....

45. Did you try to count your field expenditure and income from sale?
Yes ☐ No ☐

46. I can say that applying IPM recommendations on my field
Much increased profit ☐ Increased profit slightly ☐
Did not increase ☐ Decreased profit ☐

4 Integrated Pest Management in Vegetables

Vegetable Production in the Gezira Scheme

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The Gezira scheme covers an area of about two million acres; half of it annually produces cotton, wheat, groundnuts, sorghum and vegetables. Vegetable crops were introduced in the Gezira scheme in the early 1930s. At first, they were confined to the holdings of some notables, but slowly other tenants became familiar with them. A study on the diet of Gezira inhabitants (Culwick, 1950) revealed that vitamins and mineral salts were almost deficient. Consequently, her recommendation to establish a horticultural section in the Gezira found its way to execution. Since then, the area allotted to vegetables expanded rapidly to cover 10% of the cotton area which amounts to 50,000 acres. According to the prevailing rules, it is possible now to extend up to 75,000 acres annually.

Developments

During the seasons from 1990 to 1995, very slow horizontal development took place in the production of vegetable crops. In the 1991/1992 season a drop of 3.9% happened, but the following season, the total area started to increase by 7%, 6.6% and 6.3%.

Individual crops underwent fluctuations of varying trends during this period: Onion, the leading crop areawise, covered 41.5% of the total area allotted to vegetables (Table 1). In the 1991/1992 season it followed the same trend of the other crops when its area dropped by 10%, but it rose again by 16.5%, 5.3% and 4.8%, respectively for the seasons that followed. The normal trend of tomato area allotment is to rise one season and fall the next (Table 1). The most probable explanation is the fluctuation in prices coupled with the annually increasing cost of production. In general, significant development was observed in onion, tomato and leafy vegetables in this period of time where their areas increased by 15.4%, 26.6% and 110.4%.

Chilli peppers and okra were observed to undergo light development in the course of the five seasons. The rest of the crops showed no progress in yield per unit area.

There is great potential to produce high quality vegetables in Gezira scheme for export (Table 2).

Regional Distribution

The Gezira region, the first established part, grows twice as many vegetables as the comparatively new region, the Managil Extension. On average, the Gezira grew 75.43% while Managil grew 25.55% during the last five seasons. This may be attributed mainly to Managil tenants' low awareness of the economic and nutritional value of vegetable crops.

For simplicity, reference is made here to four regions rather than naming the administration units actually in use (Table 3). Pronounced differences in vegetable areas were observed within the four regions: the central region being in access to Wad Medani, the capital of Gezira

Table 1. Area and yield of vegetables in Gezira (area in 1,000 feddans; yield in 1,000 tons)

Crop	1990/1991		1991/1992		1992/1993		1993/1994		1994/1995		Av. yield
	Area	Yield	Area	Yield	Area	Yield	Area	Yield	Area	Yield	
Onion	19.00	131	17.10	137	19.9	159	20.9	168	21.9	175	154.0
Tomato	15.70	94	15.60	94	14.7	85	16.4	98	19.1	109.0	96.0
Okra	2.50	13	1.80	9	2.0	10	2.2	11	2.1	11	10.8
Chilli	4.80	19	2.70	11	2.7	14	3.2	13	3.2	13	14.0
Aubergine	2.00	30	2.10	31	2.0	30	1.5	22	1.5	22	27.0
Cucumber	0.16	3	1.20	18	3.1	49	0.98	16	0.75	12	19.6
Sweet potato	1.6	25	1.8	29	2.5	40	2.3	37	2.4	38	33.8
Coriander	0.6	3	0.4	2	0.5	2	0.5	2	0.2	1	2
Leafy vegetables	1.9	10	1.0	5	1.9	10	1.8	9	2.7	13	9.4
Total	48.26	328	43.70	336	48.8	399	49.78	376	52.85	394	–

Table 2. Projection of vegetable yield, consumption and export potential at the year 2000 (1,000 tons)

Crop	Total yield	Consumption	Surplus
Onion	192	125	67
Tomato	128	75	53
Okra	17	10.5	6.5
Chilli	20	15	5
Aubergine	36	16	20
Cucumber	25	·25	–
Sweet potato	40	40	–
Coriander	6	4	2

Table 3. Distribution of some vegetable crops in the Gezira (ave.of 5 seasons) (Area: in 1,000 acres)

Region	Crop: Onion	Tomato	Chilli	Leafy veg.
Southern	5.93	2.30	0.29	0.27
Central	10.02	3.58	0.36	0.55
Northern	1.80	6.86	2.17	0.54
Western	1.94	2.09	0.21	0.23

Southern = South, Centre and Jamusi groups
Central = Messelemiya, Wadi Shaeir, Wad Habouba and Makashif groups
North = Northwest and Huda groups
Western = Mansi, Tahameed, Maatug and Maturi groups

State, with its large market, grew 36.12% of the total vegetable area. Accumulation of knowledge between tenants through different systems such as rural farming at Wad El Naeem, the beginning of agricultural extension in the centre group and the establishment of the FFSs may have contributed to this development. The northern region being next door to Khartoum with high demand for vegetable crops came in the second rank (28.17%). The southern and the western regions followed at 23.26% and 12.33% respectively.

Regional specialization was noticed during the five seasons, 81.00% of onions were grown in the southern and central regions while 70.38% of the tomato crop was grown in the central and northern regions. Chilli peppers were also confined to the northern region where 37.87% was grown. Leafy vegetables were largely grown in the central and northern regions.

Survey on Present Production and Protection Practices

Information on different parameters of production was collected from 90 tenants belonging to the northern, central and western regions. The survey aimed at studying some social aspects of the tenants together with their performance in the different production processes.

Social Aspects

Of the tenants surveyed, 58% were within the age range of 20 to 45 years, which is the most effective age, although an increment of 18% was added to this effective age, as it refers to very young tenants below 20 years. A considerable 24% were above 50 years old and so should be spoken of as partially inactive.

The uneducated portion is 26%; those with elementary education, 32%; those with secondary education, 24%; only 4% have higher education. These education levels were acceptable for reading and reviewing written packages and technical information. Accumulated experience on vegetable growing was convenient, at least theoretically, where 50% had more than 10 years of experience and 40% had more than 5 years.

The family size, with special reference to the number of members who were able to participate wholly or partially in vegetable production, was surveyed. Tenants with less than three participating family members were 34%, those with three to five members were 40% and those with more than five members amounted to 16%.

The above-mentioned data led to the design of production relationships that prevailed during the season 1994/1995 in which this study was carried out. In the northern region, 73.3% of the vegetable tenancies were run by the family, 23.3% by shareholders and those run by direct labourers were 20%. In the central region 60.0% of the tenancies were family administered, 46.6% were operated as shareholding and 40.0% were run with direct labour. In the western only 13.3% were run by families and 93.3% by share-holders with complete absence of direct labour. It should be noted that some overlap took place because in many cases more than one production relationship prevailed at one time.

Knowledge of Vegetable Growing

Technical know-how was observed from the data collected from tomato and onion crops of the 1994/1995 season in the different regions. Although 90% of the tenants surveyed grew vegetables for five years and more, in many cases it was obvious that the technical information on the definite crop was not applied properly.

Tomato growers in the northern region applied primary land preparation of disc ploughing and harrowing. The practice was performed by 83.33%. The same was practised by 66.67% of tomato growers in the western region. Only 33.33% of onion growers did primary land preparation, and it was substituted by repeated ridging where 73%

of them ridged four times or more.

Tomato growers in the Gezira adopt two systems of sowing: transplanting and direct-seeding. Varying and sometimes contradictory views defending each arise here and there. In the northern regions, transplanting is the general practice while in the central and western regions both systems prevailed. Sowing date extended from the first of May up to mid-September, depending on many variables.

Onions were grown by transplanting and sowing date was usually decided by last season's prices. In the sample, 66.67% of the tenants sowed at the optimum date in August, while 33.3% chose out-of-season sowing dates in early July. This kharif (rainy season) sowing was mostly practised in the central region to achieve higher prices.

Seed rates for onions were in most cases around the optimum recommendation which is 5 lbs to the acre. In tomatoes, although 70% of the tenants used one quarter to half a pound of seeds per acre, 30% used higher rates of up to 1.5 pounds. Plant population for tomatoes is usually decided by the season; closer plants were observed in the summer crop of the northern region while wider spacing was observed in winter crops where a large canopy was expected. Onion yields are strictly decided by plant population. This may explain the differences in yield between tenants of central region who out-produced those of the western region, as 73.33% of them transplanted four rows in the ridge compared to 60% in the western region.

Earth moving seems to be an important practice for tomato growers. That is why 46.67% of them used to weed mainly to move soil just before each irrigation. On the other hand, 53.33 % weeded every other irrigation just to economize on labour. The use of herbicides for onions during the 1994/1995 season was very limited as not a single acre was treated in the western region while only 33.3% of the central region tenants used herbicides. Accordingly, the western region tenants weeded 8.1 times while the average number of weedings for the central region tenants was only 3.5. It may be the FFSs which exposed central region tenants to such knowledge.

Tomato crops experienced an exaggerated fertilization rate where nitrogen was applied. Although the recommended dose doesn't exceed 2N, in many cases as much as 5N or 6N was applied. In this study, an average dose of 6.15N was applied per acre; one extreme case of 20N per acre was recorded. Phosphorus was added at a higher rate also (2.25 P). Onion fertilization with urea was between 2.5N and 3.75N an acre. On the other hand, phosphorus fertilization was far below the dose recommended (0.41P). This is attributed to a general belief held by tenants that phosphorus fertilization lowers the keeping quality of onions. Perhaps this can be investigated by researchers.

Of the tomato tenants surveyed, 83.33% knew the whitefly and 50.0 % knew bollworms, but many other insects were still unknown to them. Leaf curl disease is also more familiar than other diseases. Such ignorance with some of the pests leads most of the tenants to spray according to a certain calendar; weekly or sometimes down to a 3-day interval schedule. That is why the average number of sprays was 24.3. Chemicals without any labels were usually bought from local dealers which also led to uncertainty. The main insect pest of onions, the thrips, was familiar to more than 90% of the tenants. Other insect pests and diseases were almost unknown. Quite a considerable percentage (10–20) of tenants didn't spray, while 13.33% in central region and 48.67% in the western region used the wrong chemicals.

Suggestions for Improvements

Future prospects for horticulture in Gezira are very encouraging, especially in the field of vegetable production. This can be achieved through:

- Research: Horticultural research is far behind the expectations of growers, so new programmes should be designed to cope with the actual needs.
- Extension: A specialized horticultural extension system is badly needed and should be given priority with adequate personnel and equipment.
- Inputs: Production inputs such as fertilizers and pesticides should be available, timely and at optimum quantities.
- Finance: Means of credit facilities should be offered to the small growers.
- Marketing: Marketing facilities available are not suitable for vegetable production. To secure good quality crops in the market, specialized cold trucks are needed. Such systems can be established by tenant organizations. Opening export opportunities will contribute to the promotion of vegetable production.
- Processing: Processing will promote production by absorbing surpluses and therefore contribute to price stability.

The Effect of Cultural Practices on Vegetable Pests and Diseases

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The Sudan vegetable production scene is dominated by low resource base farmers, tenants or share croppers in widely scattered small farms along both banks of the Nile and its tributaries or in soil bodies accumulated behind the several dams built along its way; and in the irrigated schemes in the north, centre and north-east. From the beginning, vegetable production was the sole responsibility of the small farmers without any form of government backing or support. They were left to their own resources, be they technology, know-how or materials, to wrestle a living from a harsh environment bedraggled with drought, poor seed quality, insects, diseases and weeds. Serious government intervention for the support of the vegetable producer was delayed and ineffective, for instance in the Rahad scheme.

The Sudanese market for horticultural products was and is ever expanding. Urbanization and modernization, literacy, incomes and supportive infrastructure are on the rise and are closely attended by steadily increasing levels of consumer demands for vegetables. There is presently an emerging industry and export market for Sudanese vegetables. The resources of the farmer are stretched to the limit to take advantage of this situation, and every method to increase production is thought fair game. Use of agro-chemicals, especially nitrogenous fertilizers and insecticides, proved their worth in field crop production systems, and vegetable farmers accepted them completely.

A wide range of insect and weed pests and diseases attack vegetables, and no vegetable is safe from their assault in the Sudan. The severity of their onslaught is season-dependent, and the ensuing damage is total or partial, depending on the causal organism, agroclimatic conditions and predisposition of the host plant to the attack.

Insect pests pose a special problem. Some of them, such as aphid, whitefly and jassid, are common on several vegetable hosts. This not only shows the polyphagous character of these insects but also ensures continued reinfestation (Kisha, 1984). The situation is all the more aggravated because of the type of vegetable production systems in the country. A multitude of numerous small farms anywhere between 0.5 to 2.5 ha in an area with a variety of vegetables planted on various dates even for the same vegetable crop is the norm. Furthermore, some pests, such as jassid, whitefly and budworm, are characterized by prolonged periods of occurrence. Others (e.g., stemborer, budworm, fruitworm and root weevil) are extremely difficult for pesticides to reach because of physical barriers. Diseases are varied and rampant. Pesticides in vegetable crop production came to be widely used, and the present usage levels are unsafe for the producer and consumer alike and for the environment at large in the Sudan (Siddig and Nasr Eldin Sharaf, 1990). The FAO/ARC IPM Project realized the problem and since 1993 has initiated multidisciplinary research and extension on alternative methods of preventing and/or reducing crop losses by the integration of all pest management techniques with the natural regulating and limiting elements of the environment (Schulten, 1994; Baudoin, 1994) and adopting the integrated pest management approach. All potential control methods such as cultural practices, resistant varieties, biological control and rational use of pesticides are components of IPM on vegetable crops (Dabrowski, 1994).

The cultural practices component of IPM is the most important, albeit most difficult, to convince the wary about because it is an idea, an approach, a method of production and not a product (Dent, 1991). The recipient has to perceive the benefits since they can't be seen or touched, weighed or measured in physical parameters. Also these effects are not quick to obtain but are rather accumulative. The use of optimal cultural practices in an IPM context is expected to have a dual effect, both on the crop and the pests and pathogens attacking it.

One feature of cultural control is that it seeks to modify the physical environment, abiotic factors such as soil texture, structure and composition (tillage, fertilizers, organic matter), temperature and humidity (irrigation, plant density). It can help to divert adverse atmospheric conditions (sowing date, intercropping, protective boundary crops) to the betterment of the crop and the determent of pests or pathogens. Adoption of a set of crop cultural practices suitable for a particular agroclimatic location will almost always lead to a reduction in pest populations. Thus, it is a prophylactic method of control made possible by the reduction or eradication of the sources of inoculum and insects hibernating or resting stages (tillage, post-harvest sanitation, crop hygiene, weeding) or by evasion of time of maximum pest or pathogen availability (sowing or transplanting date). These and other cultural practices are intended to reduce the initial colonization or inoculation; or once there to reduce reproduction, survival and dispersal.

Selection of Crop Species and Variety

Selection of the kind of crop and an adapted variety is not a cultural practice, but it is closely linked to the successful outcome of implementing optimal cultural practices. The potential of any crop is set by its inherent genetic make-up, but the degree of actual expression is governed by the biotic and abiotic environment. Within each kind of crop there are numerous cultivars and varieties. The first step for the farmer is to choose a suitable cultivar for the agroclimatic conditions of the region and in harmony with the prevailing socioeconomic situation. A cultivar should be adapted to local agroclimatic conditions and offer genetic resistance to specific pests and diseases (Baudoin, 1994), or it should be tolerant to pests, high yielding and attractive to consumers (Schulten, 1994).

Under Sudan conditions, the aerial part of the physical environment has a lot of bearing on the performance of crops and cultivars to the extent that vegetables are divided into summer, kharif and winter season crops. The two most important factors are the degree of temperature and relative humidity. Between them they force some vegetables out of the market by shortening the production season. For example, the higher than 40°C and lower than 10% relative humidity, which are normal summer conditions make it impossible to grow tomato old varieties such as Early Pack, Money Maker and Ace during the summer. However, with the introduction of the high temperature tolerant varieties (Strain B and Peto 86) and the use of cultural practices which reduce temperature and raise humidity, there is now a resumption of tomato production though at higher consumer prices.

Varieties of vegetable crops vary in their yield quantity and quality, satisfying diverse and conflicting tastes, in their resistance and/or tolerance to insect pests and fungal and viral diseases. Fortunately for the Sudanese farmer, a number of vegetable varieties released by the ARC and universities through the National Variety Release Committee are available.

The newly released Giha tomato variety (Dafalla, 1995b) is now joining other tomatoes resistant and/or tolerant to TYLCV. In nematode-infested areas, the nematode resistant varieties, Nemared and Monte Carlo, can be selected (Yassin, 1984a). Tomato fruit physiological disorders associated with high temperature resultant from direct contact with sun rays can be reduced by the use of indeterminate varieties with lush vegetative growth. The closed and compact-necked onion varieties like Saggi are tolerant of onion thrips unlike the open-necked ones whose loosely overlapping leaf bases constitute an ideal home. Amongst 11 tested onion varieties, Hudeiba White was found to be less infested with thrips (Abdelrahman et al., 1992). The pink root rot of onion is besetting onion production in many areas. Some varieties were found to be more tolerant, e.g., cv. Nase in north Sudan (Mohamedali, 1984) and cv. Fallati and cv. Furia in the Jebel Marra region where also some Indian cultivars were found to be resistant to the disease (Mofadel, 1994).

The spiny okra var. Khartoumia is more tolerant of insects than the glabrous cv. Karrari because of the physical barrier furnished by the spines. The physiological disorders as blossom end rot and radial and longitudinal cracking are a menace in watermelon production. Round-fruited cultivars such as Sugar Baby are almost immune, but the more popular elliptical ones such as Congo and Charleston Gray are highly susceptible. The insect pest, jassid, causes drying of leaves, stunted growth and decreased fruit production in eggplant. The variety Black Beauty was found to be more tolerant to jassid than Long Purple (Kisha, 1984).

In selecting an optimal variety, it is not enough to satisfy the needs for pests and pathogen tolerance and/or resistance. The consumer, the ultimate user, has to be given some thought too. Pungent red skinned onion with high dry matter content such as the Saggi group is the consumer favourite. Spiny mucilageous okra varieties are more preferred by the Sudanese consumer.

The kind of infrastructure available and the degree of development affect the choice and successful production of cultivars, sometimes overriding consumer tastes. A stark example is the small, flavourless processing tomato varieties which forcibly displaced the large, tasty varieties, Pearson, Ace, Money Maker and Early Pack. The latter simply could not withstand the harsh treatment from the farm gate to consumer kitchen to keep in any reasonable way their delightful shape, taste and marketability.

Crop Rotation

The practice of crop rotation is as old as agriculture and together with intercropping were in use in the old civilizations of the Euphrates and Nile rivers. Crop rotation, which is the planned systematic arrangement of growing different crops in a regular sequence in the same farm plot, is a must for satisfactory crop production. Soil nutrients are depleted from different soil layer depths according to the type of root growth. Various amounts and different kinds of organic matter are returned to the soil depending on which plant part is harvested. An inclusion of a legume crop replenishes the soil nitrogen by trapping the atmospheric gaseous form via the beneficial symbiotic relationship with nitrogen-fixing bacteria.

Farm practices are easier to plan and smoother to run if rotation is designed and followed for higher levels of farm efficiency. Well-planned rotation must take into consideration the principle that members of the same crop plant family should not follow or precede each other in the same piece of land. Also, crops such as leafy vegetables which are harvested whole and deplete organic matter should be alternated with those vegetables that provide only fruit but plenty of organic matter. Rotation is useful in that it creates conditions favourable for production of healthy crops tolerant to ravages of pests and diseases if and when they do occur.

The role of rotation as a prophylactic measure against establishment of pests and diseases merits special mentioning. Here, rotation is beneficial as a preventive measure by separating crops having similar susceptibilities in space and time (Salama, 1984). Crop rotation by denying suitable hosts for insects and disease organisms breaks the pest or pathogen cycle and discourages build up of both. It is a preventive measure abortive to colonization and inoculum build-up (Dent, 1991).

However, rotation, useful as it might be in building soil fertility and helping healthy crop production, is not effective against a wide number of pests and pathogens. It is only successful against slow moving species having a narrow host range and limited dispersal range such as nematodes and soil fungi. Successful rotation can be demonstrated by the control of *Meloidogyne* nematodes in Solanaceae, soil fungi such as the *Pyrenochaeta* pink root rot of onion (3 years), *Fusarium* wilt of legumes (up to 7 years), bacterial wilt of tomato, rot and wilt diseases and black scab in potato. The parasitic weed broomrape in Solanaceae could be controlled by a long-term rotation of 12 years.

Rotation is designed for pests and diseases as well as the general socioeconomic framework of farmer conditions. A quick tour through vegetable producing areas of Gezira shows grotesque results of abandonment of rotation. In Fadasi, north of Wad Medani, tomato fields are heavily infested with broomrape. Further north at Arbagi, onion fields are laden with pink root rot fungi. To the west at Fitais, tomato is heavily infected with root knot nematode. South of Wad Medani at Faris, broomrape and root-knot nematode are threatening tomato production. Clearly, these situations resulted from monocropping a "pet" vegetable for a long period of time. The crop (whether summer tomato production or out-of-season onion) fitted well in the socioeconomic situation of the farmers because of higher prices and big returns, and the result is season after season production of the same crop in the same piece of land.

Pests present one other problem: some are polyphagous and mobile. Hence, it is difficult to devise rotations which are 100% foolproof against all pests and diseases and satisfactory to all farmers' preferences at the same time. Each farmer needs to devise a rotation suitable for personal needs. It is simple as long as the principles of rotation are respected and fitted into the agroclimatic conditions with an eye on socioeconomic factors, pests and diseases prevalent in the area and market opportunities.

Sanitation and Field Hygiene

Plant debris is an excellent source of inocula for fungi and bacteria causing crop plant diseases. Different insect life stages find their safest places there while awaiting their opportune moment of attack. Post-harvest clean-up of such debris is an efficient cultural practice for reduction and/ or eradication of inocula and resting stages of insect pests. It is especially helpful in the control of the twelve spotted beetle and fruitfly in cucurbits; the African bollworm in tomato; stemborer in eggplant; bacterial leaf spot, wilt and early blight in potato and tomato; *Podagrica* sp. and the top borer in okra; termite in pepper; sweet potato weevil in sweet potato; the tuber moth and root and wilt diseases of potato (Ahmed, 1995a,b; Siddig et al., 1995).

Soil Selection and Tillage

The selection of soil type for vegetable production must be made with extreme care to have the best ones available so as to boost crop growth for the attainment of strong and healthy plants. Soils, from the physical point of view, can be light as those in the proximity of the Nile and its tributaries or heavy clays as those in Gezira Main. Vegetable crops can grow and produce satisfactorily in a wide range of soil classes as long as they are blessed with good drainage and high fertility. Light soils are naturally well-drained but their fertility could be improved by addition of organic matter and mineral fertilizers. On these light soils, crops enjoy good drainage and optimal soil aeration; growth is rapid and maturity is quick but the water-holding capacity and the level of natural fertility are low, requiring the addition of liberal quantities of organic matter and mineral fertilizers. Furthermore, light soils are known to harbour root-knot nematodes, a menace of Solanaceae and okra, and cutworm, an economic insect pest of potato. Light soils are more suited for tuber, root and bulb crops.

Conversely, heavy clay soils are more problematic. Drainage is poor and careful water management is required. Aggregation and ameliorization, hence drainage, can be enhanced by incorporation of organic matter. High free salt content and high alkalinity cause some nutritional problems such as unavailability of Fe, B (Baudoin, 1994) and fixation of the macronutrient P. These soils are inherently N-deficient, and for optimal growth, mineral N and P had better be exogenously added. Drying wet clay soils crack, thus furnishing entry points for several insects; foremost among them is the tubermoth, a serious pest of the potato, and the weevil of sweet potato. When their drawbacks are not acute, clays can support satisfactory growth of many vegetable crops as evidenced by the vegetable crop situation of Gezira.

Land preparation aims at the formation of a fine seedbed for the vegetable seed or transplant. The first 15–20 cm of the soil is the part needed by plants for anchorage and as a source of soil nutrients and water. This soil depth has to be manipulated in the best way to produce a fine seedbed with good tilth. The mechanical operations required are dictated by the initial condition of the field, but under normal conditions they encompass discing the soil to a depth of 18–20 cm to thoroughly disturb the root zone, harrowing to break large soil masses and levelling to smooth up the soil. The field could be used in the flat state or, if required, can be ridged at the desired ridge spacing. The kind of machinery and implements to use depends on the field size. A large array of power sources and implements is at the disposal of the farmer.

The time to start operation is very critical, particularly when working with heavy clay soils. The soil should not be too dry because it is very difficult to work and not too wet because large clods, hard to break later, are readily formed. Land preparation is best scheduled after rain or irrigation. Actual work should start when palm pressed soil is fragile enough to lose its shape when the palm is opened.

Land preparation can be used to advantage in controlling a multitude of soil flora and fauna harmful to crop plants. These include the root-knot nematodes residing to 15–20 cm deep in the soil and infesting any tomato, eggplant or okra rootlets coming near them; adults and nymphal stages of onion thrips; African bollworm pupae in tomato, eggplant and okra fields; *Laphygma* in onions and *Podagrica* spp. on okra. In addition, fungi responsible for seedling wilts and rots, and bacterium causing diseases in potato all live in the soil. Tillage practices such as discing up to 18–20 cm and harrowing have a negative effect on these organisms. The effect could be direct physical shearing or indirect by forcing these organisms out from their safe hiding places and thus exposing them to their natural predatory or parasitic enemies or to unfavourable elements of the physical environment resulting in death by desiccation.

On weed flora there are also eradicatory or controlling effects. Surface seeds of annuals may be hurled down to depths unsuitable for germination and/or emergence. Deep down seeds may be brought up where they could be consumed by birds or die due to unfavourable conditions. Living weeds are directly controlled or deeply buried by tillage. Repeated tillage is especially effective against troublesome noxious weeds such as Bermuda grass and sedge.

Indirectly, tillage operations have a positive effect on structural aspects of soils through increasing aggregation and clod breakage, aeration, percolation and helping beneficial soil life. The resultant increased oxygen availability will enhance production of weak soil acids which in turn help release needed nutrients for plant growth.

Levelling improves irrigation and discourages development of water logging conditions which so easily prevail in heavy soils. This is conducive to quick germination, emergence and robust root growth. Better irrigation management due to levelling is decisive in decreasing wilt and rot diseases in nurseries and small plants, bacterial wilt development in tomato, the physiological diseases blossom end rot and cracking in watermelon and tomato.

Ridge formation in heavy soils will ease irrigation water movement in furrows, an added precaution against water logging since water will be available to the roots through capillary movement. Ridges are especially useful in helping to avoid salt injury since salts naturally move towards the top of ridges, away from plant root zones, taking hold in the sides of the ridges as is the norm in clay soils.

Post Tillage and Pre-Crop Establishment Irrigation

After tillage operations and prior to sowing or transplanting, it is advisable to apply deep, thorough but slow irrigation to the field so as not to disrupt the still loose soil formations of plot boundaries and ridges. After the soil dries, the farmer re-enters the field, making necessary readjustments, cutting down high spots or filling low ones or doing all those other necessary small tasks in reconstructing ridges or strengthening weak spots therein.

This first pre-cropping irrigation is important in more ways than one. From the physical soil point of view, cracks are filled and soil humidity is augmented, resulting in optimal conditions for the soon-to-be-sown or transplanted crop. Soil clods untouched by the first finished tillage operations disappear, and the soil surface will be smoother and leveller. The water line—the top most level water can reach in ridge culture—can be defined prior to crop establishment. This is very important since it is on this line or just below it that seeds are sown, transplants are set and fertilizer is placed.

Some soil-bound pests and pathogens not affected by the tillage operations will have a hard time getting away from being drowned and killed by this irrigation. As a matter of fact, if things were carried further to a flood for 3 days, then nematodes (Yassin, 1984a) and pink root rot (Ahmed, 1995b) would be almost completely controlled.

Optimal irrigation of the field prior to transplanting is a must. Transplanted crops usually experience a transplanting shock which affects growth. Its severity depends on the transplant age, transplanting operation, timing, method and condition of the permanent field. A young tomato or onion plant just pulled from the nursery, transplanted into the open field and inserted in the soil will be better off to a quick start in a pre-irrigated plot than otherwise.

The best time to move into a pre-irrigated field to resume operations is critical. If it is too late then most of the benefits intended will be lost since the field is most probably dry. If it is too soon then it is harmful to the soil notwithstanding the difficulties encountered in working a wet soil. The opportune time to enter under these circumstances is when the moving feet make a visible imprint on the surface of the soil without the undersides having soil particles clinging to them.

Seeds, Sowing and Transplanting

Once an optimal cultivar is decided upon, the next step is seed selection. Everything in the vegetable production process depends on it. Due care and expenditure must be lavished on seed selection and procurement. A good seed is pure and true to type—free from seeds of other species of crops and varieties, weeds and inert matter. It must be high viability and of high rate of germination. A simple germination test might be done in order to dispel any doubts if any are lingering. Longevity of initially good seeds depends on physical factors such as relative humidity within seed (10–12% is best), temperature and relative humidity of store (the lower the better) and biological factors such as the presence of pests and diseases and crop species. Onion seeds can keep well under average storage conditions for 1–2 years, melon for 2 years, eggplant and watermelon for 5 years and other vegetables for 3–4 years (Mohamed, 1995b).

It is a top priority in growing healthy crops to have seeds, transplants and planting material free from insects and diseases. Seeds are implicated in the dispersal of several vegetable diseases such as the Yellow Dwarf Virus of onion, mosaics and mycoplasma- like diseases in beans. Diseased transplants can introduce and establish inoculum in a hitherto free soil, e.g., pink root rot of onion, garlic and tomato; and *Fusarium* wilt in tomato. Contaminated seed tubers and stem cuttings spread potato tuber moth and sweet potato weevil. Chlorosis dwarfism and mosaics in potato are spread by degenerated and diseased seed tubers. Diseased tomato transplants spread leaf spot, late and early blight diseases.

Seed Dressing

Once a seed is placed in the soil it can be victimized by a number of insects and pathogens. The germinating or emerging seedlings can be infected by agents of wilts and root rots. Seed coating with a suitable seed dressant in the ratio of 3 g dressant to 1 kg seeds protects seeds and seedlings during this vulnerable stage of their life. Some seed dressants have a delayed effect, persisting for some time, and can be handy in case protection from a late-season disease or insect is needed. Tomato seeds treated with 2.25 g/kg triademinol can be protected from powdery mildew for the first growing month (Ahmed, 1995c), and a similar protective measure was obtained against whitefly in tomato using Gaucho (Ahmed, 1995b).

Seed Rate

Seed rate is instrumental in conditioning crop plants. It is the amount of seeds used per unit area, and it depends on the crop, seed viability, time of planting, soil condition and size and vigour of resultant plants, being bigger with adverse conditions and smaller size crops. If a too high seed rate is used then competing crop plants will result in weaklings susceptible to ravages of pests and diseases. Indirectly, the plant population density, which is seed rate dependent has effects on microclimatic temperature level, wind movement and humidity thus favouring or discouraging pests and diseases. Invariably the seed rate, spacing and plant population recommended for a particular crop result in situations unfavourable for that crop's pests and diseases. For example, under very dense populations, the relative humidities are high and air movement is low, conditions favourable for whitefly colonization in tomato. However, for summer tomato production, high plant population is a requirement for the development of microclimatic conditions. Obviously, in such cases a balance has to be struck to lessen the damage of whitefly, or other components of control have to be brought to the fore.

Seedling wilts and rots, virulent diseases in onion and tomato nurseries, are aggravated under high seed rate and high soil humidity levels

(Ahmed, 1995a,b). Low populations in onion favour high thrips attack (Mohamed and Kannan, 1994b). In foliage diseases of several crops, high population densities favour quick spread of the diseases due to easy physical contact between diseased and healthy plant parts, thus affecting inoculation.

Seed Depth

Seeds have to be placed in the soil deep enough to facilitate contact with moist soil to ensure the start of water imbibition for the germination process to occur but not too deep to hamper emergence. A general rule is to place the seeds to a depth not more than triple the distance of the longest axis of the seed. Naturally large seeds are placed deeper than small seeds unless a plant property forbids it, e.g., bean seeds are sown shallow because emergence involves pushing the cotyledons up through the soil (Burgstaller et al., 1984).

The depth of sowing has direct bearing on predisposing crop plants to pest attacks and development of physiological disorders. The sweet potato weevil and potato tuber moth live in the lower areas of both plants and oviposit inside the economic crop underneath the soil. If the roots or the tuber are not completely covered during subsequent growth due to superficial planting, they are an easy prey for these insects. In onion, potato, radish and sweet potato, the physiological disorder, greening, occurs as a result of the sun rays falling directly on the bulbs, tubers and roots respectively. A suitable soil depth coupled with manual soil cultivation will stop this disorder in these crops.

Ridge Direction and Site of Planting

A temperature differential between the two ridge sides is utilized in crop production systems (Mohamed, 1991). The northern side of east–west ridges and the eastern side of north–south ones are cooler than their opposite numbers. This can be taken advantage of in production of healthy plants by growing crops on the side supplying temperature requirements best. Summer tomato production is more satisfactory when transplants are placed in northern or eastern sides, but okra, a traditional summer crop, is more successful in southern or western sides when grown as an off-season winter crop.

Direct Sowing

Normally cucurbits, okra, faba bean, coriander and some other vegetables are established by direct sowing under Sudan conditions. Seeds at the correct number per hole and recommended inter- and intra-row spacings are placed at the desired depth. The seeds should be covered with moist soil, then dried and pressed firmly with the foot to ensure seed soil contact required for water imbibition. This is followed by a light irrigation since the soil is already of high humidity and oxygen is at a low level. Time of sowing is preferred to be early morning because daylight hours with their increasing temperatures enhance germination and emergence processes. The third irrigation should be delayed as much as possible to encourage robust growth of roots. If a wet soil naturally tends to form a surface crust on drying, then ridge culture is obligatory to ensure satisfactory crop emergence. Sowing coriander seeds in groves along both sides of ridges with uniform seed distribution is better than other methods (Mohamed, 1992). Directly sown crops are likely to have missing holes. These should be resown within the first 10 days. Thinning of plants, discarding the undesirable and the weak down to the recommended number, should be done within 2–3 weeks after sowing.

Planting

In vegetatively propagated crops, sweet potato, potato stem cuttings and seed tubers are used respectively. The sweet potato stem cuttings must be from healthy mature vines, with 2–3 viable nodes, 25–30 cm long. Planting would be by inserting the proximal end of the cutting down into the soil with at least one nodal bud covered. Here the third irrigation must not be delayed, but several successive light irrigations must be given every 3–4 days til emergence of the field (Mohamed, 1995b). Planting whole potato tubers results in vigorous plants. Degenerated tubers are not recommended since they produce weak plants (Siddig et al., 1994). If cut tubers are used, they should be cut only once and only longitudinally, making sure that several well-developed eyes are present. Cutting should be done under cool weather. The first cut should not be complete, but the two halves should be left attached at the proximal end for high humidity development between the two cut surfaces; this allows for suberization, important for early protection of the tubers after planting in the soil. In potato, the first irrigation after plantings should be delayed to 3–4 days to avoid tuber rot and to keep high oxygen content since the soil was thoroughly irrigated in the preplanting irrigation. During early growth, irrigation should be light to encourage potato sprouting.

Transplanting

A number of vegetable crops are routinely transplanted: tomato, onion, eggplant, chilli, pepper and sweet pepper. Seedlings are first raised in nurseries and then later transferred to their permanent site in the field. Adoption of the nursery method for raising transplants before final transfer to permanent field site is advantageous. Economically, a lower quantity of seeds is needed to establish a feddan using this method than direct seeding, e.g., 250 g versus 500 g of seeds in tomato. A 14 m x 7 m nursery is enough to produce transplants for a feddan. This is of great practical significance, easing husbandry operations and cutting down costs. It is handier to observe abnormalities in such small areas and take appropriate remedial action than in large areas where direct sowing is practised. In addition, tomato is beset by the TYLCV, and like all other viral diseases, the damages are always greater on younger plants at the time of infection (Hein, 1984), and tomato can be infected at the emergence stage. It is possible to control the disease in the nursery by the use of non-woven fabrics as protective nets in open field nurseries (Dabrowski, 1994; Siddig et al., 1994) or by a thorough use of chemical control every 2–3 days extended later to 4–7 days (Hein, 1984), a costly operation for directly sown tomato in large areas. For better control of TYLCV, nurseries should be situated far away from established tomato fields. Adherence to such practices, in most cases, yields healthy tomato seedlings better able to successfully withstand field conditions, including tolerance to pests and diseases.

Nurseries

Nurseries could be established in the open field or in a brick-and-bamboo structure. Open nurseries are established in the open field in sites which are well drained fertile, accessible and with readily available irrigation water. Under light soil conditions such as along the Nile, seeds can be planted on the flat; but in clay soils where there is fear of salt injury or crust formation, ridge culture is recommended. Seeds are uniformly distributed in groves at a low to medium seed density. High seed rate and dampness encourage spread of nursery diseases (Omer, 1984; Ahmed, 1995a,b).

In closed nurseries such as shaded buildings, containers such as half tins and wooden flats with openings to drain excess water are used. The soil medium is prepared from sand and river silt in a 1: 2 volume ratio. Seeds are sown in the same manner with similar precautions as in the open nursery method.

Hardening

Tomato transplants are transferred to the permanent site when they are 4–5 weeks old, onion and pepper 6–7 weeks. A week or 10 days before transplanting, plants can be subjected to a hardening process consisting of withholding water or setting the closed nursery plants to the direct sun so that in future they can better withstand the open field conditions. The permanent field site should be ready and irrigated. The nursery itself can be irrigated to ease transplant pulling with minimum damage to the roots.

Transplant Shock

The primary objective during the transplanting operation is to lessen the transplant shock bound to, happen. This is, utmost care should be exercised during all operations of pulling, transport and placement of transplants. Holes should be big enough to accommodate the roots and the accompanying soil with ease. Under no condition should any part of transplanted seedlings be cut and thrown away, a practice of some farmers. In addition to the needless and foolish throwing away of food reserves, the practice can only cause further losses in food reserves by the resultant elevations in respiration due to injury. Transplanting is always better done during cool weather. The afternoons are more preferred because of the assurance of cool conditions during the night time when respiration and transpiration are lowest, availing the transplant the chance to recuperate.

Date of Sowing and Transplanting

Different vegetable crops have different optimum sowing and transplanting dates. Under Sudan conditions, Solanaceous crops grow luxuriantly and fruit well under cool weather conditions so they are grown mainly during winters. Cucurbits, on the other hand, thrive best under warm dry conditions and are grown in summers. Although most vegetables can be grown year round, growth is best at some specific periods. Satisfying the climatic requirements of crops leads to production of healthy plants which are tolerant of attack by pests and diseases, if they occur, and able to express their genetic potential to the maximum.

Synchronization of sowing date to crop needs is also a prophylactic measure since advancement or postponement of sowing dates helps in avoidance of pests having a limited period of breeding in the year like thrips in onion and aphid in cucurbits, okra and pepper (Kisha, 1984). The recommended sowing date for top onion yield also satisfies conditions for maximum avoidance of thrips. Kisha (1984) stated "In October–November transplanted plants were well established before thrips infestation occurred and produced high yields without insecticidal measures. In December, reasonable yields were got only with extensive spraying."

In recent years, onion was also grown satisfactorily without chemical intervention against thrips when the optimal cultural practices including August–September nursery sowing and October–November transplanting were adhered to in Rahad (Mohamed and Kannan, 1994b; Kannan and Abdalla, 1995), Gezira (Abdelrahman et al., 1995b) and Khartoum (Siddig et al., 1995).

In okra, the wrong sowing date may be disquieting. Abdelrahman et al. (1995b), after experimenting with sowing unadapted okra varieties in the cool season, reported, "They were slow growing stunted and attacked by all kinds of pests and diseases".

Virulence of pathogens and severity of diseases are also sowing date dependent via seasonal climatic conditions which effect inoculum build-up, dispersal and eventual inoculation and infection. Foliage diseases such as early blight and leaf spot are troublesome during wet weather (Omer, 1984). In the case of powdery mildew disease, the conidia can germinate at low relative humidities; wind is the dispersal agent, so it is not limited to the wet season and is now becoming an important summer and winter disease, especially in February (Omer, 1984; Ahmed, 1994). In winter sowings in November and December, all okra varieties tested were vulnerable to the pathogen, showing 100% susceptibility, but those sown before mid-September had no serious disease symptoms (Ahmed, 1994).

A faba bean sowing date of the last week of October to the first week of November was recommended for Rahad because, in addition to other factors, the resultant growth period coincided with low powdery mildew disease incidence. By the time the disease was troublesome, the crop had already almost completed its productive cycle, rendering chemical control inconsequential (Mohamed, 1986).

Summer production of tomato is vulnerable to development of sun-scalded fruits. If the warm conditions are coupled with irrigation mismanagement, then wide-scale blossom end rot and fruit cracking will develop.

Intercropping

The simultaneous cultivation of more than one crop species for all part of the cycle of each—intercropping—is an old agricultural practice. Alley intercropping by permitting growing of vegetable crops in strips between immature fruit trees raises incomes. Intercropping also includes mixed, row, strip and relay intercropping. Nomenclature notwithstanding, all forms of intercropping are advantageous in improving soil fertility, assuring greater total productivity by providing insurance against failure of any single crop and upgrading farmer nutrition standards since a variety of vegetables are available concurrently.

Intercropping is pregnant with possibilities that can be tapped to prevent pest colonization and pathogen establishment in an area or to reduce population increase and inoculum spread if already present. A dilution in host plant concentration distracts the pest since host and non-host plants are present; at the same time, the variety of crops present makes perfect conditions for the presence of natural enemies (Dent, 1991), and some intercropped plants are good reservoirs for natural enemies, e.g., alfalfa (Abdelrahman, 1995). The second in importance crop acts as a repellent to the target pest, thus reducing its numbers in the host environment. It may also serve as an attractant to the pest, and in this case the second crop is sprayed, saving the main crop from insecticidal contamination. In case of insect vector transmitted diseases such as TYLCV, the use of trap crops, hosts to whitefly but non-hosts to TYLCV, break the disease cycle (Yassin, 1984b). Intercropping by altering temperature and relative humidity may render environmental conditions unsuitable for the target pest.

In the Sudan, the search for a suitable plant species for intercropping with tomato to keep away whitefly and thereby check the spread of TYLCV dominates intercropping research work. This is wholly justifiable since the host is of paramount economic importance and the disease is virulent and destructive. A number of workers tried a number of plant species. In Gezira, coriander, cotton, cucumber, fenugreek, lubia and squash were tested (Abdelrahman et al., 1992, Abdelrahman1995; Ahmed et al., 1994; Ahmed, 1994). In the southern Blue Nile region, serpent melon, lubia and onion were investigated (Binyason, 1994). In Khartoum State, coriander and fenugreek were tried (Siddig et al., 1995).

Coriander and fenugreek came out as the most promising crop species for intercropping with tomato. A reduction in whitefly population was attained and a suppression of TYLCV was realized up to the first eight weeks. In Gezira, coriander showed more promise since tomato plants intercropped with it were more robust in growth with few whitefly and jassid and lower TYLCV incidence (Abdelrahman et al., 1992, 1995b; Ahmed et al., 1994; Ahmed, 1994). Because of larger vegetative cover, fenugreek was suppressive to tomato growth, and it showed other viral diseases which might be as dangerous as TYLCV (Abdelrahman et al., 1995b). In Khartoum, though both intercropped species gave good protection against whitefly, fenugreek gave better protection while coriander was more effective against African bollworm (Siddig et al., 1995).

In coriander and fenugreek intercropping trials with onion against onion thrips in Gezira, coriander was a better choice because of more modest growth; hence, there was less competition with onion. Furthermore, fenugreek was infested with aphid which migrated to the onion crop when the fenugreek plants dried out (Abdelrahman, 1995b).

To be effective in its repellent character, coriander has to be lush green throughout the tomato growth season (Ahmed, 1994) and the active period of foliage growth in onions. Coriander is a short maturing crop and should be sown at least twice, the first sowing done 2–3 weeks before transplanting the main crop and the second 6–7 months after the first sowing. Direction of sowing is crucial in preventing self-shading so coriander must be sown on the northern or eastern side of the ridge in the first sowing and on the corresponding sides in the second (Abdelrahman, 1995). Coriander seeds have to be placed uniformly in a continuous line in groves along the correct side of the ridge (Mohamed, 1995). For best results, the main crop plots should not exceed 8 m x 8 m, and the coriander should be sown in ridges, tagnats and gadwals surrounding them (Abdelrahman, 1995).

The results with other species were not so glamourous, but some interesting insights were obtained. Lubia, serpent melon and squash were highly attractant to whitefly (Abdelrahman et al., 1992; Binyason, 1994). Since lubia and serpent melon are ideal summer crops, their usefulness in whitefly control in summer tomato production must be investigated further. Lubia was also found to attract jassid (Binyason, 1994). Onion could also repel whitefly and jassid when intercropped with lubia and tomato; and onion intercropped with tomato showed less TYLCV (Binyason, 1994). These are interesting observations since they encourage the simultaneous production of onion and tomato, both being top priority crops having similar climatic requirements for growth.

Irrigation

Irrigation is one cultural practice that continues for the life of the crop. Plant health is hinged to the satisfaction of water requirements in the quantities, duration and method most suited to it. Plant factors regulating irrigation are growth habit, size of plant and physiological age. Species with extensive foliage cover and luxuriant growth habit require more water to satisfy growth needs and compensate for transpiration losses. Deep tap rooted species are watered at longer intervals and in larger quantities than shallow fibrous rooted ones where light, frequent irrigations are more in order. Plants in the flowering and/or fruiting stages are watered more than others.

The physical soil characteristics, texture and structure also play an important role in determining frequency and quantity of water applied. Heavy clay soils are irrigated in larger quantities and at longer intervals than their light-textured counterparts.

Climatic factors also affect the management of irrigation where, naturally, more water at shorter frequencies is essential during the hot summers with their accompanying high temperatures and low relative humidities. During these periods, transpiration is at maximum and applied water is a welcome compensatory measure. Furthermore, irrigation plays a role in modifying the hot and dry microclimate, cooling it to levels agreeable to satisfactory plant performance.

Important as it is in influencing plant life, irrigation has an added dividend in being a protective measure against pests and diseases. Soil bound thrips and thrip nymphs, pupae of African bollworms, termites, nematodes and soil fungi are adversely affected by irrigation water. A regular regime of irrigation followed throughout the growing season is a sure retardant to these organisms. Mohamed and Kannan (1994b) reported that satisfactory onion yields were obtained without insecticidal intervention against thrips when an irrigation frequency of 6 days was adapted.

Weed Control

A weed-free vegetable farm is a prerequisite for healthy crop growth. Weeds successfully compete with vegetables for nutrients, water and light. All vegetables are highly susceptible to weed harm during early growth, and seedlings growing in a weed-infested farm surely produce weak plants vulnerable to other attacks from other quarters.

Aside from the direct competitive effects, weeds are injurious to crop plants because they act as safe havens for insect pests and storage places for disease-causal organisms. The whitefly whose life cycle is a short 2–3 week period has more than 500 hosts, most of them weeds (El Amin, 1996; El Amin and Kannan, 1996). The leaf miner resides in weeds, especially in molaita (*Sonchus cornutus*). Thrips prefer grass weeds and trees. Gibbain (*Solanum dubium*) is a host for aphid, jassid and tingid bug. Hambook (*Abutilon figarianum*) is hospitable to African bollworm, whitefly, jassid and tingid bug.

Disease-causal organisms find safe refuge in weeds and around the vegetable plots. Powdery mildew inoculum can be found abundantly in molaita, Adan el far (*Rhynchosia memnonica*), ramtook (*Xanthium stramonium*), Tabar (*Ipomoea cordofana*) and Gibbain. TYLCV is hosted in Um Omairat (*Acalypha indica*), Saykaran (*Datura* spp.) and Gibbain.

For satisfactory and healthy crop growth, weeds must be eradicated. Tillage operations can be used to advantage prior to crop establishment. Some herbicides have been released by ARC for use in weed control in a number of vegetables. Cultivation during the growing season is a sure way to control weeds and induce favourable conditions helpful to strong root growth.

Fertilization

A total of sixteen elements are essential for normal growth and development in green plants. Water is the source of H and atmospheric air of C and O. The other thirteen are derived by the roots from the soil, six needed in macroquantities—N, P, K, Ca, Mg and S—and seven in microquantities—Fe, Zn, B, Cu, Mn, Mo and Co. In intensive crop production systems such as that of vegetables, the natural soil supply falls short of providing requirements and the gap has to be closed by the addition of fertilizers if maintenance of high yields is to be realized. Fertilizers are either inorganic or organic.

Inorganic fertilizers are products from natural mineral deposits, manufactured or synthetic products and by-products of industrial processes. The only inorganic fertilizers used in large quantities in the Sudan are those supplying N (urea 46% N) and P (triple superphosphate 46% P_2O_5).

The Gezira soil vertisols are inherently deficient in organic matter (only 0.2%) and low in N (only 0.02%). Exogenous N must be added to optimize growth and yield. At present, the only N fertilizer available is urea, and most vegetables respond positively to its addition up to 86 kg N/ ha^{-1}. The fertilizer is prone to loss by leaching, volatilization and reduction by aerobic micro-organisms under water logged conditions. To ensure that most of the added fertilizer is used by the plants, it is advised to add urea only after the crop had attained satisfactory growth—21 days after transplanting or one month after sowing—and only in two equal doses, the second being a month from the first. It pays to position the fertilizer in proximity to the roots to increase chances of its absorption by placing the fertilizer at or just below the water line. Since roots can only take up the fertilizer in solution form, a prompt irrigation after fertilizer application is advised.

The Gezira vertisols are low in available P owing to soil chemical attributes including high pH, salinity and presence of free $CaCO_3$ which render the P fixed and hence unavailable to the plants. In some crops such as onions, P addition is beneficial in optimizing growth and yield; and in legumes in particular it improves nodulation and nitrogen fixation (Mohamed, 1995). It is advised to apply 43 kg P_2O_5/ha. The most optimal is just before the last tillage operation. There is no record of K-deficiency symptoms in the vegetables grown in Gezira and it seems that all the soil K is water soluble hence readily available.

A well-balanced inorganic fertilizer programme is essential for satisfactory growth and production of healthy plants. However, excessive application of N beyond optimal levels may be self-defeating since such crop may be more inviting to insects. In addition, N at high levels induces development of blossom end rot in tomato fruits (Ahmed, 1994).

Organic fertilizers are substances produced by animals and derived from plants, such as liquid and solid excrement and plant debris and refuse. They can be used partially or completely decomposed. The released nutrients, such as N, P, K, Zn and Cu, are beneficial to the soil. However, the instrumental effect of organic fertilizers is on the physical properties of soils. Light soils are given body, and heavy soils are loosened up and become more open. Light soils, inherently low in water-holding capacity and in natural fertility, are amended by humus, a product of decomposed organic matter. It is black or brown, a loose, porous highly absorbent substance with positive effects on cation exchange capacity, water-holding capacity and microbial growth. In most clay soils, the major drawback is poor drainage. Organic matter addition and humus action help aggregation and amelioration, hence improve drainage and percolation in such soils. As long as the decomposed organic matter is free from weed seed, pests and diseases, farmers can use all the organic fertilizer they can get on their farms. It is best when well rotted and incorporated thoroughly in the soil.

Three Methods for Establishing an Action Threshold for the Cotton Jassid on Eggplant: Preliminary Report

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Correct timing of the application of pesticides is essential to avoid unacceptable crop losses and to minimize negative effects on the environment. In principle, the best timing for chemical control can be calculated in advance when the future course of the pest population density, associated damage, effectiveness of control, financial revenue of crop yield and costs of chemical control are known. The economically optimal decision minimizes costs resulting from pest damage and control. In practice, however, a decision on pesticide application is uncertain because of limited knowledge of the dynamics of the biological processes involved, actual field situation and future weather.

Economic Injury and Threshold Levels

Economic Injury Level (EIL) is defined as a quantitative measure of insect pest density that determines if an insect component of an agro-ecosystem is to be classified as a pest. An estimate of the pest density that can be tolerated without significant crop loss is essential as a safeguard against overtreatment with insecticides or unacceptable crop damage. Determination of the EIL is critical in defining the ultimate objective of any pest management programme and in delineating the pest population level below which damage is tolerable and above which interventions are needed to prevent a pest outbreak and to avert significant crop injury (Luckmann and Metcalf, 1975).

Various definitions have been proposed for EIT. Stern et al. (1959) considered it "the lowest pest population density that will cause economic damage" or "the level at which damage can no longer be tolerated and therefore, the level at or before which it is desirable to initiate deliberate control activities." On the other hand, the National Academy of Sciences (1969) define EIT as "the density where the loss caused by the pest equals in value the cost of available control measures." Headley (1982) says it is "the pest population that produces incremental damage equal to the cost of preventing the damage."

The economic threshold level (ETL) is another important parameter defined by Stern et al. (1959) as "the density at which control measures should be applied to prevent an increasing pest population from reaching the EIL." The economic threshold always represents a pest density lower than that of the EIL to allow the initiation of control measures so that they can take effect before the pest density exceeds the EIL.

This concept defined three categories of ETLs relevant to decision making in pest management:

- Threshold for economic damage (ED), the amount of damage that justifies the cost of artificial control;
- Economic injury level (EIL), the lowest population density that will cause economic damage;
- Economic threshold level (ETL), the level at which control measures should be implemented to prevent an increasing pest population from reaching the EIL.

Fluctuating threshold levels may result from factors such as local climatic conditions, time of year, stage of plant development, crop involved, plant variety (tolerant?), cropping practices, purpose for which the crop is to be used, desire of man and economic variables. High demand and short supply, low marketing standards and consumer taste may essentially result in high threshold levels and vice-versa.

Some scientists, however, consider the use of ET values derived from controlled single insect pest studies in the field to be unreliable because the ET is influenced by the above-mentioned variable factors and the time lapse since the last scouting. They recommend, instead, the use of action thresholds (ATs), derived empirically from trial-and-error verification on farmers' fields. Such AT values have been determined for four key insect pests of rice and are said to correspond better to the practical thresholds which farmers themselves have developed (Waibel, 1987). Farmers habitually monitor their fields for the occurrence of pests when they are working or while walking around their fields. They sight caterpillar, moth, sucking insects, egg masses and signs of damage over time, and they decide about treatment on the basis of experience and information (Bondong and Litsinger, 1988).

Action Threshold Concept

Recently more researchers and especially practitioners are using the term *action threshold* instead of *economic threshold* simply because it seems less ambiguous. *Action threshold* is used here as a general term encompassing all three definitions of ED, EIL and ETL. When the pest density or damage reaches the value for the action threshold then action is necessary to prevent further increases that will lead to an economic loss. The length of time between the action threshold and the EIL will be dependent on the speed with which the control measure works or the rate of pest population development (Walker, 1983). Where the delay, for instance, between the application of a pesticide and its subsequent effect is very short, then the ETL also defines the action threshold (Dent, 1991).

The action threshold was originally envisaged as constant, but in reality it is dynamic, varying according to crop cultivar, age, weather, plant density and fertilizer levels, among other things (Gutierrez, 1987). Such a large number of variables makes it extremely difficult to obtain economic thresholds that are generally applicable. Hence, although the economic threshold concept serves as a basis for decision making in insect pest management, the determination of such thresholds has proved to be one of the weakest components in management programmes, with the result that very few research-based thresholds have been developed (Poston et al., 1983).

A number of researchers working on action thresholds noted the difficulties in incorporating quantitative field data into a mathematical formula. It was easier for some pests than for others, but it will be especially difficult where natural enemies are involved in population regulation, where a number of insecticide applications are required during a season or where damage can be caused at different stages of plant growth. Reichelderfer et al. (1984) provide summary guidelines for a method that is probably as generally applicable as any:

1. For range of pest densities (including zero pests), measure yield and quality of the crop by means of controlled experiments. Pest density measurements should be made by counting or rating the percentage of plant parts damaged. These yield and pest observations should be on plots with no management actions, but they should be made early enough in the season so that management actions can be taken;
2. Total crop revenue is computed for each management action at each density by multiplying yield by price per unit of output;
3. Subtract the cost of each management action from the crop revenue for that action at each of the various initial pest densities. Call these *net revenues*;
4. Beginning at very high pest densities and moving to lower densities, compare net revenues for taking a management action with those for taking no action. By comparing net revenues, find the pest population where net revenue for taking an action is equal to that for not taking an action. The pest density where the net revenues undercontrolled and uncontrolled circumstances are equal is the action threshold.

ETLs for cotton key pests in the Sudan were determined on empirical evidence, i.e., by deduction from replicated observations and experiences with the pest in the past. These levels were reviewed for some seasons and were re-adjusted in accordance with changes in farming practices and with information obtained from continuing observations and experimentation. These long-term field observations were required to establish economic thresholds in relation to intensity of attack. Long-term assessment of economic losses on untreated check plots have permitted studies to determine levels of infestations and losses under natural conditions. The data thus obtained provided a reference to evaluate the efficacy of various control procedures tested at the same time in adjacent plots (Stam et al., 1991).

Establishing Action Threshold for Cotton Jassids on Eggplant

Studies were conducted at Kenana Research Station at Abu Naama and included cage, field controlled and farmer participatory experiments. The objectives of the experiments were to establish the jassid density-damage relationship, identify the most critical crop growth stage where there is a maximum injury or loss and determine the lowest population of cotton jassid at which farmers decide by themselves to spray their eggplant crop to maximize profits. The experiments were consecutively carried out during summer, autumn and winter in the 1994/1995 and 1995/1996 growing seasons.

Eggplant seedlings, cv. Black Beauty, were raised in nurseries and transplanted to their permanent sites (cage and field conditions) after 45 days at different determined dates. The critical crop growth stage was fixed for each experiment, i.e., seedling stage (30–45 days after sowing—DAS), the vegetative stage (60–65 DAS) and the flowering stage (90–95 DAS), respectively.

Crop Experiments

A single eggplant was transplanted into a 4-gallon earthen container(22 cm x 22 cm x 35 cm). Each container was put into an iron-rod cage, 80 cm in diameter and 160 cm in height covered with a fine cotton cloth provided with zip-fastener to facilitate easy watering and observations. Different jassid densities were introduced into each cage as five treatments: "O", representing control; 1, 3, 5 and 10 jassid/leaf and left to feed. A treatment was replicated four times in a randomized complete block design. Observations on the number of leaves, shape, size, colour changes due to damage symptoms and number of flowers were recorded weekly for 5 weeks. Analysis of data was made to reflect the mean number of leaves and flowers as yield parameters.

On-farm Experiment Managed by Researchers

Eggplant seedlings from the same nursery as above were transplanted into the field after 45 days. Five treatment levels were used; "O", representing control, 100, 300, 500 and 700 jassid levels per 100 leaves, respectively. The treatments were randomized in a complete block design and replicated four times. Experimental field was 80 m x 80 m, spacing was 70 cm between rows and 60 cm between plants. Jassid count was confined to five plants selected at random, 5 leaves were inspected; two from the top, one from the middle and two from the bottom. A plot was immediately sprayed once jassid reached a treatment level and kept at such level until harvest. Yield data included the total number of fruits/plot, weight of fruits in kg/plot and average weight in kg/fruit was taken at periodical harvest.

Farmers' Field Experiments

The experiments involved selection of interested farmer participants from different villages within a recommended domain. A farmer was provided with eggplant seedlings from the on-farm nursery and transplanted them as planned. He was free to choose his design, spacing, plot size and could decide when to spray, apply fertilizers and other agronomic practices without any influence from the researchers. Five plots were marked at each farmer's field within which five plants were tagged at random/plot. Each treatment was replicated four times and the procedure for jassid counts was similar to that followed at the researcher-managed field experiments.

Results and Discussion

Results of cage experiments demonstrated a direct relation between leaf-damage symptoms and the number of flowers used as yield component of eggplant and jassid density interaction. With an increase in jassid density from 1 to 10 jassid/leaf, there was a corresponding decrease in yield to the extent of 81.6% at the 60–65 DAS. However, eggplant transplanted at 30–45 DAS proved more sensitive (77.6%) compared to eggplant transplanted at 60–65 DAS (62.0%). The effect was only 20.3% at the flowering stage (90–95 DAS) at the same density of 10 jassid/leaf. This difference in yield response may be attributed to the variance of the crop age response. Eggplant at flowering stage were observed to be more tolerant, moderate at vegetative stage and more sensitive at seedling stage. The action threshold (AT) based on the cage experiment can be calculated as 0.5 jassid/leaf or 50 jassid/100 leaves for young plants.

Results of field experiments similarly demonstrated apparent reduction in yield with an increase of jassid levels. For two autumn seasons (1994/1995 and 1995/1996), yield reduction was 49.2%. The results also confirmed differences in yield according to different seasons, reflecting also different jassid population for each season. Mean yield per feddan was 3,885 kg/feddan (59.2 kg/plot) in summer, 682.5 kg (10.4 kg/plot) and 5,644.4 kg (86 kg/plot) for winter and autumn respectively. An increase in the mean number of jassid per leaf demonstrated an automatic decrease in yield. The mean numbers of jassid for the three seasons were as follows:

Autumn (July–Oct.)—162.4 jassid/100 leaves
Winter (Nov.–Feb.)—48.5 jassid/100 leaves
Summer (Ma.–June)—36.1 jassid/100 leaves

This seasonal population fluctuation of jassid may be influenced by rains, strong winds and changes in temperature, and suggests a need to determine AT values for each season separately (Table 1, Fig.1).

The initial evaluation of the quantitative relationships between the jassid population levels and yield reduction in summer, fall and winter seasons indicated that the level of 150 jassid/100 leaves should be used as the AT for jassid control on eggplant to prevent significant economic losses. The proposed AT takes under consideration the relatively low prices of eggplant in comparison to the cost of pesticides used for jassid control.

Empirical field observations obtained through farmers' participation concurred with results from cage and field experiments. Reduction in yield of eggplant due to jassid damage varied from one farmer to another. This was probably because farmers took decisions based on their own perception of damages and yield level affected by various agronomic practices. The general AT used by farmers fell between 50 and 150 jassid/100 leaves.

Conclusions

The relationship between pest density and damage of eggplant demonstrated that with an increase in jassid numbers, whether in the field, cages or farmers' fields, there was a corresponding decrease in eggplant yield. The proposed AT should consider eggplant growth stage and be low on seedlings and higher after transplanting into the field. The critical crop growth stage is the seedling stage when the AT value should be equal to 50 jassid/100 leaves. The AT on field established plants is estimated at 150 jassid/100 leaves, depending on the season. Yield of eggplant crop varies from season to season and therefore that variation requires modification of the AT as a season specific value.

In an estimation of the AT, it is best to avoid adjusting the AT value "on the safe side", not to be biased towards chemical control. The degree of adjustment is based on the farmers' perception of eggplant losses due to jassid infestation. The AT established solely on the cage experiments would be much lower and equal to 50 jassid/100 leaves.

Cage experiments documented clear correlation in the extent of the leaf colour changes and jassid density levels. A guide of colour pictures can be developed and used in establishing an AT under field conditions. This may perhaps be the simplest method for farmers to adopt as a replacement of the conventional counting method used by researchers. Participatory research in developing ATs with farmers has proved its value as a simple method representing the actual field situation.

Table 1. Effect of various population levels of cotton jassid on eggplant yield in different growing seasons

Season	Jassid level/100 leaves	No. fruits	Wt.of fruits (kg/plot)	% reduction fruit wt.
Summer	0	201.25	73.8	0.0
	100	184.75	67.8	8.1
	300	154.00	56.5	23.4
	500	137.75	50.5	31.6
	700	128.75	47.2	36.0
Mean		161.30	59.2	19.8
Autumn	0	32.75	12.01	0.0
	100	26.68	9.8	18.4
	300	20.72	7.8	35.1
	500	20.35	7.5	37.6
	700	16.67	6.1	49.2
Mean		23.43	8.6	28.1
Winter	0	34.60	12.69	0.0
	100	33.70	12.63	0.4
	300	28.10	10.30	18.8
	500	27.00	9.90	22.0
	700	20.70	6.63	47.8
Mean		28.80	10.4	17.6

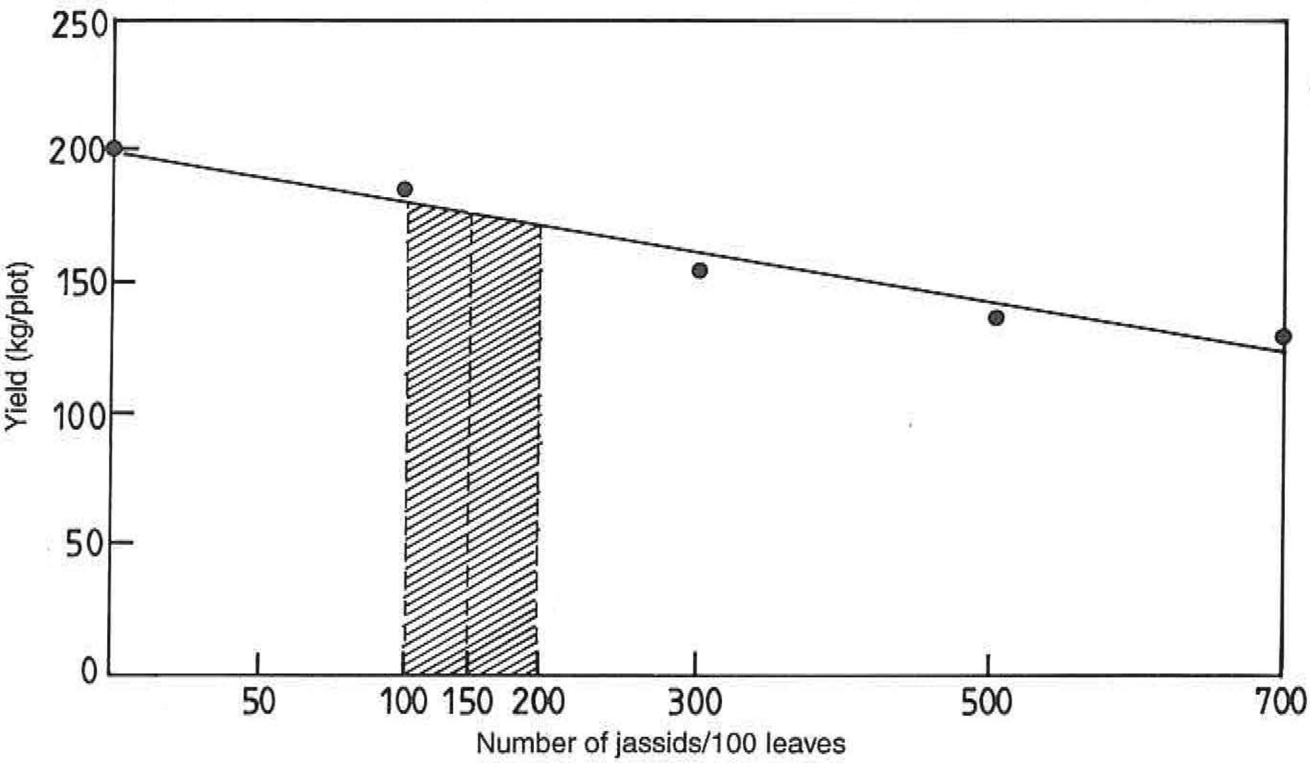

Fig. 1. Effect of cotton jassid population on eggplant yield under field conditions (average value of nine experiments carried out in the summer, autumn and winter growing seasons, 1993–1995). An Action Threshold of 150 jassid/100 leaves is recommended (shaded area)

Breeding Vegetable Resistance to Pests and Diseases

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The total area under vegetable production in the Sudan amounts to 250,000 feddans (105,042 ha), distributed all over the country. However, the northern and central states are leading in production for both domestic and export purposes. More than 40 kinds of vegetables are produced during the winter, summer and fall seasons, yet only a dozen or so are of major importance. Tomato, onion, okra, eggplant, watermelon, snake cucumber, muskmelon, green pepper, potato and leafy vegetables like jew's mellow, purslane and rocket are the most widely grown and consumed.

Vegetable production in the Sudan is challenged by serious attacks from a group of pests and diseases. The toll they take on productivity and quality is immense. Total crop failure of watermelon and tomato is common due to attack by Watermelon Chlorotic Stunt Virus (WMCSV) and Tomato Yellow Leaf Curl Virus (TYLCV). This is particularly true in rural areas where crop management is far less than optimum. The use of clean certified seeds or application of phytosanitary measures to minimize damage inflicted by pests and diseases is seldom practised in rural areas. Vegetables could be raised and left to fight their way against the attack of prevailing pests. On the other hand, excessive use of insecticides and fungicides is common in the major production areas in Khartoum and Gezira states. In spite of the high cost, Danitol, Folimat, Sumicidin, Sevin, Malathion, Tilt and Bayleton are applied generously to combat whitefly, aphid, leaf miner, beetle, bollworm and powdery mildew.

The erroneous use of pesticides—doses, frequency or method of application—usually leads to poor results and wasted resources. Due to the lack of resistant cultivars, farmers' efforts to combat a disease like TYLCV are directed towards the elimination of the whitefly. In many cases, spraying continues on a crop already infected with the virus, reducing further its ability to set fruits (Omara and Dafalla, 1995). The large amount of pesticide residues left on melon, snake cucumber, green pepper and tomato and the hazards to the environment from the misuse of chemicals are growing concerns of scientists and consumers alike.

Resistance Breeding

Using cultivars resistant to pests and diseases is a major component in most, if not all, IPM programmes directed towards effective, safe and reliable control measures. This is particularly true in developing countries where erroneous use, unavailability or inability of farmers to secure chemicals are equally harmful to both producers and consumers. Research efforts in the University of Gezira vegetable breeding programmes are directed towards the improvement of the productivity and quality of the major vegetables by selection of resistance donors and transfer of resistance into high yielding cultivars. Few scientists are available to do research, and meagre financial resources are allowed for the execution of only top priority programmes dealing with major pests and diseases on major vegetables (Table 1).

Watermelon Chlorotic Stunt Virus (WMCSV)

In a warm country like the Sudan, the highly adapted watermelon crop is a very popular cucurbit grown and consumed all year round. Around 50,000 acres are grown annually producing a total tonnage of 200,000. Two main varieties (Congo and Charleston Grey) dominate all the major regions of production. Although minor damage is usually observed from fungal

Table 1. Resistance breeding programme at the University of Gezira

Crop	Pest/disease
Tomato	Tomato Yellow Leaf Curl Virus (TYLCV), powdery mildew, bunchy top
Green pepper	Powdery mildew
Watermelon	Watermelon Chlorotic Stunt Virus (WMCSV), Zucchini Yellow Mosaic Virus (ZYMV), aphids
Muskmelon	Aphids
Snake cucumber	Fusarium wilt, powdery mildew, Zucchini Yellow Mosaic Virus (ZYMV), Cucurbit Aphid Borne Yellow Virus (CABYV)
Okra	Powdery mildew
Eggplant	Powdery mildew

and bacterial diseases, viruses seem the most troublesome agents affecting productivity and quality. A survey of viruses infecting cucurbits in central, eastern and Kordofan states was made between 1992 and 1994. Visual evaluation of symptoms was followed by the DAS-Elisa analysis (Lecoq et al., 1994). WMCSV was detected in 47.2% and 46.9% of the samples collected from eastern and central Sudan, respectively.

However, the disease was acknowledged as the most devastating on watermelons grown in these regions for years before the survey. The causal agent of WMCSV is a geminvirus transmitted by the whitefly, *Bemisia tabaci*. Infected vines turn yellow and chlorotic as if devoid of chlorophyll. The plant looks very much stunted and deficient of marketable fruits, especially if attacked early in the season. Being incurable once established in the plant, control measures are directed towards appropriate cultural management and elimination of vectors through the use of insecticides.

In addition to the inadequate supply of insecticides in the rural areas, control of the whitefly in vine crops is difficult or ineffective. Crop management could prove more reliable if directed towards elimination of the plants hosting the vector or the virus. In major production areas like the Gash Delta where close to 10,000 acres of watermelons are cropped annually, it is practically impossible for farmers to unite their efforts and eradicate host plants ahead of sowing time.

So far the disease has been reported in a few countries in Africa and the Middle East, including Sudan and Yemen (Walkey, 1992); no reports are published about its presence in Europe or USA. Seemingly this is the reason behind the lack of programmes to breed for resistance to this disease.

Realizing the urgent need to supply farmers with adapted high yielding cultivars resistant to WMCSV, a search for resistant parents started in the late 1980s where a large collection of commercial varieties introduced from Europe and USA was evaluated. Failing to detect appreciable levels of resistance, germplasm collection missions were organized to western Sudan where tremendous variability in watermelon genotypes exists in a vast region considered one of the centres of origin of the species. In addition to 15 accessions introduced from American gene banks, 178 entries collected from western Sudan were screened under natural conditions of infection in the University of Gezira Research Farm.

Selection based on visual evaluation followed by DAS-Elisa analysis indicated high resistance in two accessions of *Citrulus colocynthis* (P1 494529 and P1 386025) and four accessions of *C. lanatus* land races (UG 0039, 0060, 0061 and 0063). Crosses made with the standard cvrs Congo and Charleston Grey indicated partial dominance of resistance in P1 494529. During the winter of 1995/1996, BC3 populations were grown, evaluated and selfed. In the 1996 summer, selected F2 plants of BC3 were selfed and advanced to BC4. Two to three backcrosses are yet to be made to furnish new Congo and Charleston Grey cultivars resistant to the disease.

Powdery Mildew in Snake Cucumber and Muskmelon

Powdery mildew incited by *Sphaerotheca fuliginea* and *Erysiphe cicoracearum* is a limiting factor in the production of muskmelon throughout the world (Mecreight et al., 1986). In the Sudan the disease is most devastating on melons and snake cucumbers grown as winter crops. The disease is less destructive during the fall season and is of no significance during summer where day temperatures of 42–45°C do not favour infection or disease development.

Production of snake cucumber is totally dependent on land varieties selected by farmers through hundreds of years. Land varieties of muskmelon also formerly dominated in major production regions. However, the consumer preference is quickly shifting to the sweet and aromatic cv. Ananas. Introduced to this country in the mid-1970s, the adapted and productive Ananas enhanced more consumption of melons and added to the popularity and economic importance of the crop.

Snake cucumber and Ananas melons are highly susceptible to powdery mildew. The disease is endemic and very destructive during the winter season. Losses could amount to crop failure (Omer, 1981). Being an airborne endemic disease, cultural practices are of little value during winter as means of control. Few spores are needed to start the disease cycle leading to a rapid build-up of secondary cycles and a fast spread of the disease. In the absence of the resistant cultivars and protective spraying with fungicides, the elimination of the primary source of infection is necessary since it is difficult to eradicate the disease once established in the crop.

A search conducted in the late 1980s to locate resistant genotypes among snake cucumber land varieties has isolated few plants with low level of resistance. However, the melon cvrs PMR5 and PMR6 bred in USA for resistance to race 1 and 2 of *Sphaerotheca fuliginea*, maintained high resistance when tested in the Sudan. Being botanical varieties of the same species, melon (*Cucumis melo* var. *reticulatus*) and snake cucumber (*C. melo* var. *flexuosus*) cross readily with each other allowing exchange of genetic material in both directions. Cv. PMR5 was used as a donor parent to transfer resistance to both crops (Omara, 1992).

Two partially dominant genes are known to control resistance in PMR5. Transfer of resistance through the backcross method was a question of time. Six backcrosses alternated with selfing and screening of large F2 populations were enough to furnish the farmers with powdery mildew resistant melon and snake cucumber cultivars.

Cucurbit Aphid Born Yellow Virus (CABYV) in Melons and Snake Cucumber

The surveys conducted by Lecoq et al. (1994) on viruses infecting cultivated cucurbits indicated high incidence of CABYV in melons and snake cucumber. The disease is more spread in central Sudan, where 87.8% of the samples were infected compared to 41.6% and 47% for samples from eastern and western Sudan, respectively. The disease caused by a luteovirus is transmitted in the persistent manner by aphids, *Myzus persicae* and *Aphis gossypii* but not mechanically (Lecoq et al., 1992). Under field conditions, chlorotic patches appear in older leaves which coalesce and cover the whole leaf area. Symptoms then develop on younger leaves, and the whole vine looks yellow as if deficient of chlorophyl.

Most farmers growing melon and snake cucumber are not fully aware of the seriousness of the disease and its negative impact on productivity in the Sudan. None of the farmers surveyed in Gezira State resort to cultural or chemical control measures. Although watermelon is attacked as well, melon and snake cucumber suffer more. Early infections could lead to yield losses of more than 50% (Omara, 1994). However, CABYV does not have striking symptoms like those incited by WMCSV or ZYMV. To the inexperienced eye, it may be ignored or misdiagnosed as a nutritional deficiency or plant senescence.

During the winter of 1993/1994, the collection of melon commercial cultivars stocked at the University of Gezira gene bank, along with 54 accessions of locally grown melons, snake cucumber and tibish (*C. melo* var. *aggrestris*) were screened under natural conditions of infection. Few lines were less susceptible than the control, but none was resistant. The following winter another collection of *C. melo* land races in addition to breeding material provided by M. Pitrat (INRA - France) were field tested. The last material included a number of exotic lines resistant to CABYV when tested in France.

Table 2 summarizes the performance of breeding lines received from France, susceptible checks and recurrent parents utilized in this programme. High resistance to CABYV was confirmed in P1 255478, P1 414723, P1 282448, Inde 5 and line 90625. However, none of the lines tested was uniformly resistant. Purification of these lines was then carried out by selfing plants with the highest resistance. Progenies of selected plants were tested during the winter of 1995/1996. Leaf cuts of plants free of visual symptoms were tested in the laboratory for freedom of virus particles using the tissue plot technique. Crosses were made between resistant plants and selected recurrent parents but only those originating from donor plants free of virus particles were maintained.

Table 2. Resistance to CABYV in French breeding lines, recurrent parents and susceptible checks

Accession	Reaction to CABYV
Snake cucumber	
U.G. Silka	Highly susceptible
Inde 5	Segregating for intermediate and high resistance
Melon	
Ogen	Susceptible
Ananas	Susceptible
Ouzbaque	Highly susceptible
P1 255478	Segregating for intermediate and high resistance
P1 313970	Segregating for susceptible and intermediate resistance
P1 164723	Susceptible
P1 124440	Segregating for susceptible and intermediate resistance
P1 282448	Segregating for intermediate and high resistance
P1 414723	Segregating for intermediate and high resistance

Three recurrent parents were utilized in this programme: U.G. Silka, a snake cucumber breeding line bred for productivity and quality; Ananas, a high quality melon cultivar quickly replacing the land varieties grown in the country and Ogen, the female parent of the F1 Galia melon produced in the Sudan for air freight shipment to western Europe. Resistant plants from Inde 5 were used when transferring resistance to snake cucumber due to the close similarity between the two parents. P1 255478 and P1 414723 were utilized to transfer resistance to melon cultivars.

Resistance to Aphids in Muskmelon and Snake Cucumber

The melon aphid (*Aphis gossypii*) is capable of virus transmission and direct injury to cultivated cucurbit. Due to its high rate of reproduction, a few aphids are enough to build large colonies on leaves of susceptible hosts and cause serious damage. The indirect damage of viruses like CABYV, WMMV2, CMV and ZYMV could be of more serious consequences. Farmers have traditionally depended on insecticides to control aphids. However, in most rural areas of production of watermelon, snake cucumber, squash and muskmelon, the crop is left unsprayed. This being the case, aphids may be present in large numbers on the underside of leaves causing puckering and deformation of the young shoots and leaves and encouraging the development of sooty mould on leaf surface as a result of the production of honeydew, thereby interfering with photosynthesis.

Resistance to aphids has been described in muskmelon lines from India and the Far East. Kishaba et al. (1971) located resistance in a breeding line from India (P1 371795) and were able to transfer the dominant gene confering resistance in the P1 to the commercial cultivars such as AR Hale's Best Jumbo, AR5 and AR Top Mark. Both antibiosis and non-preference were involved in the mechanism of resistance. M. Pitrat (pers. comm.) in France bred this single dominant gene into the charentais type melons Virgos, Diego and Zumo. These three cultivars were tested in the Sudan and were found equally resistant. Virgos was selected as a donor parent in a back cross programme due to its agronomic excellence. Recurrent parents involved were the melon cultivars Ananas and Ogen and the snake cucumber breeding line U.G. Silka.

As expected, F1 and half the backcross populations were resistant. Successive backcrosses to the recurrent parents were possible, and resistant melon and snake cucumber cultivars will be tested next winter under field conditions.

In watermelon the search for a source of resistance was not so successful. Hundreds of commercial cultivars, land races and wild relatives collected from western Sudan and elsewhere were screened. The breeding material tested was highly heterogeneous, and the test done under natural conditions of infestation did not help clear separation of genotypes. Screening is carried out now in growth chambers especially during fall and summer seasons. Detected resistance was mostly of intermediate levels, i.e., less colonization, stunting or curling. At present, efforts are directed to cross selected parents and F1 and F2 populations for segregants of higher resistance to be utilized as donors.

Powdery Mildew in Okra

Okra is a very popular vegetable adapted to the warm climates of Sudan. Powdery mildews incited by *Leveillula taurica* is a limiting factor in the production of okra during the winter and fall seasons. The round whitish colonies on the lower side of leaves increase in diameter, coalesce and cover both leaf sides leading to drastic cuts in yields and fruit quality . The disease could be controlled by fungicides like Tilt, Bayleton or Benlate, especially when applied as protective sprays early in the season.

The entire collection of the USDA of *Abelmoschus moschatus* and related species (298 accessions) along with 16 locally grown land races were tested for resistance under natural conditions of infection during the winter season. Among the selections, three plant introductions, namely P1 268088 from Nigeria, P1 291123 from Ghana and P1 379584 from Japan, were highly resistant since the foliage remained free of colonies til the end of the season.

Two recurrent parents were utilized in this programme. Clemson Spineless is a high quality cultivar grown for export to Europe and the Middle East while Khartoum Abushara is the most adapted and popular land variety consumed over most parts of the country. P1 268088 was used as the donor parent. Crosses between this line and each of the recurrent parents gave rise to F1s highly resistant to mildew indicating full dominance of resistance. At present, the resistance is backcrossed into each of the selected recurrent parents.

TYLCV in Tomato

Tomato ranks among the most important vegetables in the Sudan. The crop is attacked by many pests and diseases, including whitefly, aphid, leaf miner, bollworm, powdery mildew and bacterial leaf spot. However,endemic TYLCV could be singled as the main limiting factor greatly reducing productivity and quality, leading to annual losses that run into billions of Sudanese pounds.

Almost 100% infection with the disease is common even during the mild winters where conditions are favouring less disease incidence and spread (Omara and Yassin, 1992) leading to losses of 40% or more (Yassin et al., 1982). However, the damaging effects of the disease are more profound on the summer crop. This happens in spite of the lesser prevalence of the vector. Yassin and Abu Salih (1972) found a higher rate of successful transmission during summer (59%) compared to winter (36%). From 5 to 8 viruliferous whitefly feeding for only a few minutes can transmit the virus. The growth and development of the tomato plant is greatly affected by temperature of 40–45°C and the very dry atmospheres which prevails during the April–June period (Omara and Yassin, 1992). Genotypes of a known level of tolerance to the disease during winter usually score lower ratings when tested during summer due to the heat stress.

TYLCV being incurable once established in the plant, the choice left for farmers to protect their crop is elimination of the whitefly through the use of chemicals. Pesticides like Danitol, Folimat, Diazinon and Malathion are extensively used to eradicate the vector. Believed by farmers to be indispensable for combating disease and getting good yields, chemical control, nonetheless, never gave satisfactory results. It is difficult, if not impossible, for pesticides to eliminate all whitefly present in the field and those migrating from other fields or weeds around the farm. Only a few viruliferous whitefly are needed to transmit TYLCV.

TYLCV Breeding Programme

Most of the TYLCV breeding programmes in the developed countries are carried out by private seed companies who are releasing resistant material in the form of F1 hybrids like Fiona, Top 21 and Tiking. The prices of these hybrids run into thousands of US dollars/kg of seeds which is unaffordable for farmers in the Sudan. Unless resistance is bred into locally produced open pollinated varieties or hybrids, sold at affordable prices, farmers can never acquire cultivars resistant to TYLCV. Breeding for resistance to TYLCV was thus a top priority programme strongly pursued since the mid-1980s in the Sudan. Searching for resistance was first based on screening commercial cultivars, but it was realized by many researchers around the world that emphasis should shift to tap the large pool of genetic diversity found in the related wild species that intercross with tomato. In the University of Gezira programme, utilizing different sources of resistance and different recurrent parents which kept changing through the years was behind the reason of handling three separate but interrelated programmes. A brief summary of these programmes is given below.

Lycopersicon pimpinellifolium *as a Source of Resistance*

The first programme made use of a cross made by Dr A. A. Genief of the Agricultural Research Corporation (Geneif, 1984) between *L. pimpinellifolium* accession L.A. 1478 and the commercial cultivar, Money Maker. F3 progenies of this cross received from the ARC gene bank were field tested and backcrossed to a number of heat-tolerant lines including Peto 86, Strain B, Strain C, U.G. Hillo, U.G. 94, U.G. 46, and U.G. Summerset.

Combining heat tolerance and TYLCV resistance in the same genotype is very crucial under the warm climates of Sudan. Resistances of most genotypes tested during winter tend to break down when grown during summer. Heat tolerance was found necessary to increase the action of leaf curl resistant genes. Large F2 populations were evaluated after each backcross, intercrossed, or backcrossed. Various recurrent parents were used since the heat tolerance breeding programme kept supplying better adapted lines.

The first set of TYLCV resistant stable lines was ready for field testing during the winter of 1994/1995 and the summer of 1995. Seemingly, part of the resistance derived from the donor parent L.A.1478 was lost in the new genetic background since only intermediate levels of resistance were recovered. Nevertheless, it was a significant step forward that allowed higher productivity during the hot dry summers. Three of these selections—U.G. Abdalla, U.G. Summerset and U.G. Fireset— combine tolerance to TYLCV and to hot-dry climates and are now considered the leading cultivars in the Sudan. The pedigree of each of these cultivars is given in Tables 3–5 (Omara, 1995).

Cooperative Breeding Programme with INRA/EU

The second programme was a joint effort with the French scientist, Dr H. Laterrot (INRA-France), who is coordinating a global programme on breeding for resistance to TYLCV financed by the European Union, and the government of France (Laterrot, 1992). Two populations bred in France in cooperation with a number of scientists from Africa, the Middle East and Asia were provided by Dr Laterrot for

Table 3. Pedigree and breeding programme of the U.G. Fireset cultivar

Parents involved in the breeding of U.G. Fireset were as follows:

- L.A. 1478 (*L.pimp.*)
- Money Maker — commercial variety
- Strain C — commercial variety
- L.A. 2662 (an F5 selection from the source population received from Dr Charles Rick)
- CL 5915-153D-4-3-30 (an F4 selection from this line brought by Dr A. Yassin from the AVRDC and purified in ARC field)

Breeding Programme

(1) L.A. 1478 (*L.pimp.*) x Money Maker. F1 selfed. F2 single plant selection made and selfed. (This part was carried out by Professor Geneif during the early 1980s).

(2) First backcross

F3 (432-4L) x Strain C
F1 selfed. S.P.S. made in the F2 population (1991).

(3) Second backcross

Selected F2 plant backcrossed to L.A. 2662 (an F5 selection for heat tolerance) plants advanced to F2 through selfing and S.P.S. (1992).

(4) Third backcross

Selected F2 plant backcrossed to an F4 selection for heat tolerance from the source population CL5915-153D 4-3-30 (1993).

(5) S.P.S. from the F2 population were advanced to F5. The best F5 family is now under released as U.G. Fireset (1995).

Table 4. Pedigree and breeding programme of the U.G. Summerset cultivar

Parents involved in the breeding of U.G. Summerset:

- CL 5915-153-D4-3-3-0: Selected breeding line among a number of lines brought from the AVROC by Dr A. Yassin. The segregating line was advanced through S.P.S. to F4.
- U.G. 46: This is an FG S.P.S. from a source population of an American variety called Pellite which was found segregating for heat tolerance under Sudan conditions.

Breeding Programme

U.G. Summerset is a result of a pedigree selection programme involving 2 heat tolerant selections. The F4 S.P.S. from the CL 5915-153 population has acquired great ability for excellent fruit set during summer. However, it has chlorotic foliage and a rather small fruit size. The other parent U.G. 46 had a lower ability for heat tolerance but a vigorous canopy and a large fruit size which seemed to complement the defects on the other parent.

Crosses between the 2 parents were advanced to F5 with rigorous selection for fruit set, canopy, fruit size, coverage, firmness and tolerance to TYLCV. Pedigree: U.G. 46 x F4 CL 5915-153-D4-4-3-0; F5: Summerset.

Table 5. Pedigree and breeding programme of the U.G. Abdalla cultivar

Parent involved:

- CL 5915-153-D4-3-3-0
- Strain B

Breeding Programme

Pedigree selection was practised to combine the heat tolerance of the first line with the canopy, fruit size and firmness of Strain B.

Pedigree

CL 5915-153-D4-3-3-0 x Strain B

F5

U.G. Abdalla

evaluation and selection under Sudanese conditions. Chiltylic 94 is an F2 population of BC4 of a cross involving *L. chilence* as a source of resistance and a number of selected cultivars and F1 hybrids like Fiona and Tiking. Chepertylic 94 is also an F2 population of a cross involving *L. cheesmanii* and *L. peruvianum* as resistant parents and selected tomato cultivars and F1s. Six breeding lines of each population were evaluated during the winter of 1994/1995. Single plant selections based on resistance to TYLCV, productivity and fruit quality were advanced to F5 during the following fall, summer and winter seasons. The most promising line, named U.G. Ebied, is now under release.

Utilization of Commercial F1 Resistant to TYLCV

The third programme utilized commercial F1s resistant to TYLCV, released by seed companies. These include Fiona, Tiking, Top 21, H2794, H2797, TY20, TY50 and 93T38. The pedigree method of plant breeding was employed in this programme whereby large F2 populations were screened, single plant selections advanced to F3, and this was repeated until stable lines were selected by F6 and F7. During the course of inbreeding and selection, inbred lines derived from H2794 were superior in resistance, productivity and fruit quality (firm, red, large size and good shipping). The best line selected from H2794 was named U.G. Omdurman.

The programme involving Fiona and H2797 was terminated midway due to the lack of fruit firmness in Fiona and the small fruit size of H2797. TY20 and TY50 were found to acquire low levels of resistance which tend to break down when tested during the summer growing season. F1s Top 21 and H2794 were also utilized in crosses with heat tolerant lines. Some advanced selections at the F5 level were very promising in terms of combining heat tolerance and resistance.

This is a contributory paper.

IPM Options for Tomato and Onion Diseases Validated by Farmer Field Schools

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In the Sudan, vegetable production of tomato, onion, cucurbits, eggplant, potato, sweet and hot pepper continues to gain importance for both local consumption and export. Tomato (*Lycopersicon esculentum* Mill.) and onion (*Allium cepa*) are ranked as the most important vegetables, currently occupying 75% of the total area under vegetables. However, the area for each crop varies seasonally according to the market prices and pests and disease constraints. Insects such as the onion thrips (*Thrips tabaci*), whitefly (*Bemisia tabaci*) and American bollworm (*Helicoverpa armigera*) and the diseases TYLCV and powdery mildew in tomato are major retarding factors to production.

In the Sudan, losses due to pests and diseases are paramount. TYLCV and the powdery mildew are the major production constraints and may result in more than 70% quantitative yield reduction (Yassin, 1984a,b; Ahmed, 1995b). Because they fear losses, farmers justifiably resort to extensive use of pesticides, their main weapon to reduce losses and increase the yield in the absence of other control measures. This excessive use never achieved the goal of maintaining the pests below the economic level. Pesticides, in most cases if not all, are inefficiently utilized. Farmers usually use low doses of highly toxic compounds. Besides, they spray during the hot period of the day and windward so that much of the pesticides are lost by drift. This gap in the know-how of farmers resulted in serious environmental pollution and health hazards. The obvious demanding area of research is to find alternative methods of control, complementary and not antagonistic to chemical control which is presently misunderstood in the continuous fight against pests. However, integrated pest management is the best approach to replace the existing methods of disease control. This will be utilized by combining multidisciplinary efforts of pathology, entomology, agronomy and weed science. Practical methods of biological control for most of the important diseases in vegetables have not yet materialized. This emphasis will be based on proper production practices, cultural and chemical methods to be exploited in an integrated fashion. The IPM project philosophy is to implement these integrated strategies, in a participatory approach, with farmers and extensionists in an efficient intercommunication system. This flexible system was modified to include validation of IPM strategies in Pilot Farmer Field Schools (PFFSs), educational and training sessions for farmers and extensionists and follow-up and on-site technical advice for all farmers in FFSs. The overall objectives of this programme are to:

- Study the impact of cultural practices on pests and diseases of vegetables;
- Augment cultural practices with less pesticide use in an IPM approach;
- Praise farmers' knowledge of vegetable production with low inputs and higher returns;
- Acquaint farmers with IPM options to change their attitudes about pesticides for safe vegetable production, health and environment;
- Improve farmers' skills in implementing IPM options.

The objectives were achieved through three phases:

Phase 1: Back-up on-station and on-farm research for three seasons;
Phase 2: On-farm verification of promising research findings for two seasons;
Phase 3: Validation of verified reliable high quality IPM options in the PFFS for one season.

Back-up and On-farm Research

Research was directed to address the major production constraints of important vegetables e.g., tomato, onion, eggplant and okra, with special emphasis on tomato and onion pests and diseases.

Intercropping, the simultaneous cultivation of more than one crop species in close association, is practised extensively to control diseases in many parts of the world especially in developing countries (Francis, 1986; Thurston, 1991). Coriander (*Coriandrum sativum*), fenugreek (*Trigonella foenumgraecum*), Lubia (*Dolichos lablab*), cucumber (*Cucumis sativus*), squash (*Cucurbita pepo*) and cotton (*Gossypium hirsutum*) were intercropped with tomato. It was evident that coriander and fenugreek were superior over all the other crops in reducing TYLCV incidence and severity. Their effect was at variance and mainly governed by the sowing date of both crops and their repelling effect.

The results indicated that coriander and fenugreek should be cultivated two weeks before tomato to obtain the maximum reduction in TYLCV incidence. However, coriander and fenugreek are both short maturing crops, and their effect was limited by their maturity. This drawback was checked by sowing them 2 weeks before tomato and again 4 weeks later to ensure a continuous vegetative growth throughout the tomato season.

It was concluded that coriander, when used as a companion crop with tomato, can replace the use of insecticides in controlling TYLCV. The yield obtained under this system was higher than the monocrop that received intensive insecticide spraying (Ahmed, 1994). This is in agreement with the work done by Yassin and Abu Salih (1977) and Yassin et al. (1982) who reported that *Dolichos lablab* and *Cucumis sativus* attracted whitefly, and reduced TYLCV incidence and increased yields of tomato in central Sudan.

The interaction between the intercropping system and the farmers' conventional practices in on-farm trials revealed that the tomato plants intercropped with coriander were invariably more robust in growth, with fewer whitefly and lower TYLCV incidence than those intercropped with fenugreek (Abdelrahman et al., 1995b). It is therefore recommended that coriander be introduced as a companion crop in winter tomatoes in Gezira, to be grown on the sides of small water canals (*gadwals*) and separating ridges (*tagnets*) 2 weeks before sowing tomatoes and 4 weeks later.

The results consistently indicated that after flowering, the TYLCV infectious effect is very minor and does not contribute to yield losses (Yassin, 1975; Ahmed, 1994). Therefore, stopping the spraying of insecticides at 40% flowering is ideal to get the maximum control of the whitefly and consequently TYLCV and to have a crop free from insecticidal residues.

On-farm research results revealed that vegetative growth components and yield were similar in post- fruiting sprayed and unsprayed tomato plants. Whitefly infestation and insect counts were similar in both treatments. Though TYLCV symptoms were reduced by continuous spraying after 50% of fruiting on control plants, the level of infection and severity of the disease did not increase fruit yield and growth components. This confirmed that after fruiting, TYLCV was very minor and did not contribute to fruit yield losses. Therefore, stoppage of the chemical control of whitefly after 50% fruit set is recommended in the whitefly control provenance, and hence, there is a crop yield free from insecticidal residues.

Back-up research indicated a clear interaction between the high rates of nitrogen and the watering interval. Neither the N alone nor the watering interval caused blossom end rot (BER) of tomato. The combination of high rate (129 kg/ha) and long watering interval (2 weeks) was highly conducive to BER. It could be concluded that irrigation stress, especially at the fruiting stage in plants receiving the recommended rate of urea (86 kg/ha) or the excessive rate of 129 kg/ha is highly conducive to BER.

A tomato crop that received 86 kg N/ha and was irrigated every 5–7 days did not show BER symptoms. Therefore, it is recommended to use 86 kg/ha and frequent watering of tomato every 5–7 days, especially after fruiting to avoid BER of tomato.

It was evident that early epidemics of Powdery Mildew (PM) in plants raised from untreated seeds affected plant growth directly because of lesions, associated chlorosis and drying up of the lower leaves which get infected earlier. There was a distinct relationship between early disease epidemics and yield losses. However, since both healthy crops and diseased ones are subjected to prophylactic fungicidal sprays by farmers, it was suggested that they use seed dressing with Bayleton 15% (triadimenol) at the rate of 6 g/kg seeds to control early infection by PM and improve tomato yield. This treatment could be supplemented with one spray when disease level is severe. More information is needed in this area before any more practical recommendations can be given to farmers. It was presented that Fiona F1 hybrid and UC (Petoseed) are resistant to TYLCV but they were equally susceptible to PM compared to all available commercial varieties. Fiona F1 hybrid was also resistant to bunchy top (tomato aspermy virus) and tomato mosaic virus. When UC 97-3 was subjected to ideal cultural practices for tomato production in farmers' fields, it exhibited very high resistance to TYLCV. The incidence of the disease was 1.65 %. It was also noticed that this variety was resistant to PM under field conditions.

It was indicated that sowing onion between July and September and transplanting between August and October combined with irrigation every 7 days and intercropping with coriander were the best cultural practices to avoid thrips infestation and spraying of insecticides. In on-farm research, it was found that onions grew, developed, matured and produced a very satisfying crop yield without the use of chemical sprays for thrips control. This showed that proper production practices, coupled with the cultivation of thrips-repelling crops, such as coriander, may possibly be the replacement for chemical thrips control and an improvement to onion production methods. Foliar fertilizer treated onions were similar to untreated ones in thrips infestation, but they were decidedly superior in vegetative growth and crop bulb yield.

Validation of Tomato and Onion IPM Options

The full package of IPM options validated in the FFS achieved success in controlling the most important pest and disease constraints to tomato and onion production at an acceptable level with low input cost and reduced pesticide use (Table 1).

Tomato

The land of all farmers' fields in and outside the school was prepared as recommended for tomato production in the Sudan except for using the ditcher for flat ridge preparation. The advantage of the ditcher over the ridger is that the flats are high and levelled. They facilitate proper, easy and quick irrigation and have a direct positive influence on germination rate due to damping off and good weed management.

Tomato varieties Sinnar 1 and Sinnar 2 were released in 1994 as resistant varieties to TYLCV. However, seeds for commercial production were not always available for both varieties. All the commercial varieties which interact with the package components, e.g., Peto 86 from Popviriend, Strain B from Peto seed and UC 97-3 from Pioneer, are susceptible to TYLCV. However, when UC 97-3 received proper management, it escaped infection with TYLCV and outyielded the other two varieties similarly treated (Table 2). This variety was observed to have a high degree of resistance to PM. The prospect of this variety having these combined resistant abilities is a big achievement and encouragement.

The concept of sowing winter tomato in nurseries to be transplanted was rejected by farmers. They directly seeded their tomatoes. However, only one farmer was convinced to transplant a half acre to support research findings. Three other farmers had directly seeded half of their land and transplanted the other half with the extra seedlings obtained after thinning. The direct seeded tomato was more successful than the transplanted one early in the season. It had less TYLCV incidence (Table 3), and the infection was delayed. The early infection of the transplanted tomato was reflected in high disease severity and subsequent lower yields (Table 4). The direct seeded tomato was more productive, had a longer harvesting period and bore better quality fruit. The repulsive attitude to the transplanted tomato is created by the pulling of seedlings from heavy clay soils that always result in root damage and a simultaneous check in growth which affects the plant vigour later on. Until these problems are solved and a better method of raising seedlings is availed, the acceptance of farmers to the transplanting method is doubtful.

The spacing recommended by researchers was again not accepted by farmers; 20–25 cm is the spacing of high repute among farmers with the belief that high population is the proper way to obtain high yield. The farmers' practice was compared in only one field to the recommended

Table 1. IPM options validated at the FFS, Centre Group, Gezira scheme, 1995/1996 growing season

Package components	Methods
Tomato	
Land preparation	Deep ploughing, disc harrowing, levelling and ridging
Sowing methods	Direct seeding
Fertilizer/ha	86 kg N (recommended dose)
Intercropping	Coriander on banks of all small canals and separating ridges
Use of soft chemicals	Pyrethroids when necessary
Weed control	Removal of all weeds, especially alternative hosts for TYLCV and PM
Irrigation	Every 4–5 days
Chemical use	Stoppage of spraying pesticides at 50% fruit setting
Onion	
Nursery establishment	Use of flat ridges; sowing thinly in groves; light irrigation
Land preparation	Ridging 3–4 times (farmers' practice)
Sowing date	Nursery establishment between August and September; transplanting before December to avoid thrips damage
Intercropping	Sowing coriander around the nursery, on all water canals and separating ridges before transplanting in one field
Transplanting	In 3–4 lines per ridge
Harvesting	Harvest at 50% pseudostem fall over

Table 2. Comparative incidence of TYLCV for direct seeded tomato on different varieties at late fruit set stage, 1995

Sowing date	Variety	Incidence (%)	Severity (%) Grade 2	Severity (%) Grade 3	Yield (t/ha)
22/10	Strain B	16.75	10.5	6.13	22.4
5/8	Strain B	45.40	15.1	30.30	20.1
1/11	UC 97-3	1.65	1.1	0.00	27.9
1/11	UC 97-3	1.35	1.2	0.13	25.1
25/10	Peto 86	20.50	9.9	10.60	28.6

Table 3. Comparative incidence of TYLCV on direct seeded tomato, 1995

Sowing date	Variety	Incidence (%)	Severity (%) Grade 2	Severity (%) Grade 3	Yield (t/ha)
1/9	Strain B	70.20	62.5	7.7	23.8
1/9	Strain B	51.00	38.5	12.5	22.1
1/9	Peto 86	24.50	14.5	9.9	17.1
1/9	Strain B	31.10	19.8	11.2	12.9
27/10	Strain B	8.29	4.0	4.3	23.8

Table 4. Comparative incidence of TYLCV on transplanted tomato, 1995

Sowing date	Variety	Incidence (%)	Severity (%) Grade 2	Severity (%) Grade 3	Yield (t/ha)
6/10	Strain B	83.80	59.50	24.30	19.0
6/10	Strain B	74.25	61.80	12.40	18.6
6/10	Peto 86	74.15	38.20	35.90	17.1
17/10	Strain B	30.50	22.40	0.81	14.4
4/11	Strain B	15.00	7.19	7.80	22.9

spacing. The tomato plants spaced 40–50 cm were more robust and the fruit size and yield were superior to those spaced at 20–30 cm.

Farmers were convinced to leave two plants/hole in the direct seeded tomato and one plant with transplanted tomato compared to farmers' traditional practice of 3–4 plants/hole. The plant size in the densely sown crop was exiguous compared to one plant/hole. Consequently, the yield/plant was higher, and fruit quality and size were superior.

Farmers were persuaded to water their crop lightly every 4–5 days instead of 7 and 10 days during summer and winter respectively. There was no incidence of BER on FFS fields compared to the high incidence in the fields where irregular or prolonged watering interval regimes were practised.

The spectacular crop vigour and the higher yield obtained by the crop that received 86 kg N/ha, compared to higher rates (Table 5), persuaded farmers to use urea at the recommended rate. Moreover, a high quality fruit free from BER symptoms was a merit that achieved a considerable increment in the farmers' returns.

Removal of alternative weed hosts, especially, *Solanum dubium*, a dominant weed in tomato fields and a dangerous reservoir of TYLCV, was carefully checked in the PFFS. *Acalypha indica* and *Datura stramonium* are less dominant but important hosts to the virus. *Abutilon pannosum* and *Sonchus cornutus* are, again, dominant weeds in tomato fields, always severely infected with PM and possible alternative hosts for PM of tomato. Until this hypothesis is verified, they will be considered so. *Rhyncosia memnonia* is also an important weed in that area, and it is an alternative host for bacterial spot of tomato. Although the disease is not important in winter tomato, attention was given to this weed for the benefit of the farmer.

Coriander was introd-uced as a companion crop with tomato to reduce the population of cotton whitefly, the vector of TYLCV. Although the adoption, for technical reasons, was not as recommended, no incidence of TYLCV was recorded 8 weeks after sowing. The infection level that occurred late in the season, started at the field peripheries adjacent to highly infected tomato and had no effect on the fruit yield and quality. The disease was then contained by chemical control.

The practice of stoppage of chemical control of whitefly at 50% fruiting was compared to insecticide calendar spraying adopted by neighbouring farmers. The crop in the PFFS was not sprayed until 6 weeks after sowing. However, the heavily infested *Cajanus cajan* surrounding a highly TYLCV infected tomato received a number of sprays to reduce whitefly population and restrict the movement of the virus. Unfortunately, the leaf miner (*Liriomyza* spp.) infestation prevailed which necessitated the use of insecticides. Unavailability of a potent insecticide for this pest defeated the practice, and spraying was repeated without reasonable control. Only soft chemicals (pyrethroids), which exhibited high efficiency in controlling insect pests, were used.

Along with the IPM strategy to reduce growers' misuse and overuse of pesticides more emphasis was laid on calibration of pesticide dose, protective clothes, importance of dermal and oral toxicity, disposal of pesticide containers and surplus by double spraying, application time, techniques and storage. Stoppage of spraying pesticides post 50% fruit setting was assured. Fortunately, in the participating farmers' fields, the incidence of TYLCV did not increase after stopping of spraying. In contrast, in fields of non-participating farmers, the disease was not reduced by excessive pesticide use. In addition, the participating farmers outyielded the non-participating neighbouring farmers. Efficient use of fungicides was accomplished and a single spray or two when necessary procured effective PM control and consequently higher yields.

A trial on the effect of direct seeding versus transplanting on incidence and severity of TYLCV was created to supplement IPM options with additional information that might support the farmers' conventional practices to direct seeded tomato. The incidence of TYLCV in the direct seeded tomato was delayed, lower and less severe (Tables 3 and 4). The yields obtained were higher in the directly seeded compared to the transplanted tomato. However, an increase in yield should be calculated and related to input costs to determine which practice is more valuable.

The effect of proper production practices combined with compatible cultural and chemical protocols on improvement of yield is convincing. Participating farmers, although they used low inputs in terms of less number of pesticide sprays and low inorganic fertilizer (urea) (Table 5), obtained higher yields than the neighbouring farmers. The net average profit of participating farmers increased by 103.80% over the neighbouring farmers.

Onion

In Gezira, yield losses of onion are attributable to thrips infestation, damping off and pink root rot caused by *Pyrenochaeta terrestris*. The latter pest is not of importance in the area where IPM options were validated. However, the other two are and remain the major constraints in onion production. The IPM options were directed towards the control of these constraints.

The chemical and cultural practices adopted in nursery establishment were mainly to prevent the occurrence of damping off disease. These include sowing of chemically treated seeds (Captan 50, at rate of 3 g/kg seeds) thinly in groves on flat ridges. This method was superior to broadcasting of untreated seeds on flats or flat ridges as usually practised by farmers. The germination percentage in the recommended practice was about 100%, and the seedlings obtained from the seed rate normally recommended for 0.4 ha were enough to transplant one hectare. The seed rate in this case was reduced by over 50%. Seedling vigour in terms of height, leaf colour and root density of two-week-old seedlings was better than four-week-old seedlings from the non-participating farmers. Easy pulling of transplants with minimum losses was another advantage noticed by farmers.

The recommended sowing date that results in low or no thrips infestation is August to September, and before November for nursery establishment and transplanting in the field, respectively. This recommendation had already reached the farmers in this area as a result of their personal contacts and search for advice on heavy thrips infestation previously regularly encountered.

All onion fields in the area were prepared according to farmers' conventional practice. The recommended practice was to transplant seedlings 10 cm apart in three rows/ridge for better bulb size and yield. This practice did not find acceptance among farmers as they believe that high population of 6–7 rows/ridge is the key for better production and high yield. However, they allowed a limited area (one block) in each of five fields to verify the option with compensation guarantees. These blocks produced higher yields than the farmers' practice. The increase in yield ranged from 33 to 50%.

Table 5. Yield of tomato harvested by participating and neighbouring farmers in comparison to fertilizer rates

No.	FFS Participating farmers: Fertilizer rate (kg N/ha)	Marketable	Non-marketable	Total	Non-participating farmer: Fertilizer rate (kg N/ha)	Marketable	Non-marketable	Total
1	86	26.2	5.6	31.8	108	19.75	–	19.75
2	86	26.6	5.6	32.2	193	22.95	–	22.95
3	86	28.7	6.4	35.1	139	12.2	4.65	16.85
4	86	23.6	10.1	33.7	215	15.55	4.25	19.8
5	86	24.8	10.1	34.9	425	16.55	3.6	20.15
Ave.	86	25.7	7.6	33.3	216	15.4	2.5	17.90

Two farmers adopted the recommended rate of 86 kg N and 43 kg P/ha. All the others applied urea only at the rate of 74–129 kg N/ha. Unavailability of inputs for vegetable production contributed to the application of a lower rate of nitrogen. The herbicide Ronstar 25 EC was used at the rate of 4.3 l/ha at transplanting and was supplemented by hand weedings by some of the farmers. It was noticed that *Sonchus cornutus* (locally known as *moleita*) was a dominant weed in onion fields and very difficult to control by all means. Regular and proper irrigation is a very important IPM option in onion production. Prolonged watering intervals encourage thrips infestation, while frequent heavy irrigation leads to post-emergence damping off. Therefore, it is critical to irrigate onion every 7 days to reduce risks and control possible attack by the pink root rot (PRR). The watering regime adopted by some farmers reduced thrips infestation to below sprayable levels. Coriander intercropped with onion in the field provided good control of thrips and reduced their population below the sprayable level. Thus, the farmer growing coriander did not spray against thrips. Due to the drop of onion prices, the crop was not harvested. The produce was left in the soil awaiting prices to increase. Therefore, the adoption rate of the harvest at 50% pseudostem fallover option was greatly reduced.

Despite the fact that only one farmer adopted the full package except nursery establishment and land preparation, the impact of the IPM options is indisputable. This farmer obtained the highest yield of 100 sacks/feddan (238 sacks/ha) in the area. The yield acquired by the other participating farmers was 61, 61, 70 and 80 sacks/feddan, while that obtained by non-participating farmers was 30, 32, 42, 42.5, 52.5 and 95 sacks/feddan. The farmer outside the school and who obtained 95 sacks was an ARC technician who was already exposed to the use of proper cultural practices for better production of onion.

Other Crops

During this study it was noticed that the farmers in the FFS area were reluctant to grow cucurbit. This was obviously due to past experience with infestation by pests and diseases. Powdery mildew was known to be one of these constraints which is quite manageable by chemical control. Moreover, there are unreported recurring viruses that need diagnosis and possible integrated control measures.

Discussion

The choice of the site to validate IPM options influenced the dramatic success of the Pilot FFS. The farmers at this site are educated, and they were exposed in previous seasons to some of the research findings that had a positive impact on vegetable production in that area.

The choice of participating and non-participating farmers was made in adjacent fields to minimize differences in soil type, climatic conditions and availability of water as it is the major technical constraint in that area. In addition, they could be exposed to the benefits that would arise from the adoption of the IPM options.

The land preparation for both types of farmers was identical. Despite these similarities, higher yields were obtained by the participating farmers (33.3 tons/ha) in tomato and (13.2 tons/ha) in onion, compared to the non-participating farmers (17.2 and 10.6 tons/ha) for tomato and onion, respectively. The average yield last season for the same participating farmers for tomato was 19.0 tons/ha.

The high yields obtained by participating farmers were mainly due to implementation of the recommended cultural practices in the package of IPM options and their collective effects on plant vigour and health. High net benefits were realized by participating farmers. They anticipated the high increment by containing the damage from pests and diseases to acceptable limits at economic cost (low inputs, i.e., less number of sprays and low rate of urea).

This was achieved by careful adoption of the IPM approach. This system is much more dependent on proper management and understanding of the options comprising it and how they interact with each other than considering them singly. This necessitates taking into account all practices rather than limiting them to those associated with pest control. This goal was successfully achieved by the participatory approach. Farmers were actively encouraged to participate in bi-weekly farm visits to demonstrate the problems and drawbacks in non-participating farmers' fields in comparison to the inclusive merits achieved by adoption of IPM options in participating farmers' fields. The profound benefits of these IPM options were well received by both types of farmers, especially the most pressing needs of the day, to improve the efficiency of pesticide use, not only for economic reasons but also to safeguard public health and pressing environmental concerns. The farmers are opting to determine the markets for which they are growing their crops, a quality crop free from insecticide residues. Marketing legislation should be devised to protect these farmers.

From frequent contacts with the farmers in the PFFS, it was certain that at least eight farmers in that area would continue to diffuse the knowledge they gained on how to obtain high yields of tomato and onions with low input costs and minimum danger to the ecosystem of their neighbouring farmers.

Epidemiological studies of the cucurbit viruses reported in the area are essential to devise control strategies within the IPM philosophy.

In conclusion, the participatory approach, close supervision and intimate contacts with farmers strengthened the links between researchers, farmers and extension officers. It also procured successful implementation of IPM options; it motivated quick understanding of the cumulative effect of inputs validated. In addition, the verified, reliable and high quality recommendations taken for validation in the PFFS created a strong trust and confidence in IPM findings and influenced validation at high levels.

Factors that Contribute to Sustainability of IPM in Vegetables

Sustainability of IPM option in vegetables depends on availability of tomato seeds, availability of inputs, marketing fees and expert advice. A continuous flow of new commercial tomato seed varieties to the market through unauthorized channels caused insecurity for the availability of well-known varieties and introduction of seed-borne diseases. Mineral fertilizers (urea and phosphorus) for vegetables are always smuggled from cotton and wheat. Insecticides are usually available in the vegetable market place without labels. Market fees are sometimes prohibitive to small farmers, and tax fees need to be revised to protect small farmers. Pathology advice is available only to a very limited number of vegetable farmers. The number of samples and enquiries coming from farmers for diagnosis and advice to the Plant Pathology Laboratory are tremendous. Therefore, there is a need to development an agricultural advisory service team including a pathologist, entomologist and vegetable physiologist to promote a sustainable IPM philosophy for better vegetable production.

The Role of Natural Enemies in Vegetable IPM in Central Gezira and the Blue Nile Area

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Until recently, the role of natural enemies in vegetable pest control in the Sudan was an unexplored field. Still, there are few quantitative data about the impact of beneficial organisms on pest control. Also, little is known about economic threshold levels for vegetable pests. Yet, Ahmed (1994) mentioned that protection of vegetables from pests and diseases is the most important requirement for successful vegetable production in the Sudan.

The predominant vegetable pests are mentioned by Munir (in Stam, 1992) as whiteflies (on tomato, okra and cucumber), jassids (on eggplant) and *Earias vittella* (30% damage on okra). In addition, the cotton aphids *(Aphis gossypii)* and the leaf miner *(Liriomyza trifolii)* are causing problems (Munir, 1993a and b). Ahmed (1994) gives a more comprehensive list of main pests and diseases in the seven most common vegetable crops.

Regarding natural enemies, Herrera (1986a) monitored okra crops along the Blue Nile during the off-season for cotton. He found the following predators (with the following average numbers per plant) associated with whiteflies, aphids and jassids: spiders (2/plant), *Campylomma* bugs (1.5/plant), *Geocoris* bugs (0.5/plant), *Orius* bugs (0.2/plant), *Cheilomenes* ladybirds (1.5/plant), *Coniopteryx* sp. (Neuroptera; 0.2/plant) and Mantispidae (Neuroptera; 0.1/plant). This author concluded that the predatory fauna in Sudan is surprisingly varied and complex and that many predators survive on vegetation along the river banks, whereas other specimens in cotton fields are often killed by insecticides.

Munir (in Stam, 1992) mentioned spiders, melyrid beetles, nabid bugs, *Campylomma* bugs, *Hippodamia* and *Cheilomenes* ladybirds and *Chrysoperla* lacewings as common beneficials on all vegetables in unsprayed fields. The same author recorded *Pediobius faveolatus* as a parasitic wasp from the African melon ladybird (*Henosepilachna elaterii*) on cucumber. On hot pepper (sprayed once), an average of 17.6 % of cotton aphids were found to be parasitized by *Aphelinus sudanensis*. Observations on leaf miner on the weed *Sonchus oleraceus*, from December1992 until January 1993 revealed that an average of 19.8% of leaf miner larvae or pupae were killed by an undetermined parasitoid.

During the 1994/1995 and 1995/1996 seasons, some 45 farmer fields of tomato and onion, most of them in central Gezira and some along the Blue Nile, were, if possible, weekly monitored (visually) for pests and their natural enemies, from the end of the rainy season until the end of winter. Also, bordering vegetation was sampled by sweepnet. In addition, a number of eggplant fields were surveyed but less frequently so and mostly along the river (Beije, 1996a and b). This chapter gives a summary of the main findings in these three crops, as well as in bordering vegetation. Common predator groups are, to a large extent, the same for most vegetables, other rotational crops as well as for bordering vegetation; the relative abundance of these beneficials depends not only on crop or vegetation but also on available prey insects, location and season (Beije, 1996 a and b). Generally, there were large variations in crop management practices, local conditions and, particularly for tomato, disease incidence. As a result, yields also varied a lot, making statistical and economical analysis of predator impact rather senseless. Finally, it should be mentioned that frequent irrigations are interrupting regular field observations; after irrigation, fields are inaccessible for several days. As a result, there were some fields that were not monitored for as long as one month.

Tomato

The currently planted tomato varieties are susceptible to tomato yellow leaf curl, one of the major diseases beside powdery mildew and others, which is transmitted by whiteflies and against which frequent sprayings are directed. This pesticide pressure obviously reduces natural enemy populations, making them generally much lower in tomato than in other crops.

As long as pesticide applications against whiteflies and diseases are so frequently needed, there is no scope for biological control of major pests such as whiteflies, African bollworm and leaf miner. Whitefly natural enemies cannot be expected to keep this pest below the very low economic threshold level of less than one whiteflies per plant (FAO, 1995, p.20).

Experimental sprayings with neem seed water extract against whiteflies in the 1995/1996 season were not successful, although it is important to note that average predator numbers in plots treated with neem (in addition to some regular insecticide applications) were higher than in tomato plots sprayed frequently with regular pesticides.

The beneficial predators that were encountered in tomato crops belong to the following groups (in descending order), and their average incidence over the season 1995/1996 was as follows:

- Spiders (included webs/nests): 2.1 per 25 plants
- *Chrysoperla* spp. (Chrysopidae; included counts of eggs, the most frequently observed stage): 1.8/25 plants
- *Campylomma* sp. (probably mostly *C. nicolasi*; Miridae): 0.7/25 plants.

Other predators, only occasionally observed, included ants, *Metacanthus* bugs (Berytidae; often found dead after sprayings), *Laius* beetles (Melyridae), coccinellids and anthicid beetles. Not surprisingly, less sprayed plots had more predators than frequently sprayed plots (Table 1). Applications included both fungicides and insecticides (but not neem).

Nearly always, farmers plant pigeon pea borders around their tomato plots. There is a relationship between incidence of natural enemies in these borders and in the tomato plot. However, there was not a clear correlation between predator numbers captured by sweepnet in these borders and predator levels observed on tomato. This is probably due to interference by pesticide applications: it is thought that pigeon pea borders are sometimes sprayed when there is excess of spraying liquid, but other times they are not. However, the high predator numbers (of all groups) observed in one very weedy field and in most pigeon pea borders suggest that weeds and pigeon pea are more attractive to predators than tomato plants, but the latter are also more sprayed.

It is noteworthy that average leaf miner infestation in frequently sprayed tomato plots was found to be higher than in less sprayed plots (Table 1). Apparently the pesticide applications are more harmful for natural enemies of the leaf miner than for the pest itself, which is confirmed by several references in literature (COPR, 1983, p.99; FAO, 1995, p.18).

Onion

Contrary to the situation in tomato, the onion crop can be grown profitably without or with only little pesticide input. Onion in central Sudan has only one major pest, the onion thrips (*Thrips tabaci* Lind.). Early in the season there is another thrips, probably the dark cotton leaf thrips (*Caliothrips impurus* Pr.), but that one is not causing harm.

The onion thrips usually does not become abundant until the end of January and declines towards the end of February, both in sprayed and unsprayed fields (Figs. 1 and 2). In onion fields planted before mid-November, thrips normally did not become abundant until the end of January/February; fields planted after mid-November showed thrips peaks mostly during March (Table 2).

During the 1994/1995 season (with an average of 3.1 insecticide applications over 15 onion plots), there was an average of 13 thrips/ onion plant with only 2.9 predators per 30 plants (equal to approximately one predator for every 10 plants, counting all stages); in the 1995/ 1996 season (11 plots, 1.7 sprayings) there were a few more thrips (on average, 18 thrips/plant), much higher predator numbers (over one predator for every three onion plants on average) and higher yields (Table 2). In some fields, there were predator numbers as high as 30–40 per 30 onion plants, often towards the end of the season. This means that at times, there is more than one predator for every onion plant.

Yields varied a lot: differences over 100% were recorded between fields at the same location and with approximately the same planting date. These yield variations seem primarily caused by different cultural practices and only to a minor extent due to differences in thrips infestation (Table 2).

Table 1. Intensity of pesticide applications in tomato plots of farmers, central Gezira, 1995/1996; and average incidence of predators by visual observations

No. of plots	No. of pesticide applications	Pest infestation		Predator numbers/25 plants				
		Whitefly adults	Leaf miner scale 0–3	*Chrysoperla*	Spider	*Campylomma*	Other	All
8* (av. 4.9)	0–9	1.1	0.6	3.0	2.7	0.9	0.3	**6.9**
7 (av. 11.7)	10–14	1.1	0.9	0.6	1.4	0.4	0.1	**2.5**

*4 were treated with neem (not counted under pesticide applications), in addition to some pesticide applications; only one"neem plot" did not receive any other pesticide treatment

Table 2. Transplanting dates of onion, thrips infestation, predator incidence and yield of 15 onion plots monitored during 1994/1995 and 11 onion plots during 1995/1996. Number of insecticide applications and location of the plots are indicated

		Spray	Thrips infestation/plant		Predator numbers/30 plants		
Planting date	Location	Number	Av./season	Peak: Date	Av./season	Peak: Date s/f	Yield
1994/1995							—
Sept. 1	D.f	6	18	51: 29.1	6.3	11: 8+29.1	30
Sept. 10	D.e	2	8	28: 15.1	5.2	13: 26.12	20
Oct. 10	D.b	–	9	31: 15.1	0.2	1: 15.1	?
Oct. 28	D.d	2	2	5: 29.1	2.0	11: 3.1	25[1]
Oct. end	D.e	–	11	28: 12.3	5.6	14: 12.3	45
Av. Sept.–Oct., '94		0.8	9.6		3.9		31.7[2]
Nov. 9	D.c	7	40	98: 12.2 244: 16.4	2.4	16: 9.4	33
Nov. mid	D.f	1	15	40: 12.3	3.5	8: 2.4	**75**[4]
Dec.2	M.c	2	2	10: 22.3	1.1	8: 5.4	46
Dec. 5	M.a	5	5	12: 22.3 16: 19.4	0 .8	5: 12.4	38[4]
Dec. 8	F.b	4	16	33: 22.2 33: 22.3	4.3	18: 19.4	35–40[3]
Dec. 10	F.a	6	8	26: 8.3	1.9	7: 9.4	45–52[3]
Dec. 10	F.c	2	6	18: 8.3	2.5	11: 12.4	27–42[3]
Dec. 10	D.h	6	14	58: 26.2	1.2	5: 30.4	23
Dec. 16	D.g	4	26	90: 6.3	2.8	17: 26.3	42
Dec. 20	F.d	5	9	47: 19.4	3.0	10: 19.4	24
Av. Nov.–Dec., '94		4.2	14.1		2.3		41.5
1995/1996							
Aug. 15	D.6	–	**47**	156: 4.2 30: 10.3	11.0	26: 11.2	35
Sept.10	M.1	1	12	28: 30.1 30: 27.2	12.3	34: 12.12	64
Sept.15	D.2	–	2	6: 21.1	10.3	19: 19.11	40[1]
Sept.16	D.1	1	12	93: 11.2	18.2	48: 10.12	**127**
Oct. 1	D.3	–	**25**	56: 31.12	11.2	24: 17.12	27[4]
Oct. 1	D.4	–	17	102: 4.2	8.8	19: 17.12	34[1]
Oct. 1	M.4	3	7	32: 13.2 23: 12.3	7.0	13: 26.12	91
Oct. end	M.5	4	8	35: 13.2	7.6	32: 12.3	26[5]
Av. Aug.–Oct.,'95		1.1	16.2		10.7		61.7[6]
Nov.1	D.5	5	43	154: 11.2	11.7	36: 3.3	34[4]
Nov.1	M.2	3	15	61: 19.3	8.2	32: 19.3	60
Nov.1	M.3	2	14	52: 27.2	6.8	26: 12.3	90
Av. Nov., '95		3.3	24.0		8.9		61.3

(1) harvested early while still green,
(2) yield data from only 3 fields,
(3) the first figure gives the net yield, the second is the yield including the part that was lost due to rotting,
(4) very weedy field,
(5) onion plot with very wide spacing,
(6) yield data from 6 fields only

(D = Derwish, M = Massad location, both in central Gezira; F = Fadasi, near Blue Nile)

In central Gezira, it can generally be distinguished that there are early season thrips predators (spiders, often Salticidae and *Chrysoperla* spp.) and others which mostly appear after early February, when the thrips population has built up. These late season predator groups are *Campylomma* (Miridae) and *Orius* bugs (Anthocoridae), *Laius* beetles (Melyridae) and ants (Table 3). Coccinellids were only rarely observed on onion. During December, in some onion plots, there was an average of more than one *Chrysoperla* egg per onion plant (Fig. 2).

In January the predator population, then still mainly consisting of green lacewings and spiders, was normally low (Fig. 1), which cannot be explained. This may be the reason the thrips populations increases towards the end of January. Lacewings and spiders can be considered the predators which prevent or slow down thrips population development.

The late season predators (mainly true bugs and melyrid beetles) appear when the thrips have generally reached high levels (Figs. 1 and 2); however, in some fields, *Chrysoperla* also was observed to increase again and thus contributed to thrips control. In addition, the level of spiders always went up again towards the end of the season, seemingly related to the increase in grasses between the onion plants. These grasses and weeds probably also favour melyrid beetles and other predatory groups (Table 6). Predacious thrips or mites or thrips parasitoids, which are reported as important natural enemies of thrips in other countries (Loomans et al., 1995), could not be detected.

Four unsprayed onion plots (with mediocre cultural practices) showed that thrips populations reached a peak of 149 thrips/plant on 11 February. Before that time, in January, thrips numbers had not exceeded 40 per plant, while predator numbers had been relatively low then, around four per 30 plants. On 11 February, predators (mainly *Campylomma* bugs) peaked at the same time as the thrips pest, with 26 predators per 30 plants; subsequently they brought the thrips population down to below 30/plant in 2 weeks and below 20/plant in 3 weeks (Fig. 1).

Another farmer in the same area applied good cultural practices and sprayed only once, on 27 December, though this was not necessary according to countings (Fig. 2). Also, in this plot, thrips reached a peak during the count on 11 February (93 thrips/plant, with 23 predators per 30 plants); here thrips was controlled below 20/plant within 2 weeks, and the field yielded an excellent average of 127 sacks per feddan.

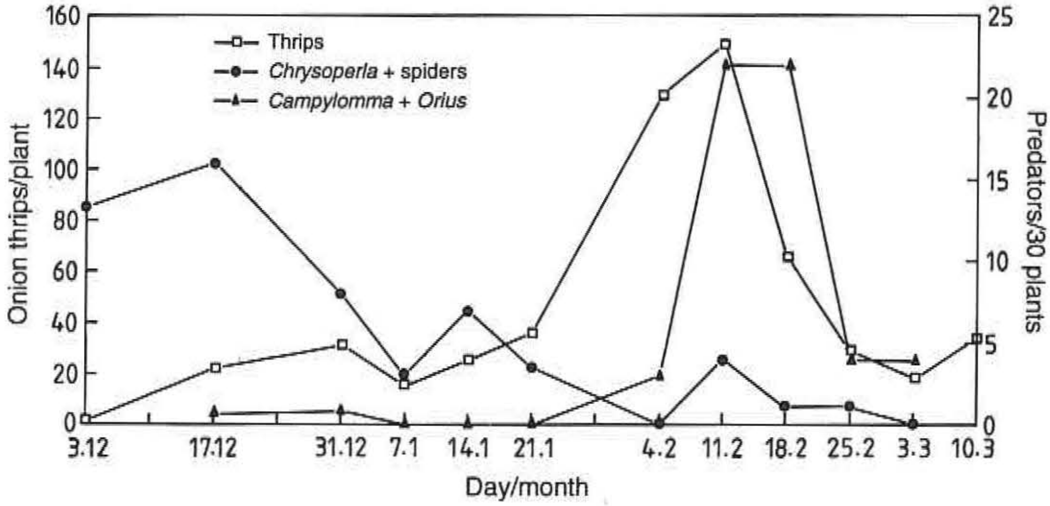
The data in Table 2 suggest that an average of 15–25 thrips/plant over the whole season does not prevent good yields for onion planted before November. Thrips levels of around 30/plant could probably be tolerated after mid-January and up to 90 thrips/plant after mid-February, provided that thrips predators are present to tackle the pest. It was found that 20–30 predator specimens per 30 plants can control severe thrips outbreaks (Figs. 1 and 2).

The impact of sprayings on thrips levels, predator numbers and yield at one location in

Table 3. Onion fields monitored in 1995–1996: transplanting dates, number of sampling dates (n), average thrips infestation/plant, number of sprays (all season; i = insecticide, h = herbicide), average number of predators/30 plants, yield and border vegetation

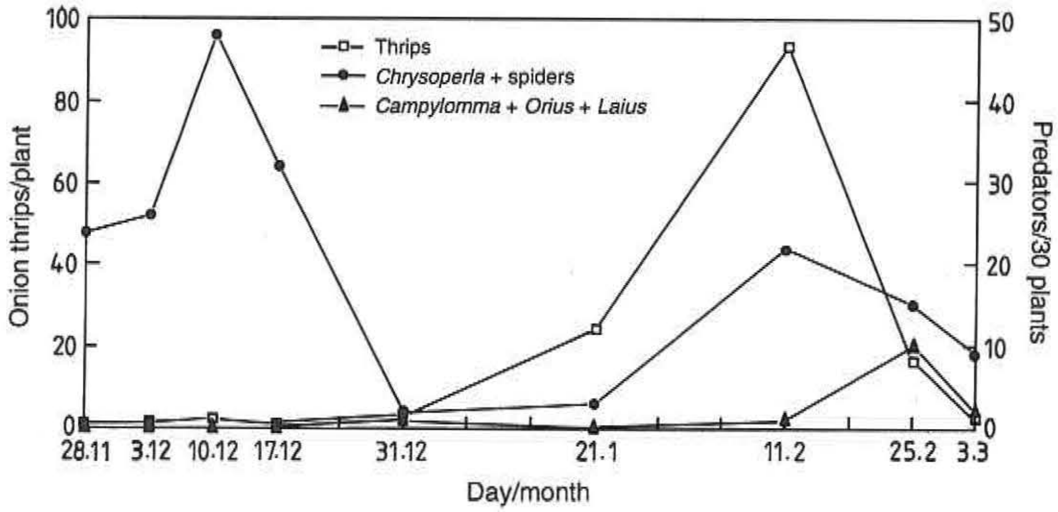
			Thrips	Spray		Av. number of predators/30 plants							Yield	Border veg.	
Field	Planting date	n	nr/pl.	i	h	Chrys	Spid	Cam	Ori	Lai	Ant	All	Sacks/f	Pp	Grass
D. 1	9.16	12	12	1	1	15.3	1.8	0.8	0.2	0.1	–	**18.2**	**127**	+	+
D. 2	9.15	8	2	–	–	8.3	2.0	–	–	–	–	10.3	40*	+	+
D. 3	10.1	8	25	–	1	9.8	0.8	0.3	–	–	0.3	11.2	27 (1)	–	–
D. 4	10.1	7	17	–	–	7.6	0.6	0.3	–	–	0.3	8.8	34*	+	–
D. 5	11. 1	16	43	5	–	4.8	0.8	2.4	3.1	0.6	–	11.7	34 (1)	–	–
D. 6	8.15	15	47	–	1	2.5	0.7	4.1	3.5	0.2	–	11.0	35	+	–
M. 1	9.10	6	12	1		11.0	0.7	0.2	–	0.2	0.2	12.3	64	–	–
M. 2	11.1	7	15	3	–	2.9	1.7	2.3	1.3	–	–	8.2	60	+/–	–
M. 3	11.1	11	14	2	–	3.4	0.4	1.2	0.6	1.1	0.1	6.8	90	–	–
M. 4	10.1	10	7	3	–	4.2	1.8	–	0.6	0.2	–	7.0	91	+/–	+
M. 5 (2)	10. end	10	8	4	–	2.4	2.8	0.2	0.9	1.1	0.2	7.6	26	–	+
Average		110	18	1.7		6.2	1.4	1.3	1.2	0.4	0.1	10.6	57		

(1) very weedy plot, (2) too wide plant spacing, (*) early harvested while still green
Chrys=*Chrysoperla*, Spid=Spiders, Cam=*Campylomma*, Ori=*Orius*, Lai=*Laius* (Melyridae), Ant=ants, All=All predators together; Pp=Pigeon pea



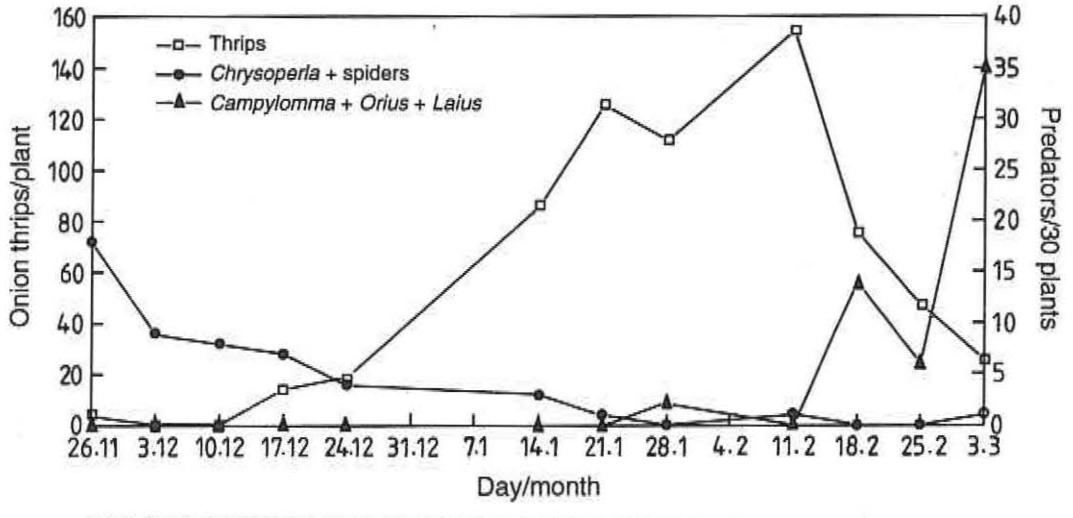
Derwish, Gezira, season 1995/96. Av. yield: 34 sacks/feddan, 2 plots still green

Fig. 1. Onion thrips and main predators in four unsprayed onion plots



Derwish, season 1995/96. Yield: 127 sacks/feddan

Fig. 2. Onion thrips and main predators in one field sprayed once, 27 December



Derwish,season 1995/96. Yield: sacks/feddan. Sprayings 9.12, 23.12, 14.1, 26.1, 22.1

Fig. 3. Onion thrips and main predators in one field sprayed 5 times

Table 4. Pesticide applications against onion thrips, 21 onion plots in Gezira and Fadasi, 1994–1996

Season	Insecticide number of thrips			Predator numbers/30 plants				Av. yield
	No. sprays	No. plots	Thrips	*Chrys*	Spider	Other	All	
94/95	0–3 (ave 1.2)	6	10.0	2.7	0.8	0.5	4.0	43.0
94/95	4–7 (ave 5.3)	7	16.9	0.9	0.6	0.8	2.3	35.9
95/96	0–3 (ave 1.4)	7	18.9	7.0	1.1	2.5	10.7	70.6
95/96	5	1	43	4.8	0.8	6.1*	11.7	34

(*) nearly all other predators were observed after the last spraying, towards the end of the season.
Yield is in sacks per feddan. Chrys=*Chrysoperla*

Table 5. Comparison of onion thrips infestation, and predator numbers, central Gezira

Season/ Location	No. plots	Thrips / plant	No. sprays	Predators (per 30 onion plants)					All
				Chrys	Spider	*Camp*	*Orius*	*Laius*	
1994/95									
Derwish	9	15.9	2.8	1.9	0.3	0.2	0.1	0.5	3.2
Massad	2	3.5	3.5	0.04	0.9	–	0.05	–	1.0
1995/96									
Derwish	6	24.3	1.0	8.1	1.1	1.3	1.1	0.2	11.9
Massad	5	11.2	2.6	4.8	1.5	0.8	0.7	0.5	8.4

Chrys=*Chrysoperla*, Camp=*Campylomma*, *Laius*=*Laius* (Melyridae)

Gezira is illustrated by comparing Figures 1, 2 and 3. In one onion field that had been sprayed already three times, thrips counts averaged 125/ plant on 21 January; after two more sprayings, thrips here also reached a peak on 11 February, amounting to 154 thrips per plant (Fig. 3). Predator populations recovered slowly to 14 per 30 plants on 18 February and then reduced thrips numbers below 50/plant in 2 weeks and below 30 in 3 weeks. Comparing Fig. 3 with Fig. 2, it can be concluded that frequent spraying against thrips in onion kills off natural enemies rather than thrips and tends to aggrevate the pest problem rather than solve it. Also, more sprayings mostly led to lower yields (Table 4). Good cultural practices are more important than chemical thrips control. Elamin & Kannan (1996) reported also that good cultural practices made onion plants more tolerant to attack by thrips: with 62 thrips per plant, the onion plants still looked healthy.

Regarding other locations, there seem to be marked differences in predator numbers and thrips levels (Table 5). Predators differ both in total numbers as in abundance of individual groups.

During both the seasons of 1994/1995 and 1995/1996 at Derwish location, the total number of predators was higher, but the number of spiders was lower than at Massad location, where they sprayed a little more (Table 5). It is assumed that this is mainly due to differences in surrounding vegetation (habitat): a more diverse vegetation, with more trees, cotton, wheat and sorghum will probably favour predators such as lacewings, true bugs and beetles; grasses or fallow vegetation favour spiders in particular (see later chapter).

Along the Blue Nile, there were more spiders, melyrids (*Laius* spp. and *Ebaeus* spp.) and anthicid beetles (*Formicomus* spp.). The two beetles groups appeared earlier than in central Gezira and played a more prominent role. Herrera (1986) mentioned that the Blue Nile borders served as a refuge area and reservoir for many natural enemies.

Along the Blue Nile, where the soil is more sandy, many farmers plant their onion crops in flat beds, not on ridges as they do on the heavy clay soils of Gezira. Salih Mohamed (pp.59–64) reported from Sennar area that thrips infestation in such (unsprayed) flat plant beds remained low until the end of the season when irrigation intervals became longer. This may be explained by a more detrimental effect of the irrigation water on thrips pupae in the soil of these flat beds, in addition to the impact of natural enemies.

Transplanting of onion seedlings in September is recommended, so as to avoid thrips infestation between January and March on still young onion plants (Dabrowski et al., 1994). The transplanting date of onion plots monitored during the 1994/1995 and 1995/1996 seasons

Table 6. Predatory insects and spiders in different border vegetation, central Gezira, 1995/1996

Border/ crop	n	spr	Camp	Other Heter	Spider	*Chrys*	Cocc	Ants	Other	All
			Predator groups:							
Pigeon pea next (Oct.–Feb.) tomato	105	3.3	14.7	0.2	0.8	0.4	0.5	0.1	–	16.7
next (Nov.–Mar.) onion	60	1 ?	22.2	0.2	0.8	0.7	0.2	–	–	24.1
Total	165		17.4	0.2	0.8	0.5	0.4	0.1	–	
Grasses/Weeds next (Oct.–Mar.) tomato	37	1.8	3.9	0.2	1.7	0.2	0.9	0.4	0.2	7.5
next (Nov.–Feb.) onion	12	3 ?	1.5	1.1	1.0	1.3	0.2	3.9	0.3	9.3
Total	49		3.3	0.4	1.5	0.5	0.7	1.3	0.2	
Millet next (Oct.–Nov.) tomato	5	4	13.2	1.4	1.8	–	0.6	5.4	0.2	22.6
Coriander* next (Jan.–Feb.) onion	5	1 ?	14.0	–	0.2	–	–	–	0.2	14.4
Grasses within dried onion field (March)	4	-	0.8	0.9	0.7	–	–	–	4.2**	6.7

* swept slowly because coriander is hard to sweep without damaging the plants
** mostly *Laius* sp.
(n = number of samples over season; spr = average number of insecticide sprayings during period of sampling, incl. the week before); Camp=*Campylomma*, Chrys=*Chrysoperla*, Cocc. = Coccinellidae

varied between mid-August and 20 December. Table 2 shows onion plots planted before and after 1 November. Average thrips infestation in the "early" onion was indeed lower than in the "late" onion plots, although some plots (such as D.6 and D.3) were a clear exception to this. Late planted onion also received more insecticide sprayings, which apparently did not have much effect, or rather the opposite effect, as mentioned above. Regarding thrips predators, more were found in the early planted onion. Generally, late plantings not only showed later thrips peaks, but predator peaks there normally also came later (Table 2). Regarding average yield, there was no clear advantage of early plantings (Table 2). Some good yields were obtained from plots transplanted mid-November and early December.

Eggplant

Observations on eggplant mostly took place along the Blue Nile. Compared to tomato and onion crops, there was a much larger variety of natural enemies in eggplant crops, as was the case for okra (see also, Herrera, 1986a). The most important pests of eggplant are jassids, tingid bugs, stemborers, budworms and fruitworms; but blister beetles, thrips (particularly during the seedling stage), aphids and whiteflies were also observed. The most common predator groups encountered were spiders (mostly jumping spiders), four groups of beetles (Melyridae, Staphylinidae, Anthicidae and Coccinellidae), true bugs (Miridae, Anthocoridae, Reduviidae, Berytidae and others), ants, green lacewings (*Chrysoperla* spp.) and hover flies (Syrphidae). The latter group and ladybirds (mostly *Cheilomenes propinqua vicina*) are only important when there is an aphid infestation. Melyrid beetles are mostly *Laius venustus* and, less so, *Ebaeus* sp.; Staphylinids are mainly represented by *Paederus sabaeus*, and anthicids are mainly *Formicomus* sp.; *Campylomma* sp. is the dominant mirid bugs. *Orius* sp. represents the pirate bugs and *Metacanthus* sp. is the common berytid bugs.

Regarding parasitoids, there was failure to find jassids egg parasitoids, which are reported from other African countries (Klerks and van Lenteren, 1991). The cotton jassids can be considered as eggplant pest number one in central Sudan. It was observed to be attacked by spiders, *Formicomus* sp. and *Metacanthus* sp. The limited scope of observations could not determine the potential impact of the various natural enemy groups in eggplant. From cotton it is known that the biological control of jassids is rather weak (see report by Beije and Ahmed elsewhere in this publication). Spiders and anthicid beetles are predators that probably play a major role in jassids control.

Field Border Vegetation and Neighbouring Crops

With vegetables, and sometimes also with other rotational crops, it is a common practice of the farmers to surround their plots with border rows of pigeon pea, another pulse or millet. Apart from obtaining another kind of produce, these border rows also serve as wind- and sun-breaks and are said to help prevent theft. In addition, field borders can play an important role as refuge and reservoir for natural enemies. However, certain pest insects, such as the American bollworm, thrips, aphids and jassids, are also known to occur on weeds and border crops.

During the 1995/1996 season, regular sweepnet samples were taken from pigeon pea borders around 12 tomato or onion fields in central Gezira, as well as from other borders, mainly consisting of grasses and weeds. In addition, some neigbouring fields of sorghum, cotton and wheat were regularly sampled by sweepnet.

The main findings on border vegetations are indicated in Table 6 and Figures 4 and 5. Borders of onion fields (both pigeon pea and grasses) were found to contain more natural enemies than tomato borders, which is not surprising, given the difference in pesticide use on these crops. Sweeping of pigeon pea yielded twice as many predator specimens as sweeping of grasses and weeds; this can partly be explained by the difference in vegetation structure: insects are probably less easily swept from low grasses than from higher, easy-to-sweep pigeon pea. The *Campylomma* bugs (probably *C. nicolasi*, Miridae) was by far the most numerous predator observed with sometimes over 50 specimens per 10 sweeps, especially in pigeon pea, but also in coriander and millet. Spiders generally came in second place. They were more numerous in grasses than in pigeon pea. Other important groups of natural enemies found in borders were *Chrysoperla*, coccinellids (mostly *Scymnus*) and ants. The lacewing was at times very abundant in grasses next to onion, possibly related to the presence of aphids there. Ants were mostly found in grasses and millet, and they could locally be predominant. Regarding time of predator peaks, *Campylomma* peaks seemed to be related to flowering of pigeon pea, but this bugs remained very common in pigeon pea all season. Some farmers cut their pigeon pea and allow regrowth to flower again later. Spiders are common during the whole season, but most were captured during the early and late season. *Chrysoperla* was also encountered during the whole period (Figs. 4 and 5). The presence of ladybird beetles was mostly limited to the early winter season.

It can be assumed that large numbers of predators will move to another crop or vegetation nearby, when an established field is drying up. In ripening wheat, it was clearly observed that lacewings concentrated in still green patches of the field (whether these consisted of weeds or wheat plants).

During the 1995/1996 season, it was found that major predator groups are the same for neighbouring fields of dura, cotton and wheat, although numbers vary depending on crop and available prey. In these rotational crops, the same predator species were encountered as in vegetables. In particular, the following predator groups of importance for vegetables were observed in other rotational crops :

- *Chrysoperla* spp.— very common in all crops and other vegetation
- *Campylomma* sp.— particularly abundant in cotton, pigeon pea and coriander
- Spiders— common in all crops but particularly in grasses
- *Cheilomenes* sp. — though generally less abundant than *Scymnus* spp., this coccinellid was found especially on crops (sorghum and cotton) with plenty of aphids.

Discussion and Recommendations

In the agro-ecosystem of central Sudan there is still a rich fauna of natural enemies, especially along the Blue Nile (see also Herrera, 1986). In particular, a number of general predators (*Chrysoperla*, spiders, *Campylomma*, coccinellids, among others) are very common, both in vegetables and other rotational crops, whenever they are not sprayed frequently. In general, parasitoids and insect pathogens seem to play a minor role only.

Prospects for a better use of indigenous natural enemies in controlling vegetable pests are particularly promising for onion, where onion thrips is the only serious pest. It was found that with good cultural practices, onion can tolerate high thrips infestations, and beneficial arthropods can, if not disturbed by pesticide applications, control thrips outbreaks within 2 weeks (Figs. 1 and 2). Frequent insecticide sprayings tended to aggravate the thrips problem while killing off natural enemies (Fig. 3).

Proper action threshold levels for thrips infestation should depend mainly on time of infestation and abundance of thrips predators. Dabrowski (1994) gave an economic threshold level of 20 thrips/plant, while FAO (1995) mentioned 20% of plants infested as action threshold. Kisha (1979) reported as few as 5–10

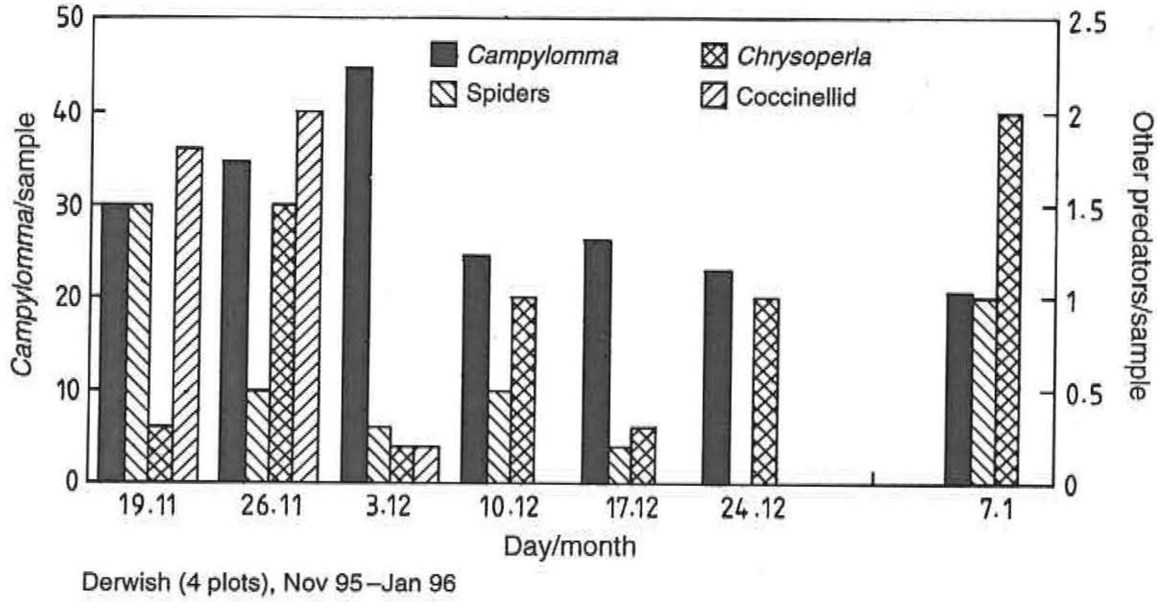


Fig. 4. Main predators in pigeon pea borders along onion (av. number per sample of 10 sweeps)

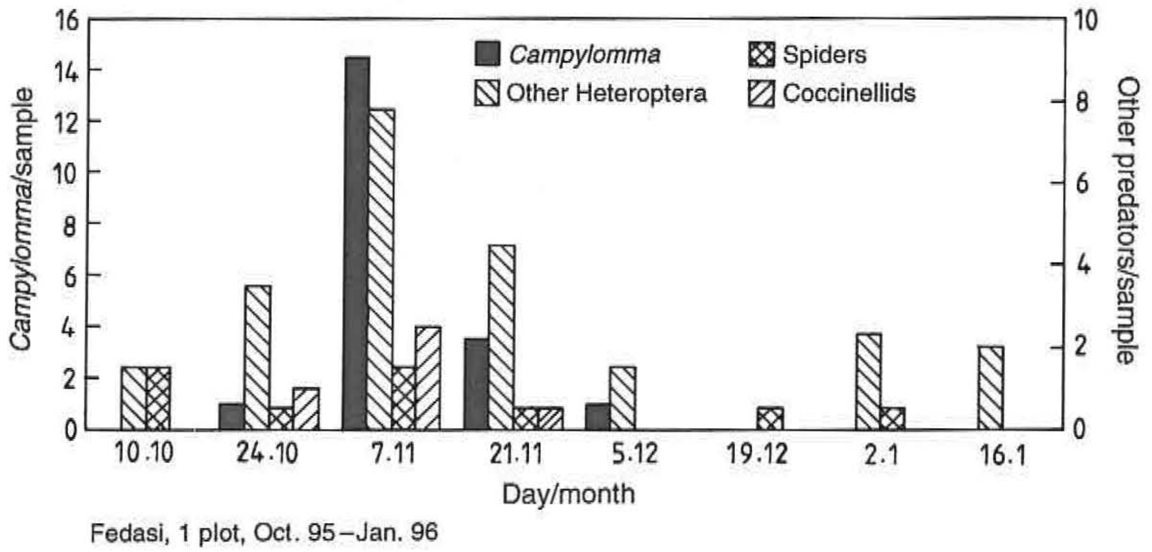


Fig. 5. Main predators in grass borders along tomato (av. number per sample of 10 sweeps)

thrips nymphs per plant as the action threshold for late plantings. The threshold of 20% is definitely unsuitable for Sudan, since severity of thrips infestation is not considered, nor are natural enemies taken into account. For leek in Europe, Theunissen and Legutowska (1991) reported that infestation levels up to 100% are required before thrips causes serious damage. The same applies for onion in Sudan. The threshold of 20 thrips/plant is a bit low, even for the early season (December until mid-January). After mid-January, when thrips infestation usually becomes more serious, threshold levels of around 30 should be tested; and after mid-February, it was found that 90 thrips/plant could be tolerated, at least with two predators (all stages) present for every three onion plants (Fig. 2). The good onion field of Fig.2 showed a seasonal average of more than one predator for every two plants, while a seasonal average of 15 thrips per plant did not prevent good onion yields. Tomato varieties currently grown are susceptible to leaf curl, transmitted by whiteflies, and several other diseases, against which frequent sprayings are directed. As a result, the role of natural enemies to control whiteflies and other pests in this crop is not very important.

Although a number of natural enemy groups (such as ground beetles and some parasitoids) have not been properly investigated, the identity of the main beneficial groups for most vegetables is now known; however, more field and laboratory research is needed to establish their (potential) impact. In particular, natural adversaries of jassids on eggplant (spiders, anthicids and melyrid beetles) deserve attention because it is not clear whether they can control this major pest sufficiently to avoid or limit chemical control measures.

Field border vegetation such as grasses or rows of pigeon pea, millet or coriander, favour major groups of natural enemies such as spiders (grasses) or *Campylomma* bugs (pigeon pea). This vegetation functions as a reservoir and refuge area for natural enemies. The positive effects of this phenomenon likely outweigh the negative effects of harbouring pests as well. More research on this topic is clearly needed.

In addition, more field research should be done on the effect of neighbouring and successive crops. Important general predators, such as green lacewings, *Campylomma* spp. and predatory beetles, are likely to move from one field to another, once the first field dries up. A neighbouring field of sorghum, harvested early November, may produce a lot of natural enemies for adjacent vegetable plots, in particular since this rotational crop can tolerate high aphids populations (which are a good diet for many natural enemies), without need for spraying.

Standardized, seasonal sampling of natural enemies in major crops and surrounding vegetation, for example by sweepnet, where possible and preferrably in combination with visual countings, is an important practice as long as it is reliable. In this way, the relative incidence of many beneficial species in different crops or vegetation can be established. Guidelines for proper sampling and for the use of a sweepnet are given by Balogh (1958), Southwood (1966), Lamotte and Bourlière (1969) and Kogan and Herzog (1980). Important aspects with using a sweepnet are speed of sweeping, different availability of insects and spiders (related to time of the day, distribution within plant level, etc.), weather conditions and efficiency of the collector. Regarding number of sweeps to be made, authors mention figures varying from 5 to 25 sweeps per sample, mostly depending on vegetation structure.

For vegetable crops such as onion, which can be grown with a minimal pesticide input, it is important to show farmers the main natural enemies and what they can do. If farmers do not see the action of beneficial insects and spiders with their own eyes and in their own fields, implementation of IPM and biological control using the existing fauna is very difficult. The IPM Farmer Field Schools established by the project are an excellent opportunity to train farmers on these aspects so as to further enhance the role of natural enemies in vegetable pest control.

Validation of Onion and Tomato IPM Options in Pilot Schools of the Rahad Scheme

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Crop protection research on vegetables at El Rahad Experimental Station of the Agricultural Research Corporation aims at reducing total reliance on chemical pesticides for pest control in the Rahad scheme. The horticultural agronomist and entomologist have been involved since 1993 in developing an integrated pest management programme on tomato and onion with the following principles: economic profitability, technological feasibility, efficiency and acceptability to an ecology-conscious society.

Onion is a leading irrigated vegetable crop of El Rahad rotation, and the onion thrip (*Thrips tabaci*) is a major insect pest, usually controlled by chemicals. The extent of damage and degree of attack are immense, particularly with the late transplanted crop. Depending on the duration and intensity of infestation, 2–4 sprays were reported to control the pest in the area. Application of insecticide, mainly Lannate, was the sole control measure known and adopted to combat the pest ravages. The continuous misuse of insecticides was, undoubtedly, a determinant to natural beneficial arthropods and hazardous to the environment. Moreover, escalating costs of insecticides and spraying equipment came to be real deterrents for profitable vegetable production. Thus, chemical control of this pest is prohibitively expensive, and alternative control measures must be sought. Timely application of cultural practices and efficient management of the resources and costly inputs can increase farmer profits and reduce hazards.

The overall objective of the current IPM activities was to demonstrate to the farmers organized in the IPM Pilot Farmer Field Schools (FFSs) that good crop yields could be obtained through judicious use of insecticides, minimizing excessive unnecessary pesticide applications and by enlarging the role of cultural practices as the first preventive mechanism to insect pest and disease attack. Rahad scheme extensionists and field plant protectionists were involved from the beginning in establishing the Pilot FFS and IPM demonstration fields (Table 1).

Validation of Onion IPM Options

The study was carried out in four farmers' fields, village 23, Group 5 in the 1995/1996 growing season. The treatments evaluated comprised of an improved production package versus farmers' conventional practices. The improved package included the following factors:

- Planting cultivar, Saggi;
- Nursery sowing in September;
- Transplanting of seedlings, early to mid-November;
- Spacing: 10 cm between plants, one plant/hole, row-spacing 60 cm and two rows/ridge;
- Fertilizer application: IN (urea) split application, one on the 21st day after transplanting and the other at one month after transplanting;
- Irrigation: frequent light irrigation early in the season to ensure crop establishment and later every 5–7 days in warm periods and 7–10 days in cooler periods;
- Insect pest control: only curative insecticide application—Malathion at 0.6 l/feddan

Table 1. Adoption rate of IPM options in the Rahad PFFS, 1995/1996

	IPM Farmer Field School		
Activities	IPM option	Adoption rate(%)	Farmers' practices
Land preparation-discing	Mid-October	92	Nov.–late Dec.
Ridging	Late October	97	Nov.–Dec.
Nursery sowing	Sept.–Oct.	100	Oct.–Nov.
Transplanting	Late Oct.–Nov.	100	Nov.–Dec.
Fertilizers	As recommended	100	Personal judgement
Weeding	3		5
Irrigation	7	87	6 –10
No. of insecticide sprayings	One spray	100	2.3 sprays
Yield	38.7 sacks/feddan		19.3 sacks/feddan

instead of Lannate commonly used by Rahad farmers.

The main IPM component included using Malathion as a safer insecticide (III toxicity class, noxious) than the previously used Lannate (Ib toxicity class, highly toxic). The farmers were also taught to identify onion thrips and evaluate its low (few thrips), medium (up to 20 thrips) and heavy (more than 20 thrips per plant) infestation. It was confirmed in the 1993/1994 growing season that the action threshold for onion thrips should be 20 thrips per plant (Walter-Echols et al., 1990; Kannan and Mohamed, 1994a; Dabrowski, 1994). All insecticides were, therefore, used only as a curative spraying when the thrips population reached the recommended action threshold in the PFFS. The population of thrips nymphs was monitored weekly. Yield was estimated after harvest and compared to the adjacent farmer's plot where conventional methods were practised.

Coriander, as a repellent crop, was sown 10 days prior to transplanting, around the tagnants, and green coriander crop was secured throughout onion growth when possible. A good crop establishment was affected and satisfactory yields were obtained. Thrips population was consistently low in the PFFS fields compared to farmers' own practice plots (Table 2). A single application of Malathion at the rate of 0.6 l/feddan was carried out as a curative spray in the PFFS field versus an average 2.3 (with maximal 6.9 sprayings) by non-IPM participating farmers.

Coriander adversely affected the thrips population if it could be secured green during onion growth. Healthy and better managed onion crops tolerated thrips population without loss in yield or further insecticide application. It was also observed that the late transplanting dates coupled with insufficient irrigation water during some periods in the growing season adversely affected plant growth and increased thrips population and damage symptoms.

Table 2. Mean number of thrips nymphs/100 leaves; village 23, group 5, Rahad scheme, 1995/1996

Date	IPM option	Non - IPM option
29 December	1.0	1.1
8 January	1.0	2.4
18 January	2.9	6.9
28 January	3.2	6.4
7 February	3.2	8.8
17 February	4.7	12.9
27 February	6.5	16.6
6 March	6.0	14.1
16 March	5.4	2.4
25 March	5.4	15.2
S.E. O	(1.7)	(3.6)
C.V.%	(27.3)	(31.9)

Validation of Tomato IPM Options

The cotton whitefly *(Bemisia tabaci* [Genn.]) is an economically important pest of tomato in El Rahad. The pest inflicts tremendous losses to the crop and transmits the fatal Tomato Yellow Leaf Curl Virus (TYLCV) disease. Recently, tomato was exposed to various kinds of insecticides in the field which acts as a reservoir of chemical pesticides harmful to both the consumer and farmer community. The objective of this trial was to demonstrate to the farmers that judicious use of insecticides would reduce the cost of production and hazards without adverse effects on yields.

The IPM options included proper sanitation and cultural practices (Dabrowski, 1994), stoppage of spraying at 50% fruiting (Kannan and Mohamed, 1994b)and using coriander (*Coriandrum sativum*) as an insect repellent plant extensively sown around the tagnant in all tomato growing fields in this particular area. Three farmers' fields in village 23 were selected to validate the tomato IPM option. Adjacent tomato fields in village 27 were used for comparison. Regular periodic counts of the cotton whitefly population were taken throughout the season. A number of insecticide applications and chemical use were recorded. Yield and number of picks were taken at harvest.

The leaf miner *(Liriomyza* sp.) was the principal pest early in the season in all tomato producing areas. Danitol-S was excessively used in non-pilot fields to control the pest, whereas less than two sprayings were administered in the IPM option fields to suppress leaf miner. The whitefly population was low in the pilot farms compared to the adjacent plots using farmers' conventional practices. This had been clearly shown by low infestation levels and less number of sprays in the PFFS fields (Table 3). Moreover, Sumicidin at the rate of 0.3 l/feddan was the only insecticide used against whitefly in the PFFS whereas a variety of insecticides was applied in the adjacent fields. The mean number of sprays in the IPM option fields was 2.7 compared to 6.3 sprays in the other farmers' practice plots. No substantial differences between the two groups of fields were detected as to the number of picks and yields/feddan (Table 3).

Summary

In addition to regular participation in FFS activities and training of extensionists, the current activity was carried out to demonstrate IPM options in farmers' fields and their impact

Table 3. On-farm validation of tomato IPM option in the Rahad scheme, village 23, group 5

Particular	IPM participating farmers		Adjacent farmers' fields
Leaf miner control Insecticides used	Mean of 1.98 sprays Sumicidin		More than 3—Folimat, Endosulfan, Kafil, Sevin, Furadan
Whitefly population	4.6/leaf		4.2/leaf
(Av. of 11 counts)			
S.E.O		(0.26)	
C.V.%		(12.3)	
Mean no. of sprays	2.7		6.3
Yield: Mean fruit weight	41.1 kg/plot		44.7 kg/plot
S.E.O		(4.3)	
C.V.%		(16.8)	
Mean no. of picks	4.8		5.3

on insect pest population and yields in tomato and onion crops. Tomato and onion growers some times experience practices (late sowing, unnecessary continuous insecticidal sprayings, untimely fertilization and heavy irrigation at short intervals) which initiate favourable conditions conducive to thrips and whitefly population build-up. Intercropping tomato and onion with coriander (*Coriandrum sativum*) as an insect repellent remarkably reduced whitefly and onion thrips in tomato and onion, respectively. Coriander manifested good results in depressing the whitefly population and reduced the number of sprays to an average of 2.7 sprays compared to 6.3 sprays in conventional practice. The population of onion thrips was similarly reduced in pilot farms to an average of 0.45 against 2.3 sprays. Continuous spraying of tomato exerted no substantial effect either in whitefly population or in crop yields, when compared to the stoppage of spraying at 50% fruiting.

Validation of Integrated Pest Management Components for Late Grown Tomato

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Wad Medani

In Gezira State, as well as in other parts of the Sudan, some vegetable farmers grow tomato and onion later than the recommended time for winter cultivation but not as summer crops as such. Their reason is to catch high prices for their tomato and onion yields at the end of the main season of the winter crops. Pilot farms for late grown tomato and onion were carried out at Hantoub and were associated with a Farmer Field School. Hantoub is a village located on the opposite bank of Blue Nile from Wad Medani.

The objectives of the pilot farms were to validate the regular IPM options for tomato and onion in their late cultivations, to monitor pest and disease problems of such cultivations and to demonstrate IPM subjects. The FFS was established in coordination with the Department of Extension Services of Gezira State represented by its Director, Mr Saoud Mohamed, and the Union of Vegetable and Fruit Producers.

Results

This report presents only an evaluation of tomato IPM options. Because specialized farmers are growing late tomato or onion crops, the FFS, Hantoub area could attract only eight farmers. The field sessions were held irregularly. The subjects covered were related to pesticide hazards, safety application of pesticides, cultural practices of tomato and onion in addition to the identification of insects and diseases encountered in the fields.

Four farmers participated in the tomato pilot farms, and each had an area of 1 to 1$\frac{1}{4}$ feddan. They were presented with recommendations on proper land preparation, modifications in establishing nursery management of the crop and selected IPM options (Mohamed, 1995; Dabrowski et al., 1994a). Selected IPM options are listed in Table 1.

Three farmers transplanted 5-week-old seedlings on 15 February, and the fourth farmer transplanted 6–7-week-old seedlings on 27 February 1996. In the nursery, the seedlings were treated 2–3 times with Folimat at 3 weeks and onward. The first three fields (transplants on 15 February) received six sprays of Folimat, fertilization with urea (80 kg/feddan) in two split doses (3 weeks and 7 weeks after transplanting) and three hand weedings. The tomato transplanted on 27 February differed by receiving three sprays of Folimat and two weedings. All fields were irrigated 16 times.

From the observations taken from these fields, seed dressing with Gaucho was effective in keeping the seedlings in the nursery free from whitefly for at least three weeks. The nursery seedbeds prepared in ridges resulted in vigorous and uniform seedlings compared to the flat plots. The only pest and disease encountered were whitefly and TYLCV later in the permanent field. Although the population densities of whitefly could be kept at low levels (0.21–0.56 adult/leaf) by spraying the insecticide, second degree (26%) and third degree (61%) infection with TYLCV were recorded. Tomato transplanted on 27 February had a higher infection. The source of the virus inoculum may be the old tomato stands in the general locality of the pilot farms. However, weeding and insecticide spraying were minimal in the tomato transplanted on 27 February (three sprays and two weedings). The most common weeds in the area were Hambouk *(Abutilon pannosum)*, Um Hebiba *(Sida alba)*, Shokal Kail *(Boerhavia erecta)*, Rabaa *(Trianthema pentandra)* and Lissan Tair (*Amaranthus* spp.). Data on economics of the late grown tomato in the IPM Pilot Farm are shown in Table 2. For comparison, some data was obtained from two other farms growing tomato in a traditional way. Due to the high variability in yields of the pilot farms and the small sample size of the traditional farms, reasonable statistical comparison may not be possible, but at least in two pilot farms the tomato yields (301 and 215 tins) superseded that

Table 1. Selected IPM options validated by farmers in Hantoub area (modified from Dabrowski et al., 1994)

- Planting TYLCV tolerant cultivar — Strain B;
- Seed dressing with Gaucho 70 WS (imidacloprid) at 0.8 g/100 g seed against cotton whitefly and with Baytan (fungicide) at rate of 0.3 g/100 g seed;
- Using ridges as seedbeds in nursery;
- Spraying Folimat 80% (0.2 l/feddan) as curative treatment when the whitefly are first noted;
- Planting pigeon pea, sorghum and *Dolichos lablab* as shelter or the whitefly trap crop on plot borders;
- Removal of weeds—alternative host of TYLCV.

of the two traditional farms (182 and 164 tins). Farmers who grew tomato in the traditional way followed direct seeding instead of transplanting, and they needed double seed rate, more irrigation water (20 irrigations) and more insecticides (eight sprays) to establish their crops.

Recommendations

Vegetable crops that are grown as the off-season crop, e.g., tomato and onion, usually receive more pesticides; therefore,cultural and non-chemical pest management practices should be encouraged to avoid excessive use of pesticides by farmers. Secondly, to meet the real needs of all vegetable farmers, the FFS activities in Gezira State should include in their curriculum the production of late grown or off-season vegetables and not be restricted to the main tomato cropping season. Tomato seed dressing with the systemic insecticide Gaucho against the whitefly in the nursery showed to be effective. However, tomato seed dressing with this insecticide is not recommended yet by the ARC. A recommendation for the use of Gaucho as seed dresser should be presented to the Pest and Disease Committee.

Table 2. Economics of late grown tomato in IPM pilot farms, Hantoub area, 1996

Farm no.	Area (feddan)	Yield (10-kg tin)	Prod.cost (S£)	Yield value (S£)	Return per feddan(S£)
IPM Field					
I	$1\frac{1}{4}$	301	206.200	602.000	316.640
II	$1\frac{1}{4}$	215	189.000	430.000	192.800
III	$1\frac{1}{4}$	133	172.100	266.000	75.120
IV	1	16	100.200	32.000	-68.200
Farmers' practices					
I	1	182	213.700	364.000	150.300
I	1	164	195.800	328.000	132.200

Integrated Pest Management Options for Off-Season Tomato

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The link between the University of Gezira vegetable breeding programme and the FAO/ARC IPM Project was very instrumental in presenting research findings to farmers. Funds made available by the FAO allowed for field days and on-farm research during the winters and summers of 1994, 1995 and 1996. Research findings in resistance to pests and diseases, modified cultural practices for better disease management and the reduction and safer use of chemicals were demonstrated. Farmers, scientists, extensionists, graduate students and officials in the agricultural sector participated in lively discussions while reviewing IPM options for vegetables.

Tomato Production in the Sudan: Historical Background

Tomato ranks among the most important vegetables in the Sudan. In the 1950s, production of the crop was limited to the winter season; early produce used to reach the markets by mid-November, supplied mainly from small holdings grown along the river banks as a *damira* (flood) crop. The bulk of the produce was available from December to February, the fruit being totally unavailable in the markets between April and October. In the mid-1960s some innovative farmers in Elalfoon village, 20 km south of Khartoum, started the production of summer tomato in small holdings along the river banks. The fertile alluvial soils and the micro-environment created by the Nile breeze, along with modified cultural practices like the use of windbreaks and partial shading of the crop were instrumental in achieving some success. What could have been of more significance was their choice of a more adapted cultivar (Chico 3) which was more tolerant to heat stresses than the classical land varieties grown at that time. Although productivity remained very low, prices were more than ten times higher compared to the winter season. The smashing success of Elalfoon farmers and the high returns achieved from their summer crop stimulated great interest among other farmers, and by the mid-1970s, the fruit was made available to consumers all the year round. The selling price, however, remained very high.

Variety Chico 3 was soon replaced by another cultivar, Strain B from Nagara Seed Company. Since its introduction in the mid-1970s, Strain B remained as the major summer cultivar for almost a decade, and the production of summer tomato later extended southward towards Gezira and Blue Nile states. However, the dominant cultivar kept changing with the introduction of more heat tolerant and better shipping varieties from the European and American seed companies. At present, two main cultivars dominate over most production areas whether it is winter, summer or fall. These are Strain B from Popvriend and Peto 86 from Peto Seed Company. They excel in size and firmness and could produce a decent summer crop when grown in alluvial soils near river banks and kept free of TYLCV. It is very common for these cultivars to fail completely if such conditions are not met; hence, most of the summer production is restricted to a narrow zone along river banks. In spite of the better performance of these cultivars compared to the land races used during the 1960s, venturing into the production of tomato during summers remained very risky. Yet, quite a few farmers never gave up trying to produce the summer tomato crop (Omara, 1995).

Of the tomato farmers surveyed during the 1993 summer in Gezira State, 93% suffered total crop failure, or productivity was reduced less than half a ton per acre. However, a successful summer crop which reaches the markets from June to August may score more than one million S£ from one acre. The price per tin (10-kg net wt.) reached a level of 7,000 S£ in July 1995, compared to a low level of 400 S£ in January of the same year, a 14-fold increase in the wholesale price despite the poor quality of the product (Table 1). Production of summer tomato, therefore, presented a challenging issue to scientists and called for intensive efforts in various aspects of research, particularly breeding of heat tolerant cultivars, modification of the micro-environment and better ways and means to control TYLCV.

IPM Programmes on Production of Summer Tomato

Traditionally, farmers in Gezira State use certain cultural practices when producing a summer tomato crop: direct seeding of the standard cultivar Peto 86 or Strain B, use of Adaci

Table 1. Tomato wholesale prices (10-kg tin) January–July 1995	
Month	Selling price (S£)
January	250–300
February	250–300
March	300–400
April	400–600
May	500–2,400
June (1st half)	2,500–3,500
June (2nd half)	4,000–7,000
July (Expt)	8,000–10,000

(*Cajanus cajana*) as a windbreak and control of TYLCV through heavy application of pesticides to eliminate whitefly. Spraying starts at the second leaf stage and continues until harvest time or the end of harvest in spite of the 100% incidence of TYLCV 5 to 7 weeks after sowing. The IPM project on summer tomato introduced a new package of modified cultural practices to the farmers. One such practice is the use of whitefly attractants and modifiers of environment. Of the many crop species tried as an attractant of whitefly, *Dolichos lablab* beans were the most suitable due to their fast growth rate, ease of spraying and the fact that they do not act as host for TYLCV. Vine crops like melon, snake cucumber and watermelon, although good attractants and fast growers, are difficult to spray. Their trailing also acts as a breeding ground for whitefly. *PhVaseolus* beans, on the other hand, are slow in growth and do not attain the large canopy of *Dolichos* beans which help through evaporative cooling to increase relative humidity and reduce temperature.

Other modified cultural practices include windbreaks, insecticides and breeding new varieties. Among the many cereals and legumes tried as breakers of the hot-desiccating winds, the tall and fast growing *Sorghum vulgare* var. Abu 70 was the best suited. Its seeds could be mixed with those of *Dolichos* beans and grown along the irrigation canals one week before the tomato. The use of pyrethroid derivatives, Danitol or Prempt (Danitol + Juvenile hormone), to control whitefly is an economical and safer use of insecticides. Spraying stops by the onset of flowering and fruiting. Three new releases from the breeding programme, namely, U.G. Abdalla, U.G. Summerset and U.G. Fireset, were tried for the first time as commercial heat tolerant and TYLCV resistant cultivars meant to replace those grown by farmers (Table 2).

Six farmers were included in on-farm research during the summer of 1995 conducted in the Nashashiba farm at Wad Medani. The heavy clay soils of the Nashashiba farm are typical of the soils in the central clay plains away from river beds. It is well suited for the production of winter tomato, but only with hard work, good management and good luck could it secure a summer crop. However, it represents the potential for immediate and future expansion for production of tomato since alluvial soils along river banks are only limited in area, and occupied by orchards and other crops. The farmers were allowed to proceed with these cultural practices and each was asked to sacrifice a piece of land to try the IPM package. The project helped the farmers by supplying free seeds, fertilizers, spraying machines and insecticides.

Being easily accessible, the site was utilized for field days and farmer schools. A field day held on 5 July 1995 presented farmers in Gezira State

Table 2. Evaluation of standard cultivars and new heat tolerant lines for adaptation to hot and dry environment, 1995

Cultivar	Growth habit	Vigour (1–9)	TYLCV (1–9)	PM (1–5)	Heat tolerance (1–9)	Fruit size	Fruit colour	Fruit shape	Fruit firmness (1–9)	Overall rating
Fiona F_1	UO	5	7	2–3	0	–	–	–	–	0
Castle	UC	6	2	2–3	0	–	–	–	–	0
Peto 86	UC	6	3	2	1	6	red	long	8	1
St.B(PV)	UC	6	3	2–3	2	5–6	L-red	long	7–8	2
U.G. Summerset	UC	7	6	1–2	7–8	6	red	globe	6	6–7
U.G. Prof Abdalla	UC	6	6	3	7–8	7–8	red	globe	7	7–8
U.G. Abdalla	pim	8	7	4	8–9	4–5	red	round	5	6

Rating scale
Growth habit:
UO = Upright open; UC = Upright compact
Vigour: 1 = small canopy; 9 = very large canopy
TYLCV: 1 = low; 9 = high susceptibility

PM: 1 = low; 5 = high
Fruit size: 1 = very small

with a successful IPM package that converted failures and big losses to high earnings (Table 3). Castle Rock, and the F_1 hybrid Fiona (included as a check variety resistant to TYLCV but lacking heat tolerance) failed completely to produce any fruits. Castle Rock, highly susceptible to TYLCV, suffered from stunting, chlorosis and curling. Both Fiona and Castle Rock suffered from total flower or fruit shedding. Peto 86 and Strain B produced 84 kg and 250 kg/feddan, respectively, and required only a fraction of the cost of production. Although U.G. Fireset had the highest rating for heat tolerance (less flower shedding and a great number of fruits/truss and per plant), U.G. Abdalla with a larger fruit size scored the highest productivity of 6.4 tons/ feddan.

Results of the on-farm research, field days and the inclusion of heat tolerant cultivars which dramatically boosted the yields and income of farmers played a big role in the acceptance by farmers of the IPM project recommendations, and farmers soon helped spread the word around Gezira State about the new technical package.

Main Season Production of Tomato

The new cultivars, U.G. Ebied and U.G. Omdurman resistant to TYLCV, along with the standard cultivars, Peto 86 and Strain B, and resistant F_1 hybrids released by seed companies, were farm tested during the winter of 1995/1996. A field day held in January 1996 demonstrated to the farmers an inexpensive and reliable means of control of TYLCV (Table 4). The new cultivars required 4–5 sprays early in the season using pyrethroid derivatives to stop early infection which may affect resistance of these genotypes. These were compared to farmers' practices of 20 sprays during the season. Farmers learnt to reduce cost of production and deliver to the market a product free of pesticide residues.

Supply of new cultivar seeds proved to be a major constraint facing the availability and distribution of quality seeds to the farmers due to the lack of modern seed production facilities in Sudan. The IPM Project was compelled to establish a small seed production unit which started its activities last winter. Construction of a larger and better equipped seed processing unit is now under way through the agreement signed between the University of Gezira and the French seed firm, Technisem.

Table 3. Production and revenue per acre of standard varieties and new heat tolerant cultivars, summer 1995

Cultivar	Production (kg/feddan)	Price/10-kg tin (S£1,000)	Total revenue (S£100)	Cost of production (S£1,000)	Cost of marketing S£500/tin	Net revenue/ acre (S£1,000)
Fiona F_1	0	–	0	250	0	-250
Castle Rock	0	–	0	250	0	-250
Peto 86	84	4.0	32	250	4.0	-222
Strain B(PV)	252	4.0	100	250	12.5	-162.5
U.G. Prof Abdalla	6,400	4.0	3,360	250	260.0	2,955
U.G. Biely	6,300	4.0	2,520	250	315.0	1,955
U.G. Fireset	4,540	2.5	1,125	250	227.0	648

Table 4. Performance of cultivars resistant to TYLCV, field day, January 1996

Cultivar	Resistance to TYLCV	Canopy	Fruit characteristics			Productivity (tons/feddan)
			Size (gms)	Shape	Firmness	
Peto 86	3	7	75	Oval	7	8.6
Strain B	3	7	72	Oval	7	9.7
U.G. Ebied	7	7	74	Round	7	22.5
U.G. Fireset	6	7	45	Round	6	15.6
U.G. Omdurman	7	8	68	Oval	7	26.5
F_1 Fiona	7	7	75	Round	3	14.0
F_1 H2794	8	6	70	Oval	7	26.5
F_1H2797	7	6	45	Round	6	18.7

Potential Uses of Neem in Crop Protection

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Chemical control of insect pests has been the rule in central Sudan until recently, when problems of synthetic insecticides used in agriculture, household and disease vector control became apparent. These include hazards to humans and animals, destruction of beneficial insects, pest resistance, high cost of plant protection and pollution of the environment.

Accordingly, worldwide search for insecticides of plant origin dominated for over 25 years. The low toxicity of these insecticides and their quickly decomposing nature qualify them as replacements for chemical insecticides. The neem tree (*Azadirachta indica* A. Juss) became one of promising plant species because its active ingredients (mainly azadirachtin) are of very low toxicity and do not kill insects by contact (hence, they do not harm beneficial insects). Moreover, insects could not develop resistance against their great number of diversified characteristics.

Neem research in the Sudan, where neem trees abundantly prevail, dates back to 1967 when this author joined the Hudeiba Research Station in northern Sudan and noticed that locust swarms do not settle on neem trees. A trial evaluating the different parts of the neem tree for the control of *Trogoderma granarium* Everts which was infesting stored wheat clearly showed the efficacy of seed powder and to a lesser extent leaf powder. Other parts of the neem trees were ineffective. This trial paved the way for further research work at the Shambat Research Station in Khartoum State. It was confirmed that neem seed powder effectively reduced damage to wheat seeds by *T. granarium*, reduced larvae mortality and was comparable to the standard insecticide, Malathion 57% E.C. (Siddig, 1980).

Control of Vegetable Pests by Neem Extracts

Pests infesting okra, e.g., whitefly, jassid, aphid, flea beetle and Egyptian bollworm, were selected for identification of the most potent neem extracts and dosage rates under field conditions (Siddig, 1990). New seed and leaf water extracts were tested at dosage rates ranging from 1 kg per 40 litres water to 1 kg per 80 litres water. Extract of 1 kg neem seed powder in 40 litres water showed the highest efficacy that significantly controlled okra pests, increased yield per feddan (4,200 m^2) and was comparable to the standard insecticide treatment in Sevin 85% P.W.+ Anthio 25% E.C.

To avoid spraying of chemical insecticides on a root crop like potato, neem seeds and leaf water extracts were tested for the control of the whitefly, jassid, aphid and cutworm infesting this crop. Potato tuberworm, being soil pests unexposed for spraying, were not considered. Neem seed water extract at 1 kg seed powder in 40 litres water showed significant control of these pests and significantly increased the yield of potato.

Separate trials comparing neem and traditional methods of protecting stored potato against tubermoth (tuberworm) attack showed a high level of protection against tuber moth when neem seed water extract at 1 kg seed powder in 40 litres water was sprayed on potato tubers and then tubers kept inside jute sacks. These findings (Siddig, 1990) led to the approval by the National Pests and Diseases Committee (NPDC) of controlling vegetable pests in general and potato pests in particular with neem seed water extract.

Following the approval of the NPDC to use neem for the control of potato pests, cultural practices conducive to the reduction of pests on potato were included as an additional IPM component. The approach was also a model demonstrating the application of neem as an efficient and major component in IPM systems for the control of insect pests in general.

In 1983, an IPM project to control potato pests was prepared and executed throughout a back-up research phase (three seasons), researcher-managed trials (two seasons) and farmer-managed trials (on-farm trials for two seasons). The back-up research phase resulted in promising findings: namely, the control of foliage pests (whitefly, jassid, aphid and younger stages of cutworm) by application of neem extracts and tuberworm by planting in November at 3-inch depth and early harvesting. In the researcher-managed trial at the Shambat Research Farm, an IPM package applying neem to control foliage pests and other cultural practices to control tuberworm was compared to farmers' traditional practices. The IPM package efficiently reduced potato pests and produced a marketable yield of 2.8 to 3.2 tons/feddan while the farmer package produced a marketable yield that ranged between 1.3 and 1.7 tons/feddan.

The farmer-managed trial at the Shehenab potato production area showed significant control of potato pests by the IPM package and an average yield of 7.1 tons/feddan, while the farmer package showed inadequate control of pests and an average yield of 3.8 tons/feddan (Siddig, 1986).

The back-up research phase identified the optimal planting period in the first week of December and placing tubers at 3-inch depth and at a wider inter-row spacing of 20 cm as cultural means of controlling old stages of cutworm larvae attacking tubers in the soil. These cultural methods were integrated with neem application for combating foliage pests (IPM package) and were tested at the farmer-managed trial at Shehenab area (light soil). Plots receiving the IPM package showed significantly lighter pest infestation compared to the farmer package of traditional practices and yielded 20.5 tons in one site and 25.6 tons/feddan marketable tubers on a second site. The farmer package yielded 12.7 tons/feddan in one site and 16.2 tons/feddan in the second site (Siddig, 1993).

Research and Extension

Extensionists of the Integrated Services for Vegetable and Fruit Farmers Project (ISVFF) were adequately trained in the use of neem as a substitute for insecticides; training was during annual meetings, sometimes at their local field stations in central, northern and Khartoum states. They conducted a number of on-farm trials and demonstration plots in different stations. Results collected by them were very positive regarding the control of pests attacking different vegetable crops and were discussed during subsequent annual meetings in Khartoum; improvements relating to the application of neem were also made.

Extensionists of Care International at El Nuhud (Western Sudan) were trained in the use of neem for crop protection during a three-week stay of the author at El Nuhud. The author and the extensionists then met with farmers and women and acquainted them with the use of neem as a substitute for insecticides. Some demonstration plots were designed for extensionists to be executed in the rainy season (Siddig, 1989). Other farmers in western Sudan were addressed twice through El Obeid Radio.

Extensionists of Khartoum State Extension Service involved in the activities of Farmer Field Schools were trained in the use of neem for protection purposes as part of their Training of Trainers sessions. Similarly, farmers of the FFS at Geily, Izergab and Remela were informed theoretically and practically on how to protect their vegetable crops using neem water extracts. A wide audience was addressed several times through Khartoum Television on how to use neem in pest control. Moreover, extension leaflets were produced and distributed among farmers in cooperation with the ISVFF project and the State Extension Service.

In general, the adoption of neem extracts by farmers as a substitute for insecticides is somewhat poor because of several reasons reported by interviewed farmers. Neem seeds are not available when needed by farmers because neem fruits are only produced from June to August, and neem trees are scattered in nature. Secondly, the use of neem is time consuming, e.g., collection of seeds in summer, storage for the growing season in winter, processing. During the growing season, vegetable farmers are fully involved in matters relating to watering, weeding, searching for gasoline and spare parts and marketing.

Neem leaves, unlike neem seeds, prevail in abundance throughout the year but are moderately effective against insects compared to neem seed extract. To break through the problem of seed scarcity confronting farmers, research trials examining different developmental stages of neem leaves were started two years ago based on the assumption that during a certain development stage of the leaves, active ingredients of neem may be at a maximum level. Results collected so far point clearly to high content of active ingredients in older leaflets of young neem leaves. This could definitely solve the problem of neem seed scarcity after completion of these trials.

As for the second problem confronting farmers, time consuming preparation of neem for spraying, the National Council for Research is now launching a project leading to the production of ready neem-based insecticides. Phase I of this project concentrates on extraction of neem active ingredients by organic solvents which is the first step towards the production of commercial neem-based insecticides.

The ongoing research also includes trials started two years ago evaluating the suitability of neem extracts in controlling the plant parasite, *Orobanche ramosa*, attacking solanaceous crops like tomato, eggplant and potato. Similarly, the results collected so far are very encouraging. It is also worth mentioning that a lot of neem research is continuing at universities (by MSc and PhD students), ARC and the National Research Council.

Based on the following prerequisites, the prospects of using neem as a substitute for chemical insecticides in the Sudan are favourable and highly promising:

- Sudan annually imports chemical insecticides valued at US$ 14–40 million;
- The destructive effects of chemical control of pests are very apparent;
- Neem trees prevail abundantly in the Sudan;
- A sizable amount of research work has been done and is still continuing, and information collected so far is convincing;
- There is an increasing trend for applying IPM systems as a strategy for pest control in the

Sudan, and neem is a major component in these systems;
- There has been acceptance of neem extracts by extensionists and farmers;
- Promising results of ongoing research work are solving the problem of neem seed scarcity and paving the way for production of ready neem-based insecticides.

Discussion

Neem extracts can control insects by three strong modes of action—repellent, antifeedant and growth regulatory effects—in addition to a comparatively weaker insecticidal effect. Thus, after been sprayed with neem extracts, insects remain alive for 24 hours but do not feed on plants or cause damage because of the strong antifeedant effect. This area therefore needs a lot of intensive extension among farmers who are accustomed to chemical insecticides with their quick initial killing effect.

Furthermore, when spraying with neem formulations, complete coverage of plants is necessary, especially when spraying against leaf-eating caterpillars. This strengthens the antifeedant, repellant and growth regulatory effects. Neem efficacy could be enhanced by mixing it with sesame oil or piperonal butixide (synergism). On the other hand, the addition of neem to 1N dose (half of recommended dose) of insecticides potentiates insecticide effect and gives a full dosage rate effect, thus reducing the cost of spraying with insecticides.

During collection and storage of neem fruits in the period from June to August, fungus-contaminated fruits with a blackish colour should be eliminated to prevent contamination of healthy fruits during storage; this consequently maintains the level of active ingredients in the seeds. Storage should be in jute sacks or baskets made of plant material. Storage in metal containers or nylon sacks should be avoided to stop deterioration of active ingredients.

This is a contributory paper.

Preliminary Observations on Fruitfly in the Gash Delta and Gezira

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Fruitflies (Tephritidae) are among the major pests affecting cucurbits (mostly melon) and guava fruit production, particularly in Kassala, the Gash Delta, Khartoum area and northern Sudan (Guddoura et al., 1984; Siddig, 1984; Ahmed 1994).

Available information on occurrence, importance and damage by different fruitfly species in the Sudan is rather scanty. Schmutterer (1969) mentions species attacking citrus and guava—*Pardalaspis quinaria* (the Rhodesian fruitfly) and *Ceratitis capitata* (the Mediterranean fruitfly; this species reportedly also affects chilli, eggplant and coffee); in addition, this author reports *Dacus ciliatus* and *D. vertebratus* from cucurbits mainly, and *Sarcophaqa destructor* on cucurbits, tomato and eggplant. Siddig (1984) mentions *P. quinaria* as a major pest on citrus and guava and *C. capitata* as a minor pest on guava. Deng (1990) provides data on biology, behaviour and chemical control of *C. capitata* on guava near Khartoum and also gives information on incidence of *P. quinaria* and *C. cosyra* (the mango fruitfly) in guava fruits there. In the Khartoum area, *C. capitata* was only found on guava, not on other fruits. According to Deng (1990), *P. quinaria* and *C. capitata* are the most common species affecting guava. It is said that fruitfly are seriously threatening the production of melon and watermelon in the Gash Delta.

During a first visit to Gash in February 1995, many deformed and rotting melon fruits near Waggar location were found to be infested with fly maggots; others were attacked by beetle larvae, probably of the melon weevil (*Baris* sp., see Schmutterer, 1969). Rearing of maggots from infested musk melon taken to Wad Medani resulted in the emergence of many "housefly", identified as *Sarcophaqa destructor* (Sarcophagidae). The only Tephritid fly that emerged were two specimens of the Baluchistan fruitfly (*Myiopardalis pardalina;* see Appert and Deuse, 1982).

Following are the main results of fruitfly trapping using dome traps in melon fields, guava and mango orchards; additional observations were carried out on infested guava fruits and watermelon. The main objective of this work was to identify the main fruitfly species involved and to test the use of dome traps for catching fruitfly. More details can be found in field reports by Beije (1995; 1996a,b).

Materials and Methods

Data on fruitflies were collected from the following locations and crops, and during the indicated periods:

1. Experimental melon and watermelon plots in Matateeb Block, Gash, north of Kassala (fruitfly trapping with 12 traps, three lures; 6 December1995 until 28 February1996);
2. Farmer field of watermelon near Aroma, Gash (collecting infested fruits; 5 March 1996);
3. Guava and mango orchards 2 km south of Kassala (fruitfly trapping and fruit sampling; nine traps, three lures; 7 December1995 until April 1996)
4. Melon fields at the University of Gezira, Wad Medani (trapping of fruitfly with six traps, three lures; 27 January until 7 March 1996).

For trapping of fruitfly, yellow dome traps, supplied by Agrisense, United Kingdom, were used. These traps function with an attractant or pheromone placed inside, while the yellow bottom of the trap gives additional attraction. The bottom of the trap is filled with water and a few drops of detergent. Three different attractants (from the same supplier) were tested. These included a general attractant, Protein Autolysate (PA); a special lure for *Bractocera cucurbitae* or *D. cucurbitae* (the melon fly), Cuelure (C); and a specific attractant for the Oriental fruitfly, Methyl Eugenol (ME). The latter is not known to occur in Africa, but researchers wanted to make sure. According to the instructions, the PA attractant was changed every 6 weeks, while the other lures were replaced after 3 months. Trap catches were recorded weekly, if possible, and all captured insects were removed then, while water as well as some detergent were added. Samples of fruitfly were taken to the IPM Research and Training Centre, ARC, Wad Medani, for identification and for making a reference collection.

At Kassala, weekly samples of harvested guava fruits were taken during February and March from the same orchard where fruitfly were trapped, so as to compare trap data with actual fruit infestation. A distinction was made between mature green fruits and ripe, yellow fruits. In early December 1995, a sample of 15 infested guava fruits was collected at Kassala and reared for emerging insects at Wad Medani. Likewise, 20 deformed or rotting watermelon fruits were collected near Aroma on 5 March 1996.

Results

The dome traps proved effective in catching fruitfly. Not only fruitfly were trapped; also caught were large numbers of other flies resembling housefly. These flies were not identified, but it is possible that some of them were *S. destructor* (Sarcophagidae), the status of which is in doubt. It is not clear whether this fly is a primary (ripe) fruit pest, as claimed by Schmutterer (1969), whether it only attacks rotting or overripe fruits, or possibly acts as a predator of fruitfly. In addition, some other insects were trapped, notably syrphid fly in the melon field and spiders in the guava orchard.

Watermelon and Melon

A total of four different fruitfly species were trapped: *Dacus ciliatus* or *Bractocera ciliatus* (the lesser melon fruitfly), *Bractocera cucurbitae* or *D. cucurbitae* (the melon fly), *D. lonqistylus* and another, yet unidentified species which is near the mango fruitfly but bigger and with more black spots on the thorax ("unident.1"). *D. lonqistylus* is a big fruitfly often observed on the common weed *Calotropis procera*, and it has a conspicuous long ovipositor. Its name probably has changed, but information is lacking on its new name. In the National Insect Collection at ARC, Wad Medani, *D. lonqistylus* is recorded as a pest of cucurbits (information by the curator, Dr Musa A.Ahmed).

Most fruitfly were caught with the PA attractant but relatively few with the other lures. With all traps, *D. ciliatus* was the predominant species. From a sample of 200 specimens taken from all traps (December– February), the species composition was as follows : *D. ciliatus* (92%), *D. lonqistylus* (6%), "unident.1" (1%) and *B. cucurbitae* (1%). The low incidence of the last species is surprising, especially in the C traps and compared with the high numbers found in the guava orchard. The maximum number of fruitfly trapped in watermelon with the general PA lure was only 38 specimens/trap/week. It was noted, though, that in the open windy fields at Matateeb, water inside the traps had evaporated within a few days, and this affected the trap catches.

Trap recordings of February showed much lower fruitfly numbers than the previous months, but this may be due to the long intervals (2 weeks instead of 1 week) between trap readings and trap cleaning in that month.

Rearing of flies from 20 collected watermelons yielded only one single tephritid (which escaped before being identified). Most of the other flies that emerged were small flies suspected to be secondary pests only. Most of the rotting of these fruits was apparently caused by other factors.

Trapping of fruitflies in experimental melon fields in Wad Medani showed that fruitfly incidence was relatively very low: on average, far less than 1 fruitfly/trap/week was recorded. Only two species were trapped at Wad Medani: *D. lonqistylus* (60%) and *D. ciliatus* (40%).

Guava and Mango

Not less than eight different species of tephritids were trapped in the guava orchard in Kassala. In addition to *C. capitata* and *C. quinaria* or *P. quinaria* mentioned by Schmutterer, traps caught the mango fruitfly (*C. cosyra*), the melon fly (*B. cucurbitae*), the lesser melon fruitfly (*D. ciliatus*), *D. lonqistylus* and two yet unidentified species. One of the latter is a small, thin species with a dark abdomen and a large ovipositor ("unident.2"); the other resembles *D. ciliatus* but is slenderer and darker brown ("unident.3"). Traps (mostly PA) employed in a nearby mango orchard trapped mostly *C. cosyra*. From the infested guava fruits collected in December, mainly *C. capitata* and *C. quinaria* emerged, in addition to smaller numbers of *C. cosyra*. Four different hymenopterous parasitoids were also reared from those fruits, presumably natural enemies of fruitfly and/or *Drosophila* fly and other secondary fruit pests.

As could be expected, in guava the ME trap did not catch any fruitfly, indicating that the Oriental fruitfly is not present in the region. The PA traps with the general protein attractant caught less flies in the orchard than the C traps (Table 1), which recorded nearly exclusively melon flies (98%). Thus, considering C and PA traps together, the melon fly was the species most frequently trapped, with a maximum (C trap) of

Table 1. Weekly average fruitfly trap recordings, guava orchard at Kassala, December 1995–March 1996

Month/Week	Attractant PA no./trap	Attractant C no./trap
Dec./II	29	15
Dec./III	18	20
Dec./IV	5	21
Jan./I	16	16
Jan./II	4	19
Jan./III+IV	11	59
Feb./I	7	19
Feb./II	3	4
Feb./III	7	1
Feb./IV	4	3
Mar./I	4	3
Average/trap/week	9	15

117 flies/trap/week. The maximum number of different fruitfly trapped with the PA traps was only 42 fruitfly/trap/week. The species composition of fruitfly trapped with PA traps (from December until February) was as follows: *C. capitata* (63%), 'unident.2' (10%), *B. cucurbitae* (7%),"unident.3" (7%), *D. cosyra* (5%), *C. quinaria* (4%), *D. ciliatus* (2%) and *D. lonqistylus* (2%). During the whole trapping period, *C. capitata* remained the most common species in the PA traps. After January, there was also in guava a general reduction in number of fruitfly trapped, probably at least partly due to a decrease in the number of ripening fruit on the trees. It was noticed that sometimes spiders (beside being caught in the traps) made webs at the entrance of traps, and this obviously hampered proper trap recordings.

The results of weekly examined harvested guava fruits are given in Table 2. Fruit infestation varied from 11 to 33%, with an average of 19% of harvested fruits infested by fruitfly. During the period of trapping, no clear decline in fruit infestation was recorded. Green but mature fruits showed less infestation (16%) than yellow mature fruits (21%) (Table 2).

Discussion and Recommendations

The Kassala region and Gash Delta appear to be a fruitfly (Tephritidae) paradise. A total of ten different species were observed. From melon and watermelon fields at Matateeb, Gash, four species of Tephritidae were trapped, mainly *D. ciliatus* and *D. lonqistylus*. In addition, rearing of infested muskmelon in February 1995 yielded a fifth species: the Baluchistan fruitfly (*Myiopardalis pardalina*). Fruitfly trapping in the guava orchard at Kassala gave eight different species, of which *B. cucurbitae* and *C. capitata* were most numerous. In comparison, in melon fields at Medani only two species (*D. lonqistylus* and *D. ciliatus*) were trapped and in much lower numbers than in Gash.

The large number of "housefly" trapped needs further investigation; in particular, the occurrence of *S. destructor* (Sarcophagidae) should be studied, and the pest or beneficial status of this fly should be clarified.

The importance of tephritid fly in melon and watermelon is still not clear. In 1995, mostly *S. destructor* emerged from infested muskmelon, and only very few fruitfly. From deformed or rotting watermelon fruits also very few tephritid fly emerged; rotting of these fruits seems to be primarily caused by other factors, possibly including sunburn.

The eight different species of fruitfly trapped in the guava orchard at Kassala from December until April suggest that there is a large range of tephritid species attacking guava and other fruits. However, not necessarily all trapped species actually damage the guava fruits, since they may have flown in from nearby melon or cucurbit fields, or from mango or other fruit trees; all those crops are actually found in the area. The limited number of infested fruits collected in December yielded only three species, of which the Mediterranean and the Rhodesian fruitfly were predominant, confirming earlier reports by Schmutterer (1969). Traps with the general attractant, Protein Autolysate, caught mostly the Mediterranean fruitfly (65% of all fruitfly), indicating that *C. capitata* is probably the most important species, assuming that the attractance of PA is equal for all tephritids. However, traps with specific lure for *B. cucurbitae* recorded numbers of the melon fruitfly that far exceeded those of *C. capitata* captured with the PA traps. This proves that ME is a much stronger attractant for the melon fruitfly than the PA lure. Regular collection of and rearing of fly from infested fruits is essential to determine the actual importance of the different species that occur in the area.

Table 2. Fruitfly infestation of harvested guava fruits (green and yellow), Kassala, February–March 1996. Sample size = number of harvested fruits examined

Month/ Week	Sample size			Infested fruits			Fruits not infested		
	Total	Green	Yellow	Total (%)	Green	Yellow	Total	Green	Yellow
Feb./II	51	34	17	11 (22)	8	3	40	26	14
Feb./III	50	25	25	11 (22)	4	7	39	21	18
Feb./IV	100	76	24	17 (17)	16	1	83	60	23
Mar./I	88	25	63	10 (11)	2	8	78	23	55
Mar./II	70	21	49	23 (33)	4	19	47	17	30
Mar./III	88	25	63	10 (11)	2	8	78	23	55
Mar./IV	100	42	58	20 (20)	4	16	80	38	42
No. fruits	547	248	299	102	40	62	445	208	237
%	100	45	55	19	16	21	81	84	79

With the traps, the number of fruitfly declined in February (Table 1), but fruit infestation levels (Table 2) did not clearly decrease. This could be explained by a decrease in maturing fruits on the trees. The use of a limited number of effective traps in the orchard (only five traps for *C. capitata* and *C. quinaria*) apparently did not prevent fruitfly damage which remained more or less the same (Table 2). Obviously, the surrounding area full of fruitfly constitutes a vast source for fruitfly influx. It is clear that the traps used are effectively catching fruitfly, but to use traps in the control of fruitfly, it will be necessary to employ more traps over a larger area; hanging traps in just one orchard surrounded by other orchards is senseless as far as fruitfly control is concerned.

Regarding the type of attractant, naturally the traps with the general attractant caught more fruitfly species than traps with specific lures. If *C. capitata* is indeed the major fruitfly species in guava, then the use of a lure specific for the Mediterranean fruitfly, which is commercially available, may be considered. For economical fruitfly control purposes, however, it seems wise to test attractants that can be locally produced, four of which are described by Stoll (1986), who also gives instructions on how to make simple traps for fruitfly. Other control options include the removal and destruction of fallen fruits, and the use of bait sprays or baited fruits (Appert and Deuse, 1982; Siddig, 1984; Hill and Waller, 1988; Deng, 1990).

Mature but still green guava fruits proved less prone to fruitfly attack than yellow ones, which is not surprising since the exposure time of green fruits is shorter; in addition, there is probably an impact of colour and smell on attraction of fruitfly. This leads to another IPM option for limiting guava fruit losses caused by fruitfly: the farmer should pick fruits before they turn yellow. Finally, Schmutterer (1969) and Siddig (1984) mention the common bush, *Zizyphus spinachristi*, as an important alternative host plant for *C. quinaria*. Removal of this bush from the surroundings of orchards is therefore recommended.

Distribution and Control of *Orobanche* in Central Sudan

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Broomrape, *Orobanche* spp., known as *halouk* in the local language, is a root parasite which causes severe damage to many crops in the Sudan. *Orobanche ramosa* L. is the species present in central Sudan, and it attacks mainly tomato, eggplant and potato. High level infestation by this parasite was noticed in Wad Medani area (e.g., Fadasi) where 3–12 shoots of this parasite were observed to attack one single tomato plant. *Orobanche* produce an enormous number of minute seeds that could be disseminated by wind, irrigation water, animals and agricultural machinery. Although *Orobanche* was first noticed in Khartoum during the 1950s, rapid southward spread along the Blue Nile bank was observed. In addition, it was also noticed to invade heavy clay soils in the Gezira scheme. In Khartoum State, *Orobanche* attacked host plants other than solanaceous crops (Babiker et al., 1993; Dafalla, 1995a; Eltayeb, 1995; Hamdoun, 1995).

Potential Control Methods

Potential suitability of selected control methods of *Orobanche* for the Sudan has been critically reviewed by the participants of the First National Workshop on Control Methods of Broomrape, *Orobanche* held on 13 August 1995 at the Integrated Pest Management Research and Training Centre, Gezira Research Station, ARC, Wad Medani (Dabrowski and Hamdoun, 1995). Various control methods were recommended by the conference participants.

The aim of preventive methods is to avoid broomrape spreading into new uninfested areas. This objective can be achieved by planting clean seeds. Locally produced seeds may be cleaned by floatation. Moving infested soil by vehicles and farm machinery within the farm and between farms should be avoided. Infested soil may be transferred with planting material. Farm machinery such as combines and containers operating on a regional basis or by contractors should be carefully cleaned. Prevention of spreading broomrape seeds by grazing farm animals can be avoided. Grazing on broomrape infested fields should be prohibited. It is a common practice to allow grazing on such fields after crop harvest. Animals should not be fed with contaminated hay or crop residues from infested fields, nor should animals move from infested to uninfested areas. Manure from unknown sources should be avoided. Only fermented manure should be used as fermentation for at least 6 months kills parasitic and other weed seeds. Irrigation water should not pass through broomrape infested fields. Soil, gravel, seeds, seedlings or other material should not be moved from infested to clean areas (especially from infested nurseries). When collecting hay, especially of legume plants, farmers should remember that even when flowering broomrape plants are detached from the host by pulling or cutting, the broomrape plant will produce viable seeds. Broomrape seed dispersal by erosion should not move from infested to clean soil. Creating better awareness among farmers, agriculture technical staff, extensionists and officials can help in fostering prevention and other control methods.

Various cultural control methods are recommended. Crop rotation with non-host requires several years for reduction of the seed quantities in soil. This is not an effective method as seeds will remain viable in the soil for periods longer than any reasonable crop rotation. Rotation with rice reduced *Orobanche* infestation in host crops through flooding effect. Flooding might serve in limited situations where water is available and topography allows it. Increased fertilization with nitrogenous compounds and chick manure can assist. N fertilizer assures a good stand of crop which results in vigorous plants with less effect of the parasite.

Hand pulling, hoeing, collection and burning are essential forms of physical control, but success depends on the stage of the broomrape because considerable damage is done to the crop prior to broomrape emergence. If the operation is done when broomrape plants produce ripe fruits, the method is useless. In addition, high stand reduction could be obtained only with repeated hand pulling for more than 2–3 years (Labrada, 1994). When only very few broomrape plants are present in the field, hand weeding is recommended to prevent seed formation. It is crucial to remove the weeded *Orobanche* plants from the field and ensure their destruction even in their early flowering stage. Such plants are able to mature and produce viable seeds when left in the field. All collected broomrape plants should be destroyed by burning outside the cultivated area. Soil solarization with or without minimum soil disturbance can be done at planting. Solarized plots are pre-irrigated by flooding; irrigated furrows are opened manually one day later in sandy soils and 4–8 days later in other soils. Plots are covered continuously using transparent polyethylene sheets. Solarization should start in mid-September and last 4–7 weeks (Braun et al., 1984; Dabrowski and Hamdoun, 1995). Solarization also reduces seed germination and infestation of root-knot nematode, *Meloidogyne*.

Awareness of Farmers on Parasitic Nature of *Orobanche*

In the 1994/1995 winter season, a number of fields with winter tomato showed a heavy infestation and yield reduction to approximately 40–80%. The participatory interactions with vegetable farmers through the IPM Farmer Field School (FFS) indicated that the farmers affected were not aware of *Orobanche* biology, mode of its spread or preventive control methods. Extension training of farmers was immediately initiated through regular weekly field discussions in the FFS as well as through TV and radio presentations (Alsaffar and Khairi, 1995).

The impact of training was later evaluated by interviewing 24 randomly selected vegetable farmers from the affected areas in Fadasi village. Of the interviewed farmers in Fadasi area, 91.7% confirmed that *halouk* had infested their fields. All respondents (including 8.3% whose fields were free from *Orobanche*) were familiar with and knew what broomrape looks like; however, 92% believed that the broomrape produces its own roots. Only 8% of the farmers were aware that *halouk* takes nutrients from the host vegetable plant; 4% thought that it gets nutrients from soil, and 87.5% could not describe from where the parasitic *halouk* takes nutrients. This indicates farmers' awareness of the problem but their lack of knowledge on the nature of parasitic feeding (Dabrowski and Khairi, 1995).

Half of the interviewed farmers observed the appearance of *halouk* during the last ten years and 8.4% more than ten years ago. Only 4.2% of farmers did not confirm the appearance of *Orobanche* on their fields. Half of the Fadasi farmers first noticed *halouk* on their own farms and 45.8% on the neighbour's field; 37.5% of farmers confirmed that the infested neighbour's field was located in close vicinity (less than 50 m) when *Orobanche* was observed for the first time. In previous years, 4.2% farmers' fields were located 50–100 m and 4.2% were 100–1,000 m from the infested field, indicating a direct threat from an adjacent infested field to a new field. In the case of 37.5% of the farmers, first confrontation was with heavily infested fields; 62.5% of the farmers observed only slightly infested fields for the first time. For 37.5% of farmers, the *Orobanche* occurrence lightly in infested fields was able to escape their notice.

Most of the interviewed farmers (83.3%) observed that *Orobanche* reduced crop productivity, and 16.7% stated that *halouk* caused crop plant death after first fruiting.

Some control methods were carried out by 95.8% of farmers. Weeding was done by 91.7% of farmers and 4.2% implemented rotation to reduce damages. Many farmers(66.7%) tried to pull *halouk* plants before flowering and some (29.2%) during flowering or at later stages; 83.3% were aware that there is a specific critical period recommended for removing *halouk* plants and 70.8% knew that pulling should be done before flowering. However, only 42% could describe the colour of *halouk* flowers, indicating that they could consider even brown mature plant as 'flowering'.

Many farmers (70%) confirmed that their neighbours were also pulling *halouk* plants from their crop; 16.7% of farmers noticed that their neighbours did not use any control method.

Most of the vegetable fields in Fadasi area do not have any fences made of thorny acacia branches or wires; therefore, 87.5% of farmers allow free movement of domestic animals (sheep, goats, cows) between fields, and only 4.2% tried to restrict grazing on their fields. The perception of *halouk* damage on tomato varies between farmers. Nearly half of the respondents indicated approximately 75% yield reduction. The time of tomato planting by 35.4% Fadasi farmers coincides with *Orobanche* appearance during the winter growing season. However, the tomato plants planted in November on seedbeds are transplanted in December. It is known that transplanted tomato plants suffer less from the *Orobanche* infestation than directly seeded plants.

In summary, Fadasi farmers were well aware of the destructive effect of *Orobanche* on their tomato crop, but they did not relate the severity of *halouk* damages with the season. The market price of tomato dictated the planting time of their crop. The farmers were able to describe *halouk* plants, but more training is needed to explain the parasitic nature of *halouk* on crop plant roots and the distribution of halouk seeds between fields. Methods other than weeding were unknown to the farmers; therefore, it is recommended that more emphasis be given to restricting *Orobanche* seed distribution between fields by domestic animals. In some other villages in the vicinity of Fadasi, vegetable farmers have already built acacia branch fences around their fields, these should restrict free movement of goats and sheep as sources of field infestation with *Orobanche* seeds from other fields.

Distribution of *Orobanche* in the Central Sudan

During the 1995/1996 growing season, regular field surveys were carried out in 2-week intervals in selected villages located between Khartoum and Sennar. Vegetable fields were monitored for *Orobanche* occurrence. Number of *halouk* plants per square metre was counted. Farmers in these locations were trained in *halouk* identification and were requested to provide the monitoring team with information regarding *halouk* presence in other fields. Most of the cooperating farmers were participants of the IPM FFSs organized along the Blue Nile.

Surveys show that *Orobanche* is well established in most of the vegetable fields located between El-Kasamber and El-Rabowa of the southern part of Gezira State (Fig. 1). *Orobanche* infestation intensity varied between four and six plants/m² (Table 1). Intensive scouting of various vegetable crops and weeds grown on infested fields in Fadasi village show a long list of host plants parasitized by *Orobanche* (Table 2).

Table 1. Infestation of tomato crop by *Orobanche* in central Sudan

Location	No. of *Orobanche* plants/m²
El-Kasamber	4
Um Dagarsi	6
Rufa'a	4
Fadasi	6
El-Rabowa	5

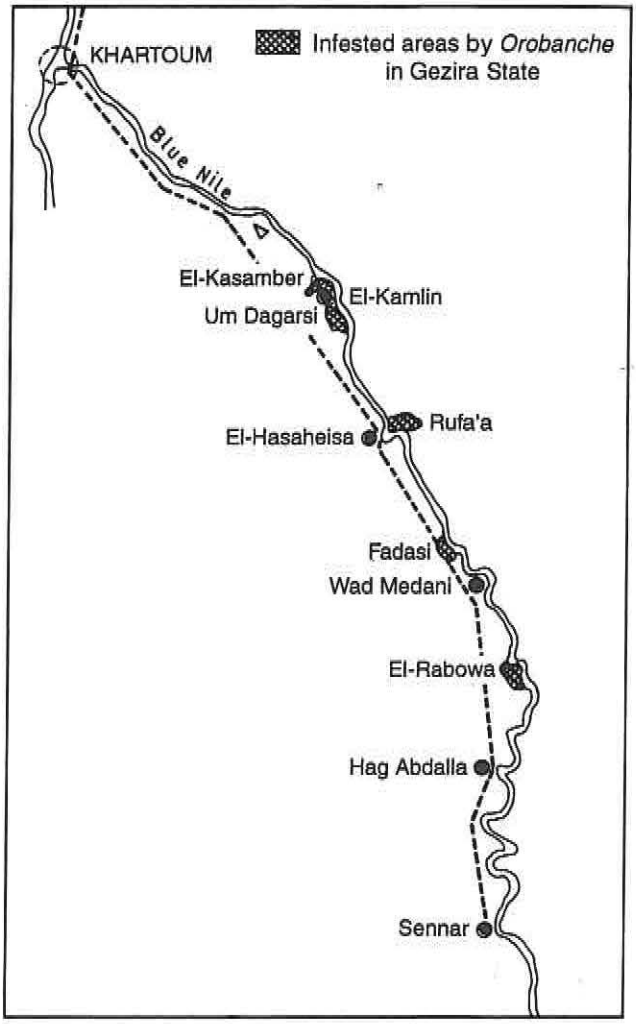

Fig. 1. Area infested by *Orobanche* in Gezira State

Validation of Selected Control Methods

Realizing the increasing threat of *Orobanche* to vegetable production by small-scale farmers, the FAO/ARC IPM Project initiated participatory research with farmers of the FFS located in Fadasi village (Gezira State) to validate some selected control methods recommended for the region. The field of high and uniform *Orobanche* infestation of up to 50 mature branches per 1m row in the previous growing seasons was selected for experimentation.

In the 1995/1996 season, selected farmers were involved in demonstrating various options of broomrape control. There were experiments on the effectiveness and economic evaluation of regular hand-pulling of *Orobanche* plants (farmers' acceptance, labour cost, effectiveness, effect on yield) and the effect of various levels of N and P on *Orobanche* and tomato crop (comparison of germination of *Orobanche* plants, growth pattern of the weed and tomato crops, effect on yield). Land preparation was done according to the recommendation of the Horticulture Department, ARC. Disc ploughing, harrowing, levelling and ridging were done, and the field was divided into plots 7 x 3 m size. All plots were given the recommended split dose of 2N/80 kg/feddan of urea fertilizer: the first dose at the 21st day after transplanting and the second dose a month later. Tomato seeds of Peto 86 variety were sown on 18 October 1995 in the nursery bed and transplanted on 14 November 1995.

The effect of solarization was tested by covering the top of well irrigated soil with transparent polyethylene sheets on 25 September 1995 at average maximum air temperatures of 36.7–39.8°C. The sheet was removed after 7 weeks, on 14 November 1995. The mineral fertilizer treatment included the 3N+1P dose as compared to the standard dose; 40 kg/feddan of triple superphosphate was applied before the first harrowing and 120 kg/feddan of urea as a split dose. The first dose was distributed at the 21st day after transplanting

Table 2. Host plants of *Orobanche* spp., 1995/1996, heavy infected fields in Fadasi area, central Sudan

Latin name	Common name	No. of infested plots/21 m²
Crop plants		
Allium cepa L.	Onion	5
Eruea sativa Mill.	Green rocken (rocket cress)	2
Cucumis sativus L.	Snake cucumber	2
Citrullus vulgaris Schrad.	Watermelon	5
Faba bona Medic	Faba bean	2
Lycopersicon esculentum Mill.	Tomato	56
Capsicum frutescens L.	Hot pepper	3
Solanum melongena L.	Eggplant	6
Corchorus olitorius L.	Jew's mellow	4
Foeniculum vulgare Mill.	Fennel	1
Cicer arietinum L.	Chickpea	5
Weeds		
Heliotropium sudarnicum F. W. Andr.	Common heliotrope	1
Euphorbia aegyptiaca Boiss.	Euphorbia	2
Osimum basilicum L.	Sweet basil	2
Hibiscus esculentus L.	Wild okra	1
Portulaca quadrifida L.	Purslane	1
Solanum nigrum	Black nightshade	3

and the second dose a month later. The effect of planting date of tomato on *Orobanche* severity was tested in three periods: by transplanting month-old seedlings collected from the nurseries planted on 1 September, 1 October and 1 November 1995. The herbicide treatment included only one spraying of 5 g/ha of *Chlorsufuron* between tomato plants a month after transplanting and before the emergence of *Orobanche* shoots. Hand pulling was done for regular removal of *Orobanche* plants immediately after emergence. The cost of employing additional labour was monitored. The experimental design was randomized in a complete block with four replications.

Results

The soil solarization of wet soil for 7 weeks in September and November completely controlled *Orobanche* (only one plant germinated in four plots), and most annual weeds and improved tomato yield (Table 3). Solarization did not eliminate mutgrass weed (*Cyperus* spp.). Plots treated with higher dosage of fertilizers (3N+1P) had significantly lower number of *halouk* plants; 11.0 per plot as compared to 18.5 on the control plots (Table 3). The yield was significantly higher on the fertilized plots than on the control plots.

Application of higher doses of fertilizers was carried out by some tomato growers already in the 1994/1995 winter season to increase tomato plant tolerance to *Orobanche* infestation. The field experiments confirmed that the farmer's practice significantly increased tomato yield.

The relationship between time of tomato seedling transplantation and the effect of *Orobanche* on tomato yield is more complicated. In spite of the fact that *Orobanche* developing on tomato plants transplanted into the field in September were weaker and smaller than *halouk* plants growing on tomato plants transplanted in November, the tomato plants produced higher yields when transplanted in October or November (Table 4). This observation confirms the present farmers' common practice of concentrated planting of tomatoes in November in Fadasi area (Fig. 2).

Spraying tomato field with *Chlorsufuron* herbicide did not reduce *Orobanche* infestation level on tomato plants nor increase tomato yield (Table 3).

Conclusions

Only solarization significantly reduced *Orobanche* infestation level on tomato crops. Because of the high cost of purchasing polyethylene sheets, the used sheets will again be re-used in the 1996/1997 season to spread the cost over two seasons.

The field surveys showed that *Orobanche* can survive on a large number of plants in heavily infested areas in central Sudan; hence rotation will have only a minor effect on *halouk*.

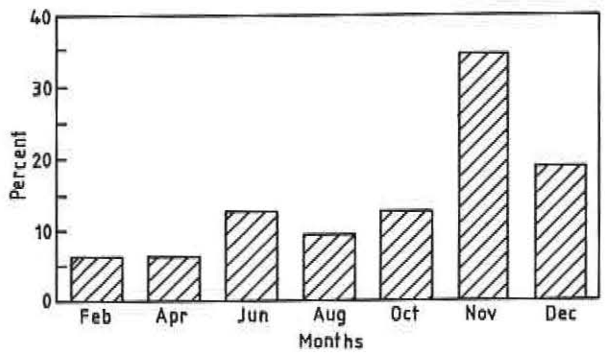

Fig. 2. Preferred planting time of tomato by farmers in Fadasi area, Gezira State (interviews in August–September 1995)

Table 3. Control methods for *Orobanche* infestation in tomato fields, Fadasi location, 1995/1996

	Treatments				
Orobanche	Solarization	Fertilization	Herbicide Chlorsufuron	Farmer practices*	Control
Average no./plot	0.2	11	15.25	19	18.5
Av. no. shoots/plot	–	5.25	7	7.75	6
Av. height	–	28 cm	27.5 cm	30 cm	29 cm
Av. fresh weight/plot	9	8.57	18.27	14.23	10.95
Tomato yield (t/ha)	21.08	17.06	8.40	10.6	7.80

* Farmer practice includes hand pulling of *Orobanche*

Table 4. Effect of sowing/transplanting date of tomatoes on *Orobanche* plants and yield, Fadasi village (Gezira State), 1995/1996

		Orobanche		Tomato		
Sowing date	Transplanting	No. of shoots/plant	Dry weight (g)	Plant height (cm)	Growth vigour*	Yield (t/fed)
1 Sept.	24 Sept.	6	1.92	46	1	5.7
1 Oct.	24 Oct.	6	2.31	51	2	6.6
1 Nov.	24 Nov.	7	2.38	60	2	7.8

* Growth vigour scale: 1=weak plants; 3=strong, healthy-looking plants

Economic Evaluation of Onion IPM Options Validated in Farmer Field Schools

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The FAO/ARC IPM Project established Farmer Field Schools as a new model of participatory approach in extension and validation of various IPM options on farmers' fields by farmers themselves in central Sudan. This report presents the economic evaluation of the IPM on-farm demonstration plots concluded in farmers' onion fields under the FFS approach. The objective of this approach was to teach and demonstrate to farmers the basics of IPM in onion production. The IPM package comprised the following:

- Use of improved varieties;
- Use of improved agronomic and management practices such as optimum sowing time and timely application of fertilizer;
- Use of cultural and biological prevention practices such as resistant varieties, wild host plant removal and planting repellant plants;
- Better use and handling of pesticides.

The trials were conducted on participating farmers' fields, fully managed by farmers and supervised by resident extension staff. Although agronomic data revealed the superiority of the IPM package over farmers' traditional practices, economic ranking is necessary because of differences in factor costs.

Data and Methodology

Data was collected from participating farmers and an equal number of their neighbours for comparison. Farm record booklets (questionnaires) were distributed at the beginning of the season. Data was recorded by the extension staff through direct interviews of school participating farmers and their neighbours. Data collected covered farmers' socioeconomic characteristics and management practices up to harvesting and marketing. More emphasis, however, has been put on aspects of pest control.

Data was coded, fed to the computer and analyzed by SPSS. Frequencies and simple descriptive statistics were calculated for both farmer groups. A partial budget was developed and net benefits (return) were calculated. Note that the net benefits reflect returns to the use of the IPM package but not to onion production. Finally, marginal rate of return (MRR) was calculated which was equal to the package net benefit increment over its additional cost. MRR reflects the rate of return to investment in the package.

Table 1 shows general socioeconomic characteristics of farmers in the three areas—Arbagi, Fadasi and Hag Abdalla. Around 80% of the farmers have some form of education which is a positive situation as it is generally believed that educated farmers are more receptive to new technology. As for the production style, 41% are farm owners while 59% are share croppers. This also has implications regarding the target and differences in resource ownership and decision-making. Onion production area averages 2.5 feddans which amounts to 29% of the total farm areas, indicating that the crop is an important cash earner.

Table 2 shows production features of FFS participants and the neighbour groups; 23% of school farmers used intercropping while no neighbouring farmers used it. This also is a positive feature as the practice is one of the components of the package. Land and bed preparation reflects the soil and farming system type which is different across the two groups.

Table 1. General farmer characteristics (% farmers)

School (area):	
Arbagi	28
Fadasi	36
Hag Abdalla	36
School members	46
Education:	
Illiterate	21
Khalwa	26
Primary	25
Intermediate	18
Secondary	11
Production style:	
Farm owners	41
Share croppers	59
Average age (years)	42
Average farm area (feddan)	8.3
Average crop area (feddan)	2.5

Table 2. Farm production features (% farmers)

Item	All	School	Non-school
Cropping style:			
Sole crop	89	77	100
Intercropping	11	23	0
Bed type:			
Flat plots	59	50	67
Ridges	41	50	23
Land preparation:			
First ploughing	100	100	100
Second ploughing	96	100	93
Levelling	75	69	80
Ridging	39	46	27
Plotting	59	50	67
Prewatering	60	54	50
Land cleaning	82	100	67

Table 3 presents the land use intensity for the two groups. Crop rotation and land use intensity were not substantially different between the two groups, but school farmers tend to cultivate their land more intensively. For the preceding crop, 25% of non-school farmers had onion preceding onion compared to only 8% of the school farmers. This is also one of the components which call for crops to be succeeded (preceded) by different crops, in order to restrict the buildup and intensity of pests and diseases.

Table 4 shows some cultural practices. More school farmers are using the recommended variety Saggi. Both farmer groups, however, reported a high germination rate. Again, more school farmers are transplanting their onion crop during the recommended time (November). All farmers use urea, while a few use TSP.

Table 5 shows the aspects of weed control. Main weeds reported by farmers are *sida* and *nagil*. More than two-thirds of the farmers use manual weed control.

Table 3. Land use intensity (% farmers)

Item	All	School	Non-school
Crop rotation	89	10	80
All year cultivation	29	31	27
No. of cultivations:			
1	63	69	57
2	24	15	43
3	4	8	0
4	4	7	0
Preceding crop:			
Onion	17	8	25
Tomato/eggplant	29	33	25
Leafy vegetables	8	8	8
Fallow	42	42	42
Cucumber	4	9	0

Table 4. Some cultural practices (% farmers)

Item	All	School	Non-school
Variety:			
Saggi	57	77	40
Local	43	23	60
Seed rate (lb/feddan)	5.4	4.9	5.7
Germination rate (%)	83	88	78
Sowing date:			
September	4	0	6
October	7	8	7
November	61	84	40
December	25	88	40
After December	3	0	7
Fertilizer:			
N fertilizer (urea)	100	100	100
N dose (kg urea/feddan)	74	67	81
P fertilizer (TSP)	14	8	20

The strategy of IPM is to emphasize the use of cultural and biological prevention methods together with efficient use and handling of pesticides.Table 6 highlights some cultural and biological prevention methods as considered by the farmers. School farmers showed more awareness of the importance of these methods as reflected by the figures in the table.

Tables 7 and 8 present aspects related to the use and handling of pesticides. The intensity of pests and diseases as well as their average damage, as reported by farmers, was relatively lower for school farmers than for their

Table 5. Weeds and weed control by FFS participants and non-participants (% farmers)

Item	All	School	Non-school
Main weeds:			
Sida Cyperus rotundus L.	50	54	47
Control:			
Manual	76	86	71
Manual + chemical	21	14	29
Nagil Cynodon dactylon (l.)			
Pres.	61	64	53
Control:			
Manual	79	86	71
Manual + chemical	21	14	29
Weeding times:			
1	100	100	100
2	96	100	93
3	57	69	47
4	21	33	13

Table 6. Cultural and biological prevention methods

Item	% farmers All	School	Non-school
Resistant varieties	21	46	0
Alternative host removal	75	100	53
Planting repellant plants	18	39	0
Prewatering	39	77	7
Seed treatment	4	8	0
Other	14	31	0

Table 7. The use and handling of pesticides

Item	% farmers All	School	Non-school
Thrips intensity:	89	100	80
Low	44	54	33
Medium	44	46	42
High	12	0	25
Chemical control:			
Malathion	68	92	47
Sevin	7	0	13
Jmks	7	0	13
Other	18	8	27
Quantity (let/fed.)	0.98	0.92	1.1
Average no. of sprays	2.5	2.0	3.0
Insecticide efficiency:			
Low	22	18	25
Medium	9	9	8
Good	69	73	67
Average damage (%)	12	6	19

Table 8. Disease control

Item	% farmers All	School	Non-school
Powdery mildew	25	30	20
Intensity:			
Low	27	25	33
Medium	57	75	33
High	14	0	33
Chemical control:			
Av. no. of sprays	1.3	1.0	2.0
Fungicide efficiency:			
Low	60	67	33
Medium	0	0	0
Good	40	33	50
Average damage (%)	21	8	33

neighbours. This could be attributed to the use of the prevention methods and to the more efficient use of chemicals. The number of sprays, however, was lower for the school farmers. Table 9 shows that all farmers are well aware of the efficient use and the safe handling of pesticides. This was reflected by the high percentages of farmers using sprayers and spraying at the best time.

Economic Evaluation

Partial budget analysis was used to examine the profitability of the IPM package over that of the traditional practices (Table 10). Costs were calculated in relation to the components that vary between the two groups. School farmers incurred a 5% higher cost than their neighbouring farmers. This was due to the use of more costly seeds and more hand weedings. However, they spent 25% less on pest control. Their average yield, on the other hand, was 29% higher than that of the neighbouring farmers. The net benefits attributed to the package came out to be S £ 81,633 per feddan. This indicates that the higher package cost was compensated for by its higher yield.

Finally, marginal rate of return (MRR) was calculated and found to be 4150%. It means that for every pound invested in the package, the farmer is expected to regain that pound plus an additional S£ 41.50. This in turn reflects the high profitability of the package.

Conclusions

This report presents the results of the IPM on-farm plots conducted under the FFS approach. The data shows a better understanding of the target group of the IPM strategy as reflected in the use of improved varieties, use of improved cultural and management practices, use of cultural and biological pest and disease prevention measures and better use and

Table 9. Pesticide handling

Item	% farmers All	School	Non-school
Spray tools:			
Sprayer	92	100	85
Cloth	4	0	8
Broom	4	0	7
Spray time:			
Morning	27	23	31
Evening	38	46	31
Morning/evening	37	31	23
All day	8	0	15

Table 10. Partial budget analysis

Item	School	Non-school	Difference
Variable cost (S£/feddan)			
Seeds	16,130	11,860	4,270
Nitrogen	5,295	6,365	-1,070
Hand weeding	9,385	7,885	1,500
Pest control	8,207	10,940	-2,733
Cost that vary	39,017	37,050	1,967
Benefits (S£/feddan)			
Yield (kg/feddan)	8,400	6,500	1,900
Price (S£/kg)	44	44	0
Gross benefits (S£/feddan)	369,600	286,000	83,600
Net benefits (S£/feddan)	330,583	248,950	81,633
MRR (%)		4150%	

handling of pesticides. Management practices include optimum sowing time, timely application of fertilizer and a tendency towards mechanical rather than chemical weed control. Resistant varieties, host plant removal, repellant plants, prewatering and seed treatment are sucessful measures. Better pesticide use includes fewer sprayings and use of sprayers and protective measures. The implications are that there will be higher yield and returns, good quality (less contaminated) products, less expenditure on pest control less pesticide load and feedback from the FFS experience.

Economic Evaluation of Tomato IPM Options

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IPM validation fields were established in Pilot Farmer Field Schools (PFFSs) to teach and demonstrate to farmers the strategies of IPM. The strategy is based on cultural and biological pest and disease prevention methods in addition to safe use and handling of pesticides (Table 1). This report presents the economic evaluation of tomato IPM options validated on farmers participating in three schools: Bashkar village in the Gezira scheme, Faris in Sinnar State and Village 23 Rahad scheme in the 1995/1996 growing season. The trials were conducted on participating farmers' fields, fully managed by farmers and supervised by resident extension staff. The objective of this study is to assess the economics of this IPM package and to monitor farmers' attitudes towards its various components.

Table 1. Validation of selected tomato IPM options on farmers' fields, 1995/1996 (modified Dabrowski et al., 1994a)

1. Improved land preparation of disc harrowing, levelling and ridging compared to the traditional practices of ridging and split ridging;
2. Transplanting in contrast to farmers' practice of direct seeding;
3. Intercropping with coriander along all small water canals and separating ridges (see Nafisa E. Ahmed and Wani, this volume);
4. Removal of all weeds, especially alternative hosts to TYLCV and PM;
5. Nitrogen fertilization in the form of urea at a rate of 80 kg urea (2N) per feddan, instead of farmers' higher rate that might reach 5 to 6N level;
6. Irrigation at 4 to 5 days interval in contrast to farmers' irrigation regime at longer watering intervals;
7. Use of soft chemicals (pyrethroids) when necessary compared to farmers' indiscriminate use of a variety of broad-based pesticides;
8. Reduction of chemical use by stopping pesticide spraying at 50% fruit setting in contrast to farmers' practice of frequent and continuous spraying.

Data and Methodology

Data was collected from participating farmers and an equal number of their neighbours for comparison. Farm record booklets (questionnaires) were distributed at the beginning of the season. Data was recorded by extension staff through direct interviews of school participating farmers and their neighbours. Data collected covered farmers' management practices, input use, cost and prices. More emphasis, however, has been put on aspects of pest and disease prevention and control.

Data was coded, fed to the computer and analyzed by SPSS. Frequencies and simple descriptive statistics were calculated for both farmer groups. A partial budget was developed and net benefits (return) were calculated. Note that net benefits here reflects returns to the use of the IPM package but not to tomato production. Finally, marginal rate of return (MRR) was calculated which equal the package net benefit increment over its additional cost. MRR reflect the rate of return to investment in the package.

Table 2. Tomato yield from fields using IPM package and farmers' practices

	Yield (t/feddan)		
PFFS location	FFS	Non-school	% increase
Bashkar	10,800	2,667	305
Faris	16,387	10,644	54
Rahad	1,157	581	99
All	10,723	4,273	151

Results

The yield obtained by school farmers (IPM package) and their neighbours (non-school) in the three field schools differed significantly (Table 2). In all three schools, the IPM package out-yielded farmers' traditional practices. The increase in yield was 99%, 54% and 305% in Rahad, Faris and Bashkar, respectively. The variability between schools is related to the difference in implementation level of various package components as well as to differences in natural conditions (soils) and farmers' experience in tomato production. The average yield of school farmers is higher than that of non-school farmers by 151%.

Four components of the IPM package (transplanting, coriander intercropping, September–November sowing and levelling) affected yield variability (Table 3). Each factor has out-yielded farmers' traditional practices. Coriander intercropping and sowing time have statistically significant effects while transplanting and levelling were not significant. Use of triple superphosphate (TSP) and foliar fertilizer had highly significant effects on yield, which suggest the need for more back-up research so that specific recommendations can be offered to farmers. Irrigation, urea dose and spraying were components which showed a substantial difference between school farmers and their neighbours. School farmers gave higher number of irrigations, lower nitrogen dose and lower number of sprays (Table 4).

When the types of pesticides used by farmers were compared, there was no clear difference between the two farmer groups, nor was there much difference with respect to the use of the two chemical categories (toxicity) within each farmer group (Table 5). The question of pesticide use is market related in terms of availability (access) and prices. However, extension remains a crucial matter in the area of efficient and safe use of pesticides.

Table 3. Effect of some practices on yield and their level of implementation

Item	Average yield (kg/feddan)	Level of implementation (%)	
		FFS	Non-school
Sowing method:			
Direct seeding	5,814	69	73
Transplanting	12,510	31	27
Intercropping:			
Coriander	8,058	62	0
Other	7,183	38	100
Levelling:			
Done	10,267	62	27
Not done	5,651	38	73
Sowing date:			
Sep.–Nov.	6,501	100	75
Other	1,256	0	25
TSP			
Used	7,777	39	27
Not used	7,762	61	73
Foliar:			
Used	7,010	38	36
Not used	8,221	62	64

Table 4. Average levels of inputs

Input	FFS	Non-school
No. of irrigations	26	20
Urea (kg/feddan)	102	152
TSP (kg/feddan)	23	14
No. of sprays	5.5	13.1
No. of hand weedings	3.7	3.3

Table 5. Pesticides used

Chemical	Level of implementation (%)	
	FFS	Non-school
Less toxic:		
Malathion	22	36
Danitol 20	50	43
Sumicidin	44	7
Higher toxicity:		
Danitol S50	11	28
Folimat	50	64
Diazinon	22	31

Table 6 shows farmers' knowledge of and attitudes towards prevention methods. Generally, farmers show a good understanding of pest and disease prevention methods such as resistant varieties, host plant removal and use of repellant plants. Compared to results of field surveys and observation a few years back, there was a substantial improvement in farmers' understanding and attitudes towards these methods, not only by school farmers but by their neighbours as well. The change in attitudes and practices towards prevention methods is attributed to the effective extension and the educational FFSs.

Partial budget analysis was used to examine the profitability of the IPM package over that of traditional practices (Table 7). Costs were calculated in relation to components that vary between the two groups. School farmers incurred less than 1% higher cost than their neighbouring farmers. However, they spent 27% less on pest control. Their average yield, on the other hand, was 151% higher than that of neighbouring farmers. Net returns attributed to the package came out to be S£ 1,118,446 per feddan. This reflects the package superiority and cost effectiveness. Finally, marginal rate of return (MRR) was calculated and found to be 71,972%. This means that for every pound invested in the package, the farmer is expected to regain that pound plus an additional S£ 719.72. This in turn reflects the high profitability of the package.

Table 6. Farmers' knowledge of prevention methods

Item	% farmers FFS	% farmers Non-school
Resistant varieties to		
1. Leaf curl		
Strain B	71	20
Peto 86	29	80
2. Powdery mildew		
Strain B	0	50
Peto 86	0	50
Removal of host plants of pests		
1. Ramtouk, *Xanthium brasilicum*		
Leaf curl	11	17
Powdery mildew	77	50
Whitefly	11	33
2. Hambouk, *Abutilon pannosum*		
Leaf curl	33	–
Powdery mildew	67	–
Whitefly	0	–
3. Gobain, *Solanum dubium*		
Leaf curl	0	–
Powdery mildew	100	–
Whitefly	0	–
4. Molaita, *Sonchus oleraceus*		
Leaf curl	100	100
Powdery mildew	0	0
Whitefly	0	0
Planting repellant plants		
1. Coriander		
Leaf curl	8	0
Powdery mildew	0	0
Whitefly	92	100
2. Lubia		
Leaf curl	0	0
Powdery mildew	0	0
Whitefly	100	0

Conclusions

This report presents the results of the IPM pilot plots conducted in farmers' fields under the FFS approach. The approach emphasized teaching and demonstrating to vegetable farmers the strategies of IPM which are based on cultural and biological prevention methods and on the safe use and handling of pesticides. The results show a better understanding of the target group (school farmers) and their neighbours to the IPM strategy. The IPM package proved agronomic superiority and economic feasibility over farmers' traditional practices which are reflected in:

- A significant yield increase (151%) of the IPM option over traditional practices;
- Cost effective technologies (MRR =719.72);
- Reduction in number of sprays which implies less cost of protection and saving of foreign exchange;
- Good quality (less contaminated) products;
- Less pesticide load which implies fewer hazards to farmers, consumers and the environment.

Table 7. Partial budget of the tomato IPM package

Item	School	Non-school	Difference
Cost (S£/feddan)			
Irrigation	50,500	40,000	10,500
Hand weeding	10,500	9,131	1,369
Protection	81,281	110,737	-29,456
Harvesting	57,174	38,033	19,141
Cost that vary	199,455	197,901	1,554
Benefits (S£/feddan)			
Yield (kg/feddan)	10,723	4 ,273	6,450
Price (S£/kg)	180	180	180
Gross benefits	1,930,140	769,140	1,161,000
Net benefits	1,730,685	571,239	1,159,446
Intercrop returns	15,800	56,800	-41,000
Net returns	1,746,485	628,039	1,118,446
MRR (%)		71,972	

5 Integrated Pest Management in Wheat

An Improved Monitoring Procedure for the Wheat Aphid

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Wheat production received high priority during the early 1990s, but yields in the principal irrigated schemes south of Khartoum remained or stayed low, due to heat stress among other factors. Between 1988 and 1994 about 640,000 feddans yearly were planted with wheat in the Sudan; 520,000 feddans were planted yearly between 1991 and 1993 in Gezira scheme. Since the 1994/1995 season, wheat has been reduced to an average of 391,000 feddans per year in Gezira scheme (Table 1). Recently there has been a change of policy; cotton production is being regarded as more important again.

Table 1. Wheat production and number of sprayings against wheat aphid, Gezira scheme

Season	Area (feddan)	Av. no. sprays	Cost S£/feddan
1990/91	613,305.5	1.5	51.3
1991/92	532,813.5	2.15	113.0
1992/93	514,033.5	1.68	800
1993/94	522,940.25	0.91	1,169
1994/95	392,690.0	1.03	3,740
1995/96	390,777.0	0.52	7,506

Note: Cost of spraying includes cost of pesticide and spraying

High fluctuation in yields is a common phenomenon which is attributed to the duration and intensity of the winter cool period. Generally, long and cold winters are conducive to higher yields. This has been clearly demonstrated in the 1991/1992 season, with one of the coolest winters and the all time highest yield of 0.87 million tons, which brought the Sudan for the first time to the level of self-sufficiency.

Wheat may be regularly attacked by a wide range of insect pests, and grain losses as high as 30% were recorded. Potential wheat pests include aphids, termites, stemborers, leaf miners, rodents and birds (Schmutterer, 1969). To mitigate the damage effect of the wheat aphid, aerial control measures have been launched in the past to spray the crop with chemical insecticides against aphids, termites, rodents and birds using aircrafts in Gezira scheme.

Aphids, presently considered the main economic pest of wheat in the Sudan, exists as two species: the maize aphid (*Rhopalosiphum maidis* [Fitch]) and the greenbug (*Schizaphis graminum* [Rond.]). The former appears early in December and colonizes the heart of the plants in the seedling stages and leaves the crop at the onset of the booting stage. Its attack does not cause any economic loss. However, *S. graminum* is the more important species that attacks the crop in late December and persists to the end of the season. This species colonizes the leaves on both surfaces, and their feeding causes yellow-brown lesions on the leaves which under heavy infestations become dry and result in the death of the plants. *S. graminums* is responsible for most of the grain losses referred to and against which the annual chemical control measures are actually launched.

The economic threshold level (ETL) for wheat aphids was established at 35% plant infestation based on repeated field experiments in the 1970s (Sharaf Eldin, 1979a, b). First Metasystox and presently Ekatin and Pirimor are the recommended insecticides by the National Pests and Diseases Committee in the Sudan. An average of 1–2 aerial sprayings were applied between the 1990/1991 and 1993/1994 growing seasons at a cost that varied from 2.0% to 9.0% of the total production costs. Although this is reasonably low compared with that of cotton (which reached 35%), problems of over-reliance on insecticides and the possibility of cost escalation with the introduction of a free market economy are anticipated.

Considerable efforts were recently made through the FAO/ARC Integrated Pest Management Project and the Nile Valley Regional Programme on Cool-Season Food Legumes and Wheat, both financed by the government of the Netherlands to develop and implement an IPM strategy on irrigated wheat in the Sudan. The following components of the IPM have been studied through on-station and on-farm research:

- Improvement of the aphids monitoring system based on more intensive scouting and a modified ETL for decision making on insecticide spraying;

- Role of natural enemies in reducing outbreaks of wheat aphids;
- Potential value and stability of wheat varietal resistance to aphids;
- Use of more selective insecticides.

The FAO/ARC IPM Project has been primarily responsible for the two first groups of activities.

Modification of Action Threshold for Wheat Aphid Control

In order to develop a more realistic action threshold that incorporates the density of aphids in addition to the number of plants infested, four field experiments were conducted between the 1993 and 1996 seasons. C.v. Debeira was planted always at the Gezira experimental farm at the end of November. Experimental design was completely randomized block with six treatments and six replications.

The "Degree of Infestation" method was used to record the infestation level and was calculated by multiplying the number of plants infested in a sample of 100 tillers (= percent plant infested) by the category (class) of infestation. An aphid population density was expressed in three categories:

Category 1—infestation of 1-9 aphids/tiller
Category 2—10-29 aphids/tiller
Category 3—more than 30 aphids/tiller

Thus, the degree of infestation (DOI) will be:

DOI = % plants infested x category of infestation.

Six treatments represented the following infestation levels:

(1) 50 DOI; (2) 100 DOI; (3) 150 DOI; (4) 200 DOI; (5) ETL equal to the presently recommended 35% infested plants and (6) untreated control.

Observations were carried out twice a week in each plot (30 m²), and when the established DOI was reached in respective plots, they were treated with Ekatin at the rate of 0.25 l/feddan (Table 2). Yields were recorded for each treatment, and data were statistically analyzed using Turkey (MSD) pair wise comparison method.

Some differences in the average yield between sprayed and unsprayed plots were observed in the 1993/1994 experiment. Untreated plots produced the lowest yield, but the plots treated with maximal number of 2.7 sprayings did not produce the highest maximal yield (Table 3). Turkey (MSD) pair wise comparison did not show significant differences between treatments.

In the 1994/1995 season, two sprays were applied on plots under the treatment—35% infested plants and 50 DOI. The yield increase varied from 107 to 132% in two experiments between untreated control and sprayed plots. One spray applied at the end of February 1995 did not increase yield in one experiment, but increased yield between 108 and 117% in the second experiment. The differences were statistically insignificant.

Two experiments planted in the 1995/1996 growing season confirmed the previous two years' observations that there is no direct correlation between number of sprayings and yield. The yield increase varied between 105 and 108% in sprayed plots of the A experiment and only 108% in the plots sprayed two times at the 50 DOI degree of infestation (Table 3).

Unsprayed treatment of the 200 DOI degree produced higher yield (16.7 kg/plot) than control (15.7 kg/plot) in the A experiment. The 150 degree treatment of the B experiment yielded only an average 14.4 kg/plot in comparison to 15.9 kg/plot of the untreated control (Table 3). The differences were again statistically insignificant.

The three-year on-station experiments have shown that insecticide spraying increased yield only in 36% of treatments when the sprayed plots are compared with unsprayed plots (e.g., untreated control and some untreated plots of 200 DOI). In most cases, a substantial yield increase was realized with treatments where Action Threshold between 100 and 150 DOI was

Table 2. Wheat infestation treated with Ekatin at various levels of infestation and number of plots sprayed (x), Gezira Research Farm, ARC 1993/1994

	Dates							
Treatment	2 Jan.	13 Jan.	19 Jan.	22 Jan.	26 Jan.	5 Feb.	23 Feb.	2 Mar.
35% ETL[1]	18.7	58.6 (6)	4.7	29.3 (1)	45.3 (4)	44.0 (4)	19.3	35.0
50 degree[2]	16.2	65.3 (4)	22.6 (1)	40.0 (1)	64.6 (4)	52.6	28.0	17.3
100 degree	14.4	68.5	103.3 (2)	73.3 (2)	80.6 (2)	88.6 (1)	27.3	25.3
150 degree	12.8	69.8	97.3	142.6 (2)	138.0 (3)	72.6	29.3	20.0
200 degree	12.2	55.2	100.6	136.0	158.6	142.6 (2)	46.6	31.3
Untreated control	16.5	53.5	92.7	126.7	186.7	181.3	36.0	16.0

(1) Insecticide treatments at the presently used ETL at 35% of infested plants regardless of the aphid population density;
(2) DOI calculated as the product of the % of infested plants by the average category of aphid density on infested plant.

used (Table 3), but even in this case, only approximately 40% of fields showed a yield increase.

In summary, the results of the three-year experiments confirmed that there is no clear correlation between the number of insecticide sprayings and yield increase. Some other factors have modified the effect of insecticide treatments on wheat yield.

A Modified Monitoring Procedure

The decision for spraying is presently based on the recommendation of the Pests and Diseases Committee that 10–15% of the area grown in each block is sampled at two stops on each field and 300–600 plants are inspected at each stop. Infested plants are counted without reference to the intensity of aphid infestation. Data are compiled and expressed in percentage of infested plants. A decision for spraying is made if the infestation reaches the recommended ETL of 35% infested tillers. The chemical treatment is carried out on the whole block of 2,000–10,000 feddans. There is wide speculation between specialists that this methodology gives an exaggerated estimate of the potential damage of wheat by aphids.

A new decision-making methodology has been tested based on revised ETLs and occurrence of natural enemies. The improved monitoring system included:

- Scouting of each "number" individually;
- Categorizing infestation intensity (single aphid or small colonies to nine aphid); medium size colonies of 10–29 aphids and large colonies above 30 aphids as 1-3 classes);
- Occurrence of natural enemies (predators; *Chrysoperla*; coccinellids; syrphids and spiders).

Two experimental sites at the Abdel Hakam block of the Central Group in Gezira scheme and the Um Shadida block of the Tahameed Group in Managil were selected for large-scale field experiments. Scouting teams in both areas were trained to recognize various developmental stages of major groups of natural enemies occurring on wheat.

The 1993/1994 Growing Season

The area under wheat was about 5,050 feddans (2,463 ha) in Tahameed in the 1993/1994 growing season. Preparation of land and sowing date was according to the recommendations of the ARC. Fertilizer was applied in the middle of October; the variety of seed used was Debeira.

The area selected for the experiment was 1,301.5 feddans (635 ha). The general survey started in the second week of December 1993; the infestation rate was low at that time. More intensive scouting started on 5 January 1994. Fifteen numbers within the area of 1,301.5 feddans and five units per number were selected for counting. The mean infestation was 32.5 aphids and 1.2 natural enemies/100 plants at the first survey. The rate of infestation was 32.5% with 28 natural enemies (predators)/100 tillers on 20 January 1994. On 24 January, 534 feddans (41% of total scouting area) showed a mean aphid infestation of 37.03% and 3.0 natural enemies per 100 tillers, and this area was sprayed with Pirimor, at a dose of 0.11 kg/feddan on 28 January (Table 4). After spraying, an average of 0.43 aphids and 0.7 natural enemies (predators) per tiller were observed. It should be emphasized that at the time of spraying, a significant reduction of wheat aphid below ETL took place in unsprayed fields, probably due to occurrence of natural enemies.

Table 3. Effect of insecticide sprayings determined by new aphid action thresholds on wheat yield, 1993–1996, Gezira

Treatment	Yield in kg/plot									
	1993/1994		1994/1995 A		1994/1995 B		1995/1996 A		1995/1996 B	
35% infestation as ETL	7.4	(2.7)[2]	11.0	(2)	11.4	(1)	17.0	(2)	15.4	(2)
50 degree[1]	8.9	(2.5)	9.8	(2)	13.2	(2)	16.6	(2)	17.1	(2)
100 degree	8.1	(1.1)	9.3	(0)	10.9	(1)	16.7	(1)	15.4	(1)
150 degree	8.8	(0.8)	8.3	(0)	11.8	(1)	16.6	(1)	14.4	(1)
200 degree	6.6	(0.3)	8.6	(0)	11.8	(1)	16.7	(0)	15.1	(0)
Untreated control	6.04	(0)	10.3	(0)	10.1	(0)	15.7	(0)	15.9	(0)

[1] DOI is calculated by multiplying % of infested plants by average category (class) of infestation.
Categories: 1— 1–9 aphids/plant
2—10–29 aphids/plant
3— more than 30 aphids/plant
[2] Number in brackets indicates the average number of sprayings per treatment.

Table 4. Effect of improved monitoring procedure on wheat yield in Tahameed Group, 1993/1994, Gezira scheme

Treatment	Feddans	Sprayed feddans	Rate of infest.before spray	Mean no. of sprays	Pesticide used	Yield (sacks/feddan) Average	Sprayed areas	Unsprayed areas
Area under experiment	1,301.5	534	37.04	0.41	Pirimor	3.87	4.2	3.7
Control	3,748.5	3,748.5	31.90	1.00	Pirimor	3.81	3.81	–

Savings on spraying on 59% of area under the improved scouting procedure.

Savings on pesticides should be counted on 59% of the total area under improved scouting procedure.

In the Abdel Hakam block of the Centre Group with a total area of 3,950 feddans under wheat; 1,185 feddans were selected for the experiment on new scouting technique. Aphid population density was evaluated in three categories, and natural enemies were counted. On 23 January 1994, all experimental numbers showed high aphid population density and were sprayed on 24 January 1994 with Pirimor, dose 0.1 kg/feddan. Decision on spraying was made and based on the present recommendation of 35% infested plants. The majority of the plants showed first category infestation (1–9 aphid/tiller).

Regular counting of wheat aphid and their natural enemies in the 1993/1994 growing season showed that considerable reduction of cotton insecticide aerial spraying in the Gezira and Rahad schemes during the last two years already caused a significant increase of natural enemies migrating into wheat fields early in the season (middle of December 1993). Numerous adults, eggs and larvae of *Chrysoperla*, coccinellids (mainly *Cheilomenes*) and syrphids were observed already on wheat in 4–5 leaf stage. Their numbers increased during the growing season.

The 1994/1995 Growing Season

Analysis of wheat infestation by aphid in the 1994/1995 season showed that heavy infestation of wheat by aphid started early in December 1994 in West Shair and North Group—Kab Elgidad block of North Group (49.8% plant infestation) of the Gezira scheme. In other groups, high aphid infestation occurred late in the third week of January and reached its peak in February. The East Group had the lowest pest level, not exceeding 2%. Spraying started in January and peaked in February following the late infestation and variation in crop development. The average number of sprays was 1.03 for the 1994/1995 season in Gezira scheme (Table 1) and the decision for chemical control was based on the current recommendations (35% of infested tillers).

Two large-scale experiments on the development of improved monitoring system were repeated in 1994/1995 on 1,132 feddans in the Abdel Hakam block, Central Group and 1,301 feddans in the Um Shadida block, Tahameed Group. All experimental numbers in Um Shadida were sprayed when the infestation reached 35% (Table 5). A careful analysis of infestation classes showed that 22.8% of the plants were infested only by category 1, 11.0% by category 2, and 4.2% by category 3 when the decision for spraying was made.

In Abdel Hakam, a gradual increase of infestation was observed from January onwards, with a peak on the fifth week and then a decline on the seventh week after planting. An increase in aphid population took place on the eighth week on unsprayed fields. Based on the new monitoring technique, 64.4% of the pilot area was sprayed, and savings on spraying should be calculated for 35% of total area under wheat.

Natural enemies followed the same trend, i.e., a gradual build-up until the fourth week, then a reduction following chemical spraying and again rapid increase during the late increase of aphid population. After spraying, 67% *Chrysoperla* and 28% syrphid larvae were recorded in comparison to the pre-spraying period, indicating that green lacewing were less susceptible to the chemical.

Comparison of yield of the pilot fields showed that the improved monitoring technique increased yield only 103.5% in the Um Shadida block (from 5.49 to 5.68 sacks/feddan) and 113% in the Abdel Hakam block (from 6.01 to 6.79 sacks/feddan) (Table 5).

The analysis of yields from individual fields in selected numbers showed significant differences. The differences are probably related to the husbandry practices of individual farmers. To identify relations between various cultural practices, aphid infestation and yield, a Farmer Field School approach was recommended to start in the 1995/1996 growing season.

The 1995/1996 Growing Season

In Abdel Hakam block, the whole experimental area of 838 feddans was left unsprayed in the 1995/1996 season, in comparison to 29% of

Table 5. Average yield per feddan for the different treatments, 1994/1995				
			Yield	
Treatment	Sprayed	Area (ha)	Av. sacks/ feddan	Kg/ha
Um Shadida Block (Tahameed Group)				
Improved	+	1,301.5	5.68	1,352
Traditional	+	1,189	5.49	1,307
Abdel Hakam Block (Central Group)				
Improved	+	729	6.79	1,616
Improved	–	403	5.68	1,352
Traditional	+	66	5.49	1,307

1 sack = 100 kg

unsprayed area under traditional scouting procedure (Table 6).

In the Um Shadida block of Tahameed Group (Managil), only 13% under new monitoring procedure was left unsprayed (total area under experiment —1,337 feddans). The average yield for the whole experimental area was 7.69 sacks/ feddan; from the sprayed fields, yield was 7.7 sacks/feddan and from unsprayed fields, yield was 7.53. The yield from the whole block under traditional scouting procedure was equal to 6.58 sacks/feddan. The higher yield and savings on insecticide spraying can justify an increasing cost of more intensive scouting of wheat aphid and natural enemies. The lower aphid infestation on wheat can be related to weather conditions or higher occurrence of natural enemies in the 1995/1996 growing season.

The Role of Natural Enemies in the Wheat Ecosystem

Intensive field observations on the role of natural enemies in the wheat ecosystem were initiated in the 1994/ 1995 season. Ten field numbers in Block no. 14 in central Gezira were weekly monitored for aphid infestation (100 plants at random/field), and observed beneficial insects were noted. In addition, three sweepnet samples per field were taken each week, one sample consisting of 15 sweeps. Generally, aphid populations were building up towards the end of January in most fields, reaching a peak around early February and declining afterwards.

Different locations show different numbers of natural enemies. This means that the importance of certain groups of enemies can vary from one location to another, and possibly also from one year to another. For example, Munir (1993a, b) mentions that coccinellid are the major aphid predators in wheat. This is probably true for the fields at ARC and maybe also for Tahameed, Managil, but another picture of predator numbers emerged at Block 14. At the end of December, *Chrysoperla*, Nabid bugs and spiders were dominant. During the month of January, syrphids (hover fly, mostly *Ischiodon aegyptius)* became number one, with up to seven flies per sweepnet sample; however, for some fields spider were the dominant group, in particular later that month. Towards the end of January, *Chrysoperla* also gained importance, becoming the most frequently captured predator in February, with up to six specimens per sample, both adults and larvae. That month spiders came on a strong second place; syrphids were third. Nabidae (i.e. *Tropiconabis capsiformis*) were still common in January, but less so later in the season. During crop maturing, spider (over seven per sample) and coccinellid (mostly *Hippodamia variegata*; more than nine per sample in an unsprayed field) became the predominant groups, with hover fly still in third place. Before harvest time, melyrid beetle also appeared.

Comparison of six, once-sprayed fields (mostly at mid-February) and three unsprayed fields showed rather similar numbers of the major predator groups of lacewings, hover flies and Nabidae before spraying; only spiders were nearly twice as common in the unsprayed fields. However, the latter group recovered in the sprayed plots towards the end of the season, then showing similar numbers for both unsprayed and sprayed fields. As could be expected, overall natural enemy numbers in unsprayed fields were higher (though not much), and in those fields there was a negative correlation between average

Table 6. Average yield per feddan, 1995/1996				
			Yield	
Treatment	Sprayed	Area (feddans)	Sacks/ feddan	Kg/ha
Um Shadida Block (Tahameed Group)				
Improved	+	1,160	7.71	1,835
	–	177	7.53	1,792
Traditional	+	1,369	6.58	1,566
	–	–	–	–
Abdel Hakam Block (Central Group)				
Improved	+	–		
	–	838	7.58	1,804
Farmer Field School	–	90	10.78	2,566
Traditional	+	156	8.81	2,097
	–	66	6.75	1,607

degree of aphid infestation and numbers of beneficial insects (Tables 7 and 8).

Regarding yield, the average production in the unsprayed plots was 5.9 bags/feddan compared to 6.8 bags in the sprayed fields (Table 7). This means 13% more yield with spraying, but it seems doubtful whether this can cover the cost of spraying. Thus, with the aphid infestation levels of the last season, it seems more economical to use the natural enemies that are present.

If the Gezira Central Block is compared with fields observed at ARC and in Managil, in wheat fields at the last two locations the ladybird, *Hippodamia* appeared as the predominant predator earlier in February, while *Cheilomenes*, another coccinellid, was also present during January in Managil. As far as aphid parasitoids are concerned, one main species, identified as *Aphelinus varipes* was found. The first mummified aphid were observed during the first half of January and they became a little more common in February; however, they never were very abundant, probably due to hyperparasitoids (Encyrtidae and Charipidae). Thus, they seem less important than predators.

More research is needed to establish the precise role of aphid natural enemies. In particular, observations are needed on the actual aphid predation rate of major predator groups. Spider appear to be one group, the importance of which so far has been underestimated. They were the predominant predators in some fields at certain times. Spiders are predacious during all development stages. They do not have stages that are not predacious, as is the case with adult lacewing and hover fly. In addition, actual spider numbers are likely higher since some species are nocturnal, hiding in the soil during the day, and so these are not caught with the sweepnet. Considering these two factors, it could be stated that spiders are the most abundant predator group; however, it is not certain yet whether Chrysopid and Syrphid larvae are as easily caught in the sweepnet as spiders; they may stick more to the plants.

Together with the probably better known Chrysopid, spider and (less so?) Nabid bug are the groups that are most important in preventing or slowing down the build-up of aphid populations towards the end of January. With low aphid numbers, effective predators need to be highly mobile, as most spider are. Once large aphid colonies have been established, the groups of Syrphid and Coccinellid (when present) will be most effective, considering that parasitoids are not abundant.

For the rest, it appears that monitoring and sampling should be improved, since there were many inconsistencies between various data on

Table 7. Comparison of the degree of aphid infestation (DOI), numbers of main natural enemies (NEs; Chrysopidae, Syrphidae, Coccinellidae, Nabidae and spiders) and yield in sprayed and unsprayed wheat fields, 1994/1995, central Gezira

Field	Spray date	DOI peaks & date	DOI average (season)	NE average (season)	NE peaks & date	Average yield (bags/feddan)
A/El Hakam 5	–	51, Jan. 31 84, Feb. 28	32	9	13, Feb. 14 17, Mar. 7	6.4
A/Hafiz E 12	–	85, Feb. 9 105, Feb. 16	38	9	11, Jan. 26 19, Feb. 2	5.6
Beika 13	–	163, Feb. 14 109, Feb. 28	47	7	12, Jan. 17 13, Feb. 28	5.8
Average unsprayed fields:			38.8	8.4		**5.9**
A/Hafiz E 3	13 Feb.	99, Jan. 19 81, Feb. 9	43	10	15, Jan. 19 22, Feb. 2 12, Feb. 23	5.0
A/Hafiz E 8	13 Feb.	119, Feb. 9 184, Feb. 16	45	6	9, Feb. 2 10, Feb. 23	5.7
A/Hafiz W 3	14 Feb.	80, Feb. 9 74, Feb. 16	28	7	14, Jan. 19 14, Feb. 2 12, Feb. 16	6.9
Beika 2	13 Feb.	108, Feb. 7 62, Feb. 21	41	8	13, Jan. 9 19, Feb. 28	8.8
Beika 4	13 Feb.	114, Jan. 31 95, Feb. 14	56	6	12, Jan. 31 4, Feb. 14	6.8
Beika 9	31 January	103, Jan. 31 141, Feb. 14 167, Feb. 28	53	9	16, Jan. 31 22, Feb. 28	7.7
Average sprayed fields:			44.4	7.5		**6.8**

Table 8. Predator numbers in wheat during February 1995; comparison on unsprayed and sprayed fields at central Gezira

		Chrysoperla		Syrphids			Coccinellids				Sampling	
Field No.	Spray date	Larva	Adult	Larva	Adult	Spiders	Larva	Adult	Nabids	Total	Dates	No.
Early February, unsprayed fields:												
A/Hafiz E12	–	–	38	3	10	19	–	–	2	72	2.2 + 9.2	6
A/Elhakam 5	–	11	8	–	4	22	–	–	–	45	31.1+7.2	6
Beika13	–	3	15	–	7	15	–	–	1	41	31.1+7.2	6
Average/sample		0.8	3.4	0.2	1.2	3.1	–	–	0.2	8.8		
Late February, unsprayed fields:												
A/Hafiz E12	–	13	18	–	5	20	1	–	2	59	16 + 23.2	6
A/Elhakam 5	–	8	18	1	7	35	–	–	3	72	14 + 21.2	6
Beika 13	–	8	20	–	7	19	1	–	–	55	14 + 21.2	6
Average/sample		1.6	3.1	0.1	1.1	4.1	0.1	–	0.3	10.3		
Early February, fields to be sprayed:												
A/Hafiz E8	–	2	12	2	14	10	–	–	–	40	2 + 9.2	6
A/Hafiz E3	–	6	20	2	8	33	–	–	3	72	2 + 9.2	6
A/Hafiz W3	–	2	24	2	11	6	–	–	6	51	2 + 9.2	6
Average/sample		0.6	3.1	0.3	1.8	2.7	–	–	0.5	9.1		
Beika 2	–	3	–	1	–	3	–	1	–	8	7.2 only	3
Beika 4	–	–	16	–	17	14	4	3	–	54	31.1, 7.2	6
Beika 9	–	2	24	–	27	9	–	–	3	65	24 + 31.1	6
Average/sample		0.3	2.7	0.1	2.9	1.7	0.3	0 .3	0 .2	8.5		
Late February, fields after spraying												
A/Hafiz E8	13.2	9	9	–	4	25	1	1	–	49	16 + 23.2	6
A/Hafiz E3	13.2	5	13	–	11	19	–	2	1	51	16 + 23.2	6
A/Hafiz W3	14.2	7	14	–	4	26	–	–	1	52	16–23.2	6
Average/sample:		1.2	2.0	–	1.1	3.9	0.1	0 .2	0.1	8.4		
Beika 2	13.2	6	15	–	–	10	–	–	–	31	21.2 only	3
Beika 4	13.2	–	3	–	–	8	–	–	1	12	14.2 only	3
Beika 9	31.1	6	5	1	1	5	–	–	–	18	7 + 14.2	6
Average/sample		1.0	1.9	0.1	0.1	1.9	–	–	0.1	5.1		

aphid infestation, natural enemy numbers, decision for and efficacy of spraying and yield. Some of these inconsistencies will be due to the fact that samples were not always taken in the same field area because of irrigation. In addition to that, sampling usually occurs in just a corner of the field. The proper use of a sweepnet will definitely be a more complete and reliable method of sampling predators than visual counting per plant. It is suggested that samples should be more evenly distributed over the field, that weather conditions (wind, dew, cold) and time of the day are taken into account and that technicians should be better trained on recognition of less familiar groups such as true bug, spider and parasitoids. For the monitoring of aphid, it seems more practical to only count the top three leaves per tiller (as many technicians do anyway).

During the 1995/1996 growing season, more than twice the number of beneficial insects were observed per 100 wheat tillers in unsprayed fields in comparison with the previous season, while the average degree of aphid infestation was less than half of that of 1994/1995. However, sweepnet sampling revealed less differences. The major natural enemies of the wheat aphid in central Gezira were identified as:

- Green lacewings (*Chrysoperla*): They are observed during almost the whole wheat season in large numbers.
- Hover flies (Syrphid): These are specialist aphid killers which are particularly important when aphid populations become high at the end of January and early February.
- Spiders: They are, in some fields, the most common predators captured by sweepnet; laboratory experiments indicate that the common crab spider can kill an average of 10–15 aphids per day.

- True bugs (*Campylomma* and Nabid): Their importance seems to vary; they were the most numerous group captured by sweepnet in 1995/1996 (mostly *Campylomma*), but their impact is less clear. In addition, they are often not observed with visual countings.
- Beetles, mainly Melyrid and Coccinellids: They tend to appear rather late in the season, when aphid control is less relevant. However, in other locations they can reportedly play an important role.

Aphid parasitoids apparently play a very minor role in aphid control, possibly due to their own natural enemies, mostly two hyper-parasitoids. Lacewings and spiders seem to be the most important predators to prevent or slow down a rise in aphid populations. Hover flies, beetles and, less so, true bugs are probably more important once aphids appear in larger colonies. Wheat fields with relatively low aphid numbers were found to have an average of 28 predators per 100 wheat tillers, while during peaks more than one predator for every two plants could be observed (counting all stages of predators).

Discussion and Conclusions

In the 1970s, an economic threshold level (ETL) for wheat aphid was developed through repeated field experiments (Sharaf Eldin, 1979 a, b). However, already at that time some problems had been noticed in the interpretation of data where 1–2 sprays with Ekatin E.C did not increase yield significantly (Table 10). Sharaf Eldin and Dabrowski (1994), realizing some deficiencies of presently used values, advocated for critical evaluation of the presently used monitoring procedure and decision making for spraying. They recommended to consider occurrence of natural enemies in wheat in decision making for insecticide spraying on large areas. Both small-scale field experiments in the Gezira Research Farm and large-scale experiments were undertaken since the 1993/1994 season on their initiative.

Because of strict definitions on developing economic thresholds for pests based on physiological, biological and modelling methodologies, this discussion uses an Action Threshold (AT) terminology. An *action threshold* is defined here as the pest density that warrants the initiation of a control strategy. The term "action threshold" is used here instead of "economic threshold" simply because it seems less ambiguous. When the pest density or damage reaches the value for the AT then action is necessary to prevent further increases that will lead to an economic loss. The AT is dynamic, varying according to the crop cultivar, age, weather, plant density and fertilizer levels, among other things. Such a large number of variables makes it extremely difficult to obtain economic thresholds that are generally applicable.

It is known that establishing ATs is especially difficult where natural enemies are involved in population regulation or where damage can be caused at different stages of plant growth. Cost of control, market value of harvested product and the effectiveness of control are also put under consideration.

Small plot experiments on establishing economic thresholds for wheat aphid have shown their limitations by exposing unpredictable relations between number of insecticide treatments and wheat yield. The differences in plant stand, water access, bird damage and other factors could contribute to observed variability. Large-scale field experiments reveal that the present ETL (35% of plants infested with aphids) is too low and does not consider the intensity of infestation by individual aphids, small or large colonies. Because of large variability in wheat infestation by single aphid related to prevailing winds,it is recommended that farmers modify the presently used AT of 35% of plants infested by aphid colonies (not single aphids), which is equivalent to a DOI of 70–100.

Occurrence of natural enemies should be included in decision making on wheat spraying as follows (Table 9): Spray if 35% tillers show infestation with large aphid colonies (do not count single aphids and small colonies) and in the absence of predators (spiders, syrphid larvae, *Chrysoperla*, coccinellids); however, if 35% of the plants show heavy infestation with aphid in the presence of approximately 5 predators per 100 plants, wait until next counting in 3 days' time.

Significant differences in yields between individual fields in the same number indicate differences in husbandry practices used by individual farmers and/or some agronomic problems related to watering (problems with levelling, stagnant water, etc.). Establishing FFSs for wheat growers should improve management of wheat fields by farmers without increasing inputs.

Using the 1994/1995 data, it is possible to calculate the potential benefits of introducing the improved scouting techniques as follows:

- Reduction of area treated by insecticides—35%
- Total area under wheat production—392,690 feddans in Gezira scheme
- Cost of insecticide and treatment—3,740 S£/feddan
- Potential savings—514,029,340 S£ in the 1994/1995 season.

Recommended methodology of decision making on spraying against wheat aphids should include the following steps:

1. Scout each "number" individually instead of making decisions based on present scouting procedure on spraying for the whole block;

Table 9. Preliminary suggestions for threshold levels of aphid predators in wheat based on visual counting of 100 plants (Note: The figures mentioned give consideration to the fact that the average observer will see far fewer insects than actually present)

DOI	Approx. equivalent in % plants (heavily) infested	Number of predators* per 100 tillers	Action
DOI < 50	< 25	not (very) relevant, but should be near 5	No action
50 < DOI < 100	25 < 50	0–2	Spray
		3–5	Make an other count in 3 days [1]
		5–10	Another count in 5 days [1]
		Over 10	Another count in 7 days
100 < DOI < 150	50 < 75	Less than 5:	Spray
		5–10	Another count in 3 days
		10–15	Another count in 5 days
		Over 15	Another count in 7 days
DOI > 150	> 75	Less than 10:	Spray
		10–15	Another count in 3 days [1]
		Over 15:	Another count in 5 days
			Spray if aphid infestation not lower

* Predators include: *Chrysoperla* (eggs, larvae), Syrphids (eggs, larvae), spiders, Melyrid beetles, Nabid or *Campylomma* bugs, Coccinellids (larvae, adults).

(1) Spray if aphid inféstation is not lower AND if predator numbers are not higher.

Table 10. The economic threshold level for spraying against wheat aphids; no. of aphids/100 plants; data transformed to (X+1) (after Sharif Eldin, 1979b)

Treatment	Date of spray	No. of aphids	Yield	
			Tons/feddan	in % to control
5% infestation (1 spray)	12 January	5.93	0.688	99.6
5% infestation (2 sprays)	12 + 24 January	3.51	0.692	100.1
20% infestation (1 spray)	17 January	7.00	0.716	103.6
35% infestation (1 spray)	21 January	11.12	0.741	107.2
50% infestation (1 spray)	24 January	21.91	0.632	91.5
65% infestation (1 spray)	28 January	29.87	0.646	93.5
80% infestation (1 spray	31 January	32.61	0.679	98.3
Control (unsprayed)		34.05	0.691	100.0
S.E. ±		(1.41)	(0.032)	

2. Include only aphid colonies (not individual aphids) in calculating the percentage of infestation for Action Threshold (AT) (35% infested wheat plants with *aphid colonies*);
3. Considering the occurrence of natural enemies in decision making on spraying. Other options for decision making are given in Table 8–10.
4. Include farmers in decision making and training them in Farmer Field School on production and protection requirements.

A low average increase of yield observed in large-scale field experiments on wheat aphid control in the Gezira and Managil (Fig.1) confirmed the data collected in the USA and Europe.

Attainable yield, crop development stage and timing and intensity of infestation were of major importance in explaining variation in damage, e.g., in the Netherlands, only 30% of chemical applications against *Sitobion* on average were found to be cost-effective. The sprayings were carried out according to the approved damage threshold representing pest intensities at which expected costs of control just exceed expected costs of no control (yield loss) (Rossing, 1993). It is strongly recommended that the site specific and actual field information on pest intensity and cost-benefit analysis of decision alternatives will be used to critically review decisions on pesticide application on wheat against wheat aphids in Gezira scheme.

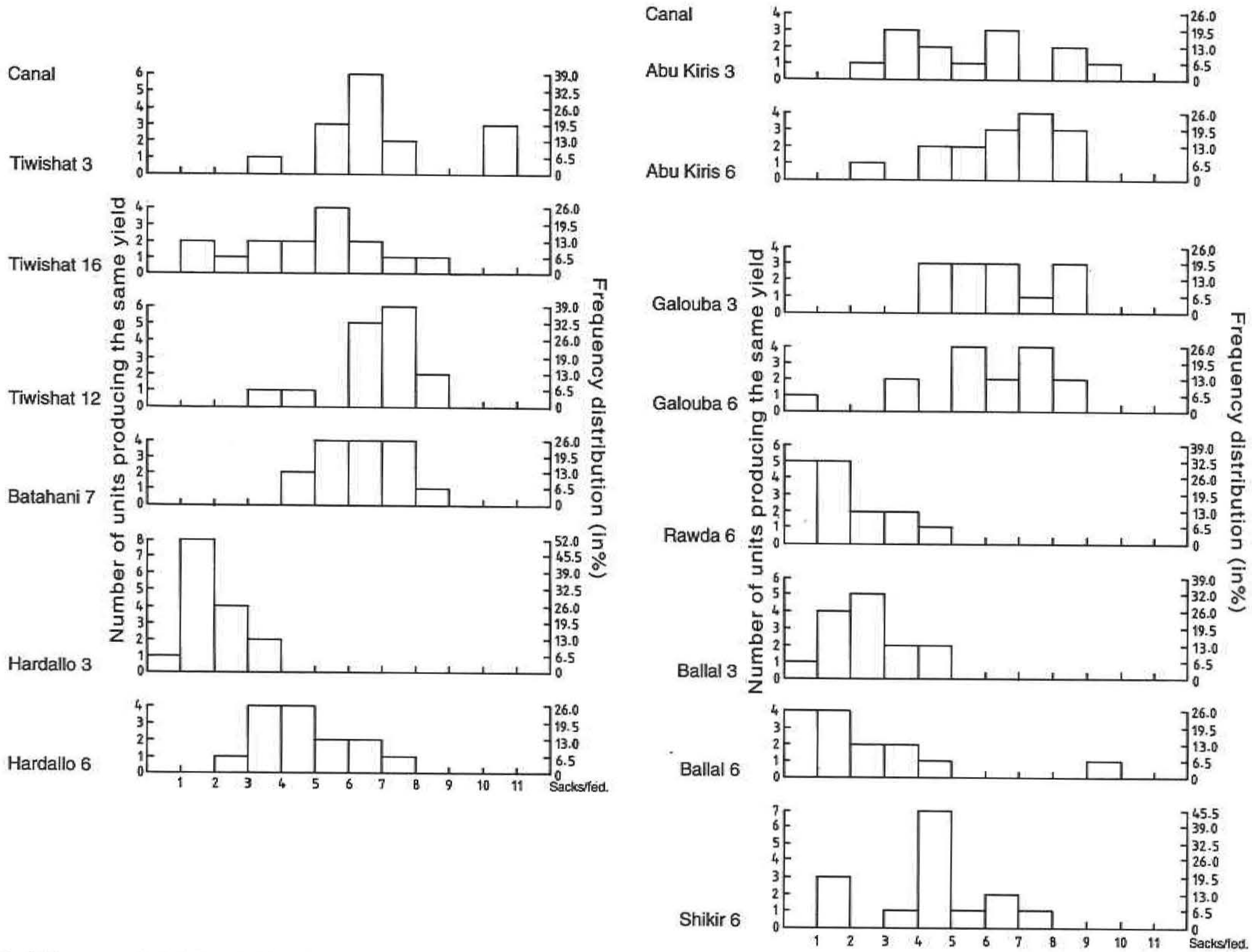

Fig. 1. Frequency distribution of wheat yield (number of sacks/feddan) between 14 plots (units) grown by individual farmers in the same field (cotton number) of 90 feddans; Tahameed block, Managil; 1994/1995

Curriculum Development for Wheat Farmer Field Schools in Gezira

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In the Sudan, wheat was traditionally grown since early history in the northern part of the country. The areas were restricted to the banks of the Nile between latitudes 17 and 22°N. Irrigation water is supplied by pumping. With the increasing demand for wheat, expansion of the area was more feasible towards the southerly large plains of the centre and east. These plains, which extend between latitudes 13 and 15°N, are irrigated by water raised by dams and delivered by gravity flow. These new areas constitute between 70 and 80% of the total area of wheat in the Sudan. In addition to being warmer and having a shorter season compared to the traditional areas, they have other constraints that lead to low yields (Ageeb, 1993).

The Gezira scheme contributes between 55 and 78% of the domestic wheat production (Hassan and Faki, 1993). Wheat in Gezira is grown in a four-course rotation, preceded by cotton and followed by a combination of groundnuts and sorghum and then fallow. The farmer of the scheme is allotted a tenancy of 20 feddans (8.4 ha), divided every year into four plots of 5 feddans (2.1 ha). Land allocation to wheat and cotton is decided by the Gezira administration. The overall cropping intensity of the scheme is based on water supply.

The basic farming unit is the *hawasha* which usually varies in size from 5 to 10 feddans. Each *hawasha* is subdivided into irrigation basins called *angayas* by ridges referred to as *tagnets* and small watering channels known as *gadwals*. The *hawashas* are fed by small irrigation channels known as *Abu Sitta* which in turn are supplied with water from the larger Abu Ishareen irrigation channels which run down the length of the "number". Farmers in the different schemes have between 3 to 25 *hawashas* located in different "numbers" depending on the crop rotation followed. For the convenience of irrigation and cultivation, the *hawashas* are grouped into "number" of approximately 90 feddans and each "number" is used for a single crop. A typical "number" may be 1,350 m long by 280 m wide.

Due to silt accumulation in the fields near the canals, the irrigation of these parts of the fields has become difficult. It is estimated that about 12% of the Gezira cultivable area can no longer be properly irrigated. Precision land levelling is of high priority.

It is estimated that approximately 15% of the registered tenants in Gezira are absentee farmers, holding jobs in the city or involved in self-employment occupations. Sub-leasing of the land by the official tenant to one or several others and various forms of sharecropping, mainly for the production of groundnuts and sorghum, are common. In the future, it might become legal to pass on tenancy rights from one farmer to another.

Yield Variability in Gezira

In Gezira the constraints for wheat production have been studied, and the major factors involved were identified (Hassan and Ageeb, 1992; Hassan and Faki, 1993). The large variation in yield is mainly due to the variation in those factors. The factors are environmental, i.e., temperature and soil; managerial, i.e., seed quality, tillage, sowing date, weeds management, fertilizer, irrigation and harvesting date; and biological, i.e., pests and diseases. High temperatures have the most adverse effect on yield. They determine the sowing date and lead to yield variations within and between seasons. High and significant correlation (0.87) was found between wheat yield and mean temperature of December, January and February (Hassan and Faki, 1993).

The soil of Gezira is fairly uniform, heavy cracking vertisols. It is alkaline (pH 8.5), heavy, prone to water logging and needs certain operations for good land preparation. It is deficient in nitrogen (300 ppm) and available phosphorus (4–6 ppm). In spite of the high uniformity, differences in soils are found to be associated with variation in yield with location. Studies in 1992/1993 showed that high yielding blocks had yield advantages of 1.02 and 1.7 tons/ha over medium and low yielding ones. Similarly, in 1993/1994 significant yield gaps of 1.09 and 0.59 tons/ha were found between demonstration plots and low and medium yielding blocks, respectively. In the same season, high yielding blocks were significantly superior in yield by 0.72 and 0.85 tons/ha to medium and low yielding blocks.

The total yield gap between high and low yielding farmers was found to be 2.46 tons/ha. This gap is caused by locational and management factors. A study on the effect of individual factors, conducted in 1993/1994 by the Nile Valley Programme revealed the importance of tillage (0.306 tons/ha), preceding crop (0.334 tons/ha), urea application (0.139 tons/ha), location (0.283 tons/ha), Sudan grass occurrence (0.24 tons/ha) and irrigation quality by (0.468 tons/ha). The first important management factor is related to crop establishment which is a major determinant of yield. Crop establishment is affected by land preparation, including field levelling, seed placement and the first irrigation Hassan and Ageeb, 1992; Hassan and Fahi, 1993).

The second factor is the sowing date. Due to bottleneck in land preparation and irrigation water, farmers tend to plant late. Sowing time is found to be more critical in Gezira than in Hudeiba (North) or New Halfa (East) (Ibrahim, 1995). With the new cultivars, it was recommended to plant wheat in Gezira in November.

The third factor associated with yield variation is the fertilization of the crop. The general recommendation in Gezira is to apply 86 kg N/ha and 43 kg P/ha in the early phases of crop growth (sowing or tillering). The best results are obtained when P is applied with the seed or incorporated in the soil and N can be broadcasted. High responses to the fertilizers are obtained from timely sown wheat. Results of work on micronutrients were inconsistent, but there are a number of experiments that showed a positive and high response (Ibrahim, 1995).

The fourth important factor that affects variability in yield is water requirement. The recommendation is that water should be applied every 14 days during the vegetative phase and every 10 days during the reproductive phase (total of eight irrigations). Water difficulties and improper irrigation practices lead to a lesser number of irrigation in most cases, while over-irrigation is also frequent (Hassan and Faki, 1993). Farmers giving 7.8 irrigations are getting 23% more yield over the scheme average (5.7 irrigations) and 43% more yield than that with four irrigations (Farah, 1995; Farah and Abdelrahman, 1980–83).

The fifth important factor that affects yield is weeds. It was found that yield could be reduced between 17 and 35% as a result of infestation by weeds. There are about eight species of weed that grow with wheat, but the most damaging is wild sorghum. Occurrence of 3–10 plants of wild sorghum in a metre row could reduce yield by 18–35%. Weeds can be controlled by good land preparation, prewatering, using clean wheat seeds and weeding 2–4 weeks after emergence. Chemical control with herbicide is also recommended in case of wild sorghum (Puma).

The sixth important factor in yield variation is the damage caused by pests. Aphid, termite, stemborer, leaf miner, rodents and birds do occur on wheat in the Sudan. However, only wheat aphid were reported to cause average grain loss of 25–35% in on-station experiments. Chemical spraying once or twice was the general practice to control wheat aphid in Gezira. However, an integrated approach to minimize the use of chemical spraying in wheat is being pursued (see Dabrowski et al. in this volume). The use of resistant or tolerant cultivars, application of selective insecticides (Pirimor) or seed dressing by Gaucho are the components used in areas of regular and high aphid infestation. The economic threshold level is being revised to consider the intensity of infestation and occurrence of natural enemies.

Termites which attack wheat seedlings are getting more serious in recent seasons. Cleaning the fields from plant debris, using insecticides as seed dressing, applying the recommended nitrogen fertilizer and irrigating more frequently (7–10 days) showed reduced termite damage.

The seventh factor that relates to yield variation is harvest losses. Delay in harvest results in losses caused by wind, birds, rats or movement of people in the field. During harvest there are losses due to the header (speed) or processing losses in the combine. In Gezira, an average total loss in yield of 13% was recorded in the 1993/1994 season.

Introduction of Improved Technologies in the Gezira Scheme

Based on impressive results from on-farm tests in the 1980s, the Agricultural Research Corporation released improved wheat production technologies (according to Hassan and Faki, 1993) as follows:

- Replacing the long-season variety, Giza 155, with the relatively short-maturing semi-dwarf wheat cultivars, Condor and Debeira, which respond to high fertilization and gives better yields;
- Disc harrowing and levelling to improve crop establishment and avoid waterlogging;
- Mechanical planting on 20-cm rows at a seeding rate of 143 kg/ha for optimum population, uniform plant growth and better root development.
- Planting between 12 and 26 November;
- Mechanical application of 86 kg/ha nitrogen immediately before planting and 43 kg/ha phosphorus incorporated in the soil before harrowing or applied with seedlings;
- Irrigating seven to eight times with 14-day intervals.

However, over the past 20 years, average wheat yields in Gezira remained at a very low level of 1.3 tons/ha, partly because of the production practices in use (Hassan and Faki, 1993). Conventional land preparation consisted of only two ridging operations. Seed was broadcast by hand at an average rate of 120 kg/ha, leading to irregular plant spacing and low plant density. Disc harrowing, levelling, and mechanical sowing were not used. Farmers applied only nitrogen fertilizer to wheat, broadcasting it manually and at very late dates. The average amount of nitrogen fertilizer applied to wheat during 1978–1988 was only 24 kg/ha. During the 1990 season, Gezira wheat received an average of five irrigations; very few farmers applied more than five irrigations to wheat over the growing season, which extends for more than four months (Hassan and Faki, 1993).

A new package of improved wheat production practices has been extensively tested under farmer conditions in Gezira over the past five years. On-farm testing of the new technology was conducted as a part of the ARC/International Centre for Agricultural Research in the Dry Areas (ICARDA) pilot project for verification and adoption of improved wheat technologies in Sudan. The project started in 1985 with funding from the Organization of Petroleum Exporting Countries (OPEC) and the Government of the Netherlands and technical backing from ICARDA and *Centro Internacional del Mejoramiento del Maiz y Trigo* (CIMMYT). The results of on-farm research indicated the high potential gain in wheat yields from good seedbed preparation, optimal sowing by machine and timely application of adequate amounts of water. Based on that research, a new technological package was promoted by the ARC for Gezira wheat farmers (Table 1).

Over the past six years, versions of this package have been tested independently on farmers' fields in Gezira by ARC Sasakawa-Global Agricultural Project (SG 2000) and the Sudan Gezira Board. The wheat package was also tested on the World Bank-funded Gezira pilot farm but without phosphorus and with fewer than seven irrigations on average. A wide gap between yield levels was realized under traditional practices and those obtained with improved methods.

Comparison of the average yield achieved by wheat farmers over the last five seasons (1991–1996) with the average yield of 1.36 tonnes/ha for the period 1989–1990 and 1.28 tonnes/ha for the 20 years prior to 1989 shows that growth in wheat yields has been disappointing. The new wheat technology has been tested and promoted as a standard package for all farmers in the Gezira scheme. However, Hassan and Faki (1993), who critically reviewed the new technology adoption and variation existing in farmers circumstances between 1986 and 1991, observed that blanket recommendations for all farmers in a scheme as large as Gezira would not lead to economically optimal use of inputs. Soil characteristics, irrigation water, temperature and many other physical and economic conditions vary significantly between farmers and locations in Gezira. Optimal levels and combinations of the practices that constitute the new technology may vary over different locations (Hassan and Faki, 1993).

Significant differences still existed in 1993 where the FAO/ARC IPM Project established large-scale field experiments on the efficacy of aerial spraying against wheat aphid(see Dabrowski et al., in this volume). Yield varied both on unsprayed as well as sprayed fields, indicating the strong effect of other factors on yield (Fig.1).

Establishment of the Pilot Farmer Field School

The FAO/ARC IPM Project has responded to the observed differences in yield between adjacent fields, numbers and blocks by developing a model of the wheat Farmer Field School. This approach was first developed and evaluated by the FAO IPM Indonesia Rice Project. The Farmer Field Schools participatory activities combine local

Table 1. Three levels of wheat production technologies used and validated in the Gezira scheme (Hassan and Faki, 1993)

Practice	Traditional technology	Potential intermediate technology (Gezira pilot farm)	Potential full package (ARC technology)
Seed rate (kg/ha)	120	143	143
Nitrogen (kg/ha)	43	86	86
Phosphorus (kg/ha)	0	0	43
Disc harrow	no	yes	Yes
Number of irrigations	5	6	7
Levelling	no	conventional	precision
Planting method	broadcast	mechanical	mechanical
Yield (tonnes/ha)	1.28	1.90	3.10

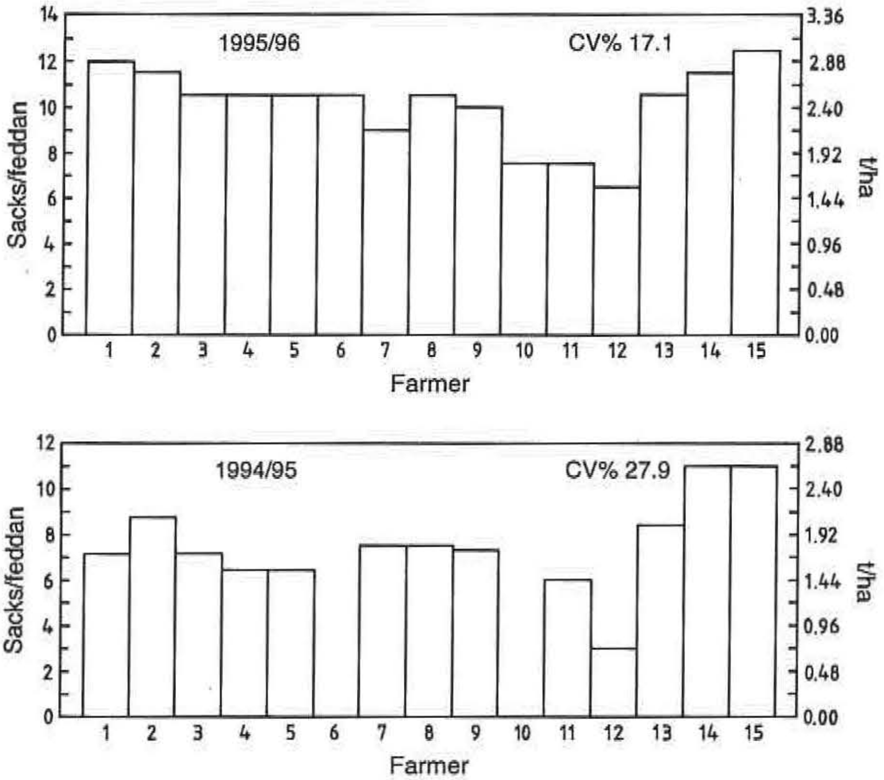

Fig. 1. Variation in wheat yield harvested by FFS participants, 1995/1996, compared to the pre-training 1994/1995 season; Abdel Hakam block, Central Group, Gezira scheme

ecological knowledge created through field exercises with strong culturally appropriate building exercises distilled from non-formal education (Kenmore et al., 1987). Their approach did not focus on transferring specific technologies as bits of information. Rather they seek to capacitate farmers to take sound decisions by providing some basic principles (Dabrowski et al., 1994b; paper on other Farmer Field Schools in this volume).

The PFFS was established in Abdel Hakam block, Central Group, Gezira. Twenty farmers were chosen as participant members while other farmers were free to attend the training sessions. The members were divided into four subgroups each headed by a leader. The purpose was to have small groups which are easy to work with. The school was officially opened on 11 November 1995. Weekly training sessions were organized by an extensionist and plant protectionist from the Gezira scheme and representative of the FAO/ARC IPM Project on Thursday mornings under an *acacia* tree close to the wheat field.

Fourteen training sessions were conducted. The training sessions included a discussion and practical work in the field if applicable. The lecturers were scientists from the Agricultural Research Corporation and the Integrated Pest Management Programme. Topics covered and attendance are shown in Table 2.

The first session covered the objective and philosophy of the FFS, the importance of timely land preparation for weed control, levelling in proper water management and good crop establishment. The importance of sowing date as it relates to temperature and plant development during the season was emphasized. Subsequent sessions discussed methods used in seeding, the importance of covering seeds with soil and partitioning of the field into small basins to facilitate irrigation, especially the first one—all for good crop establishment and to eliminate waterlogging to which wheat seedlings are very sensitive.

The lecture on fertilization emphasized the importance of the two types of fertilizer (N and P) needed by the soil, dose and time of application. Irrigation management emphasized the amount of water to be applied, as well as the importance of irrigation intervals and their effect on the plant as it develops towards maturity. Lectures on weeds included identification of weeds, their adverse effect, critical time of weeding and methods to control weeds in general. Farmers' views on wheat seedling damage during hand weeding were discussed. Lectures on pests, rodents and birds showed the damage they cause, critical levels of infestation and the means of controlling them. The role of aphid natural enemies was emphasized, and the approaches to maintain these enemies was clarified. Farmers were taught about interaction between the number of aphids, damage level on leaves and yield reduction. The economic threshold of 35% infested tillers was discussed, and the FAO/ARC IPM Project approach to introduce a modified method of decision making on spraying was clarified. The farmers were shown how predators

Table 2. Programme and farmers' attendance in the wheat IPM FFS,1995/1996, Abdel Hakam block, Central group, Gezira scheme

Date	% of attendance	Subject of training
11 Nov. 1995	100	Opening ceremony; Introduction to FFS objectives; discussion on production constraints
16 Nov. 1995	96	Concepts of IPM FFS; group interaction; sharing knowledge between leading farmers and others
23 Nov. 1995	75	Land preparation; wheat sowing and fertilization
31 Nov. 1995	90	Optimal irrigation and fertilization with N, P
7 Dec. 1995	80	Revision of irrigation and fertilization
14 Dec. 1995	90	Revision of all previous subjects presented and discussed; introduction to pests and diseases of wheat
21 Dec. 1995	80	Weeds in wheat and methods of their control; identification of major species
28 Dec. 1995	90	Revision on weeds, aphid, termite and their identification in farmers' fields
2 Jan. 1996	90	Aphid and their effect on wheat yield; relation of infestation level to yield reduction
18 Jan. 1996	80	Aphid and their natural enemies; other insect pests of wheat
25 Jan. 1996	85	Natural enemies of wheat pests; why we call them "farmers' friends"; identification of major groups in farmers' fields
1 Feb. 1996	100	Continuation of discussion on natural enemies and their role in reducing aphid population; video show of previous field exercises
8 Feb. 1996	100	Rats and methods of their control; farmers' perception of rat damage on wheat
13 Feb. 1996	100	Field day with participation of the group and headquarter management of Gezira scheme; ARC researchers and IPM Project staff, Theme: "How to minimize losses in wheat"

eliminated whole aphid colonies on leaves. When aphid infestation reached 35% of tillers, natural enemies were counted and farmers decided not to spray until the next weekly field practicals. "Numbers" were not sprayed in the 1995/1996 season. The adverse effect of delayed harvest was also explained. At the end of the season, a field day was organized for participating farmers as well as other farmers growing wheat in the vicinity of the PFFS. Farmers had a chance to compare fields and know-how of FFS participants and untrained wheat growers.

Table 3. Farmers applying recommended practices in the PFFS, 1995/1996

Practice	% adoption
Land preparation	75
Planting time	95
Irrigation management	80
Fertilizer rate and time of application	100
Weed control	45
Rat control	80
Harvesting aspects	90

Adoption of Recommendations by FFS Participants

The training included lectures and discussions on recommended ARC practices. Gezira farmers have the right to adopt different practices, although some are decided by authorized sections of the Sudan Gezira Board. These include selection of wheat variety, seed rate, fertilizer rate, release of water to sub-canals and aerial spraying. Most of the FFS farmers adhered to the recommendations with the exception of weed control which was practised by 45% (Table 3). Farmers of the experimental area did not practise weed control in wheat fields in previous seasons as they were not aware of the damage caused by weeds. Due to the dense growth of wheat, farmers' perception was that damaging wheat plants during manual weeding reduces yield.

FFS participants also confirmed that they were unaware of the role of cultural practices and natural enemies and their role in reducing pest populations. They expressed a desire to adopt the same approach in other crops. Before the training, all farmers believed that spraying of insecticides was the only answer to pest control.

The impact of training was well documented by a significant increase in yield due to the improvement in the cultural practices and more regular follow-up of wheat plant growth. Average yield obtained in the wheat FFS was about 1.078 t/feddan (2.56 t/ha), while other treatments gave an average yield of 0.8 t/feddan(1.9 t/ha), i.e. about 36% lower yield. The control treatment, i.e., the one that did not receive good management gave an average yield of 0.642 t/feddan(1.53 t/ha), which was about 40% lower than from the PFFS (Table 4).

Table 4. Average wheat grain yield in the PFFS compared to adjacent fields of A/Hafiz and other experimental areas in the Central Group, Gezira scheme 1995/1996

Canal	Number	Average yield kg/fed.	t/ha
PFFS	3	1,078	2,566
A/Hafiz	2	420	1,000
A/Hafiz	4	739	1,758
A/Hafiz	5	888	2,113
A/Hafiz	7	713	1,697
A/El Hakam	2	887	2,111
Beika	5	454	1,080
Beika	8	498	1,185
A/El Huda	1	735	1,749
A/El Huda	7	642	1,604
W/Elasha	2	642	1,528
W/Elasha	8	575	1,607
A/El Huda	11	1,055	2,511

Explanations: Only A/El Huda No. 11 and W/Elasha No. 2 were sprayed according to the presently recommended ETL of 35% plants infested with aphids

In addition to the significant yield increase by the FFS participating farmers in the 1995/1996 season in comparison with the previous seasons, the interfield variation expressed by a coefficient of variation was reduced from 27.9% to 17.1% in the last season, indicating increased quality of management by a larger group of farmers (Fig.1).

In summary, the FFS participants were more informed than other farmers on the effect of various practices on wheat yield.They were very keen to apply most improved cultural practices as the IPM of their wheat crop in the future;50% of FFS participants confirmed that they were willing to transfer their newly gained knowledge to other farmers.

New Challenges

The experience gained from the first PFFS is quite encouraging in spite of some difficulties in integration of all recommended practices by farmers in their wheat production system. Some farmers believed that the seed rate should be increased to secure a high yield. Some farmers tried to delay the first irrigation until the cool season, but the school organizer explained the temperature requirements by various growth stages of the wheat plants. Mistakes were noticed in the layout of fields which caused seed accumulation in some spots after the first irrigation. A large number of farmers have shown a tendency to apply excess amounts of water during the first irrigation which later had an adverse effect on germination and seedling growth. The susceptibility of wheat seedlings to waterlogging was, therefore, re-emphasized by the school organizer. Some farmers resisted hand pulling of weeds, especially during the first month of crop establishment. Later, comparison of hand-weeded fields with uncleaned ones convinced some farmers to practise removal of weeds during the next season. They also expressed a strong desire to introduce herbicide use in wheat fields.

The direct participatory interaction between farmers, school organizer and subject matter specialists was evaluated by the participating farmers who requested the continuation of the school next season by including other crops grown in the rotation. The impact of the PFFS was also acknowledged by the block administration. It is recommended that field inspectors can establish numerous FFSs (at least three by each inspector) in the Gezira scheme. The management of the Sudan Gezira Board has already taken the first steps in retraining 220 inspectors in extension methodology (including participatory approach) and on the basis of IPM as a part of more rational and sustainable production.

It is also recommended that field inspectors be responsible for establishment and further expansion of FFS to other locations (villages). The significant yield increase gained by FFS participants in comparison to yield collected in other 'numbers' of the Abdel Hakam block was obtained through better integration of the recommended practices by FFS farmers because of their increased knowledge of wheat crop requirements and the consequences of negligence in the quality of cultural practices. The FAO/ARC IPM Project did not provide farmers with subsidized seeds, fertilizers or other inputs as other projects used to do in the past. Some farmers still expect to receive them from the FFS.

Based on the last year of experience, a modified curriculum is proposed (Table 5). Detailed information on wheat production will be published soon by the ARC in their technology manuals for major crops grown in the Sudan.

Table 5. Recommended curriculum for the wheat FFS, Abdel Hakam block, Gezira scheme, 1995/1996

Proposed date	Subject of training
September Second–Third week	Selection of location, site and farmers to follow up the first steps in the land preparation (Kharif ridging); informal discussions with farmers and arrangements with Block management
Fourth week	Opening ceremony; IPM FFS concepts and objectives; farmers' participation and group interactions; discussion on wheat production constraints
October First week	What IPM and ICM mean; wheat growing stages and specific requirements of low temperature, water, nutrients; explain recommended sowing 12–26 November
Second week	Land preparation; importance of levelling, ridging, split ridging or disc harrowing for a good seedbed; sowing and first irrigation
Third week	Optimal use of inputs: seed rate, mineral fertilizers, water and pesticides; production constraints perceived by farmers in previous seasons; develop a programme of discussions and field practicals based on farmers' needs
Fourth week	Follow up of land preparation and needs for manual improvement; field visit to check the cleaning up of plant debris and perennial weeds
November First week	Sowing date and method; how proper land preparation, seed rate, sowing date and sowing method influence crop stand and yield; broadcasting by hand versus mechanical sowing; role and cost of pre-sowing irrigation; application of nitrogen and phosphorus fertilizers; field visit to check quality of disc harrowing and levelling
Second week	Field practicals: re-checking the quality of the levelling; why proper seed rate and method of sowing are important; cross ridging; division of the area to *gadwals, tagnets* and *rubats* to facilitate proper irrigation
Third week	Irrigation and fertilization; introduction to wheat diseases; effect of nitrogen and phosphorus on plants in consecutive growth stages; plant requirements for water in various developmental stages; water requirements affecting yield; effect of excess water and nitrogen
Fourth week	Field visit after wheat germination: Observation of germination rate and water distribution; specific factors responsible for non-uniform water distribution in various fields of FFS participants
December First week	Revision for irrigation and fertilization; field visit to evaluate the effect of land levelling and irrigation on uniformity of germination; waterlogging; check root systems of "sick" samples for diseases
Second week	Weed control; major weed species and why they grow in Gezira:

Local name	Scientific name	Importance
Adar	*Sorghum* spp.	Difficult to separate from wheat seeds; clean seeds obtained by gravity separation; sometimes distributed by grazing animals; hand weeding or chemical control in highly infested fields
Saesaban	*Sesbania* spp.	Difficult to remove seeds; hand weeding recommended
Molaita	*Sonchus* spp.	Difficult to remove by hand but should be hand weeded twice
Difra	*Echinochloa colona*	Highly competitive for wheat but can be easily pulled by hand weeding
Ankog	*Ischaemum afrum*	Difficult to remove from wheat field but weeding in early growth stage is recommended
Adana	*Rhynchosia memnonia*	A creeper that winds around wheat stems and makes harvesting difficult; seed easily contaminates wheat seeds; prevent infestation by using clean seeds and hand weeding
Ramtouk	*Xanthium* spp.	Hand weeding recommended. Visit to the field and checking the weed population density. Discuss handpulling of weeds; respond to the farmers' consciousness of damaging wheat young plants during hand weeding.

Proposed date	Subject of training
Third week	Diseases and pests affecting wheat in Gezira; symptoms of damage and development pattern; pests: maize aphid (*Rhopalosiphum maidis*), greenbug (*Shizaphis graminum*), termite, rats, birds

Table 5. Continued next page

Table 5. Continued

Proposed date	Subject of training
Fourth week	Revision of weeds, aphid, termite; introduction to natural enemies; field practice to identify main weed species; observation of root systems for disease and termite damage; observing too wet and too dry patches; checking grasses and wheat for aphid colonies and natural enemies; collection of major natural enemies; tagging aphid colonies; taking notes of their size; observing presence of natural enemies
January	
First week	Aphids and their effect on wheat yield; symptoms of aphid damage on leaves; two wheat aphid species; Action Threshold; natural enemies considered in decision making for spraying with insecticide; field practice in counting aphids in five fields in the FFS "number"; evaluating aphid colonies as small, moderate, big
Second week	First practices in the field: Evaluating aphid infestation level in 3–5 fields; counting natural enemies; discussion with Block Plant Protectionist on decision on aerial spraying; and comparing of aphid countings in other numbers and decision on spraying of whole block
Third week	Natural enemies as "farmers' friends"; predators; natural enemies on tagged colonies; major groups of predators
Fourth week	Continuation of practical work on aphids and natural enemies with later field practical; farmers' decisions on spraying needs
February	
First week	Revision of wheat diseases and pests and their control; video show of previous field practicals
Second week	Rat and bird control methods; farmers' opinions and perceptions of wheat losses by rats and birds in Gezira
Third week	Timely harvesting to reduce grain losses; Field Day with neighbouring farmers and block management; subject matter specialists respond to farmers' questions on new problems
Fourth week or 1–2 weeks later	Field Day: How to minimize wheat losses; evaluation of farmers' knowledge gained during FFS; management and scientific problems addressed to Block management, specialists and ARC researchers to avoid constraints in the next season

The Impact of Major Predators on the Wheat Aphid in Gezira

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The main objectives of this research project were to determine the impact of natural enemies in the control of the wheat aphid (*Schizaphis graminum*) under actual field conditions, and to study, in particular, the feeding capacity of the ladybird predator group, represented by *Cheilomenes propinqua vicina*.

During the 1995/1996 season, eleven commercial wheat fields in central Gezira were monitored weekly by counting aphid and natural enemies on 100 tillers, in addition to taking four sweepnet samples per field. The latter was done particularly for monitoring adult aphid predators. Also, in unsprayed research plots at ARC, 200 wheat tillers were tagged in order to follow more closely the population dynamics of aphid and their enemies. An originally planned cage experiment, with potted wheat plants and different coccinellid densities and stages, was abandoned due to problems acquiring sufficient quantities of aphid in time. Instead, a petri dish experiment was carried out in the laboratory, but that presented problems with getting sufficient numbers of coccinellids. Results show that aphid infestation in central Gezira wheat fields during the 1995/1996 season came late and occurred at a relatively low level, so that none of the 11 fields were sprayed.

As during the previous season, five major groups of natural enemies, all predators, were identified (Table 1): *Chrysoperla* spp. (Chrysopidae), hover flies (Syrphidae), spiders,

Table 1. Average of all developmental stages of aphid predators in wheat per sample of 15 sweeps, Gezira scheme, 1995/1996

		Predator groups								
Date	n	*Chrys.*	*Syrph.*	Spiders	*Camp.*	Nabid	Cocc.	*Lalus*	Ants	All
Location: Portobell/Abdelhafiz (Derwish), 5 wheat fields										
28.12	24	2.3	0.8	0.2	1.0	–	–	–	–	4.3
13.1	20	1.8	0.5	0.1	0.7	0.1	0.1	–	–	3.3
18.1	24	0.2	0.5	0.1	0.9	0.1	–	–	–	1.8
25.1	20	1.3	0.2	1.5	3.1	0.2	–	–	–	6.3
1.2	20	5.5	0.4	2.6	14.4	0.8	0.1	0.1	–	23.9
8.2	12	5.5	0.4	1.2	10.7	0.8	–	0.3	–	18.9
15.2	24	2.9	0.2	1.3	6.6	0.3	–	0.1	–	11.4
29.2	24	5.8	1.4	2.2	4.6	0.5	0.3	0.1	–	14.9
7.3	24	0.8	0.3	0.8	1.0	–	0.3	0.2	–	3.4
Average	192	2.7	0.5	1.1	4.3	0.3	0 .1	0.1	–	9.1
Location: Beika/Abdelhakam, 6 wheat fields										
23.12	20	2.3	0.7	0.2	1.0	0.1	0.1	–	–	4.4
30.12	20	3.9	1.0	0.5	0.2	–	0.2	0.1	0.1	6.0
8.1	20	2.2	0.5	0.4	–	0.1	–	–	–	3.2
15.1	20	5.0	0.4	1.4	0.8	0.2	–	0.1	–	7.9
22.1	20	5.1	0.1	6.5	5.2	0.4	0.1	0.1	–	17.5
29.1	20	5.7	0.6	6.9	3.4	0.3	0.1	0.1	–	17.1
5.2	20	2.9	0.1	2.0	7.7	0.3	–	0.1	–	13.1
12.2	20	1.7	–	1.9	6.8	0.3	–	0.1	–	10.8
26.2	20	1.3	0.1	10.1	4.7	–	0.2	0.6	0.1	17.6
4.3	20	0.2	0.1	1.1	0.7	–	0.2	0.2	–	2.5
Average	196	2.9	0.3	3.0	3.0	0.1	0.1	0.1	–	9.5

n = Sample size, Chrys=*Chrysoperla*, Syrph=Syrphidae, Camp=*Campylomma*, Cocc.=Coccinellidae true bugs (mainly *Campylomma* sp. (Miridae), a few nabid (Nabidae)) and ladybirds (Coccinellidae). The latter group was rather insignificant in Central Gezira but less so at ARC. The dominant beneficials in Gezira were *Chrysoperla*, syrphids, spiders and *Campylomma*. Sweepnet sampling and direct, visual countings of natural enemies are complementary methods, each of which has limitations. For example, direct observations yielded relatively few spiders and *Campylomma;* on the other hand, no eggs or pupae and only a few larval stages are collected with the sweepnet.

Observations on tagged wheat plants at the ARC field confirmed that the main aphid population peak occurred during the first half and early second half of February, declining as the plants dried, with an average of 2,290 aphids/200 plants over the whole season (range 1–200/200 plants, see Table 2). Aphid numbers on some plants went up and down during the month of February. Early that month, with aphid populations relatively high, the dominant predator was hover fly, while green lacewing became more abundant during the second half of February; however, most numerous at that time were ladybirds (*Hippodamia* sp.) with an average of 60 specimens (all stages) per 200 plants over the whole month (range 7–125/200 plants; Table 2). The total number of all predators was high at the end of February (148/200 plants) when aphid populations had already decreased.

Predators apparently concentrate on medium and large aphid colonies; small aphid colonies seem to escape natural control more easily (Fig. 1a, 1b, 1c). On wheat tillers with bigger colonies (10 or more aphids), there were more predators, and aphids were better controlled within one week, compared to plants with small colonies that increased considerably after the first week. After two weeks, when 7% of wheat plants dried and the total predator population reached its maximum, aphid population levels were similar for all plants: around 13 aphids/plant on average. After three weeks, aphids were controlled, but 88% of wheat tillers were dry; at that time predators were still abundant.

Under laboratory conditions, single *Cheilomenes* adults in a petri dish were found to consume an average of 35 wheat aphids per day, while middle-aged, single larvae consumed 28 aphids/day. At higher predator densities (four specimens per dish), relatively fewer aphids were consumed.

From the field observations it is concluded that hover flies, although not numerous in sweepnet samples (Table 1), were the most important predators to control wheat aphid outbreaks (Table 2), while green lacewings and spiders were most important for preventing or slowing down aphid build-up. Ladybird beetles seem to be important in certain border locations only, but they arrived rather late and did not play a role in preventing aphid outbreaks. The total impact of aphid predators in Gezira was reflected in the low aphid levels this year (making chemical control unnecessary) together with the relatively high numbers of predators.

During predator peaks, there was more than one predator for every two wheat tillers, while during most of the season the average number of predatory specimens (counting all stages) seemed to be around one for every five tillers.

Table 2. Numbers of aphid and main predators per 200 tagged wheat tillers, by visual observation, including all stages, Gezira, 1995/1996

		Predators						
Date	Aphid	*Chrys.*	Syrph.	Spiders	*Campyl.*	Cocc.	*Laius*	All
10.2	3,746	4	18	1	–	7	1	31
17.2	4,672	20	8	3	1	2	–	34
24.2	2,950	25	1	1	1	120	–	148
28.2	77	5	2	3	–	125	–	135
2.3	3	–	–	2	–	43	3	48
Average	2,290	10.8	5.8	2.0	0 .4	59.5	0.8	79.2

Chrys=*Chrysoperla*, Syrph=Syrphidae, Campyl=*Campylomma*, Cocc.=Coccinellidae

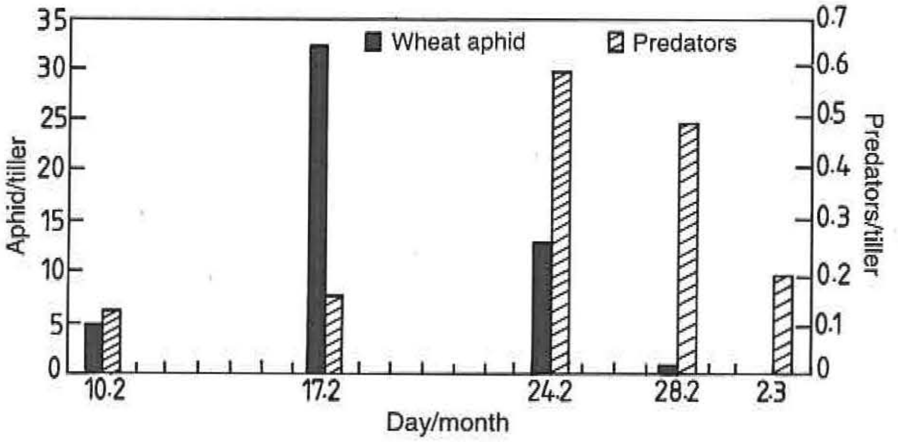

Fig. 1a. Development of small colonies of aphid and predators on tagged wheat tillers

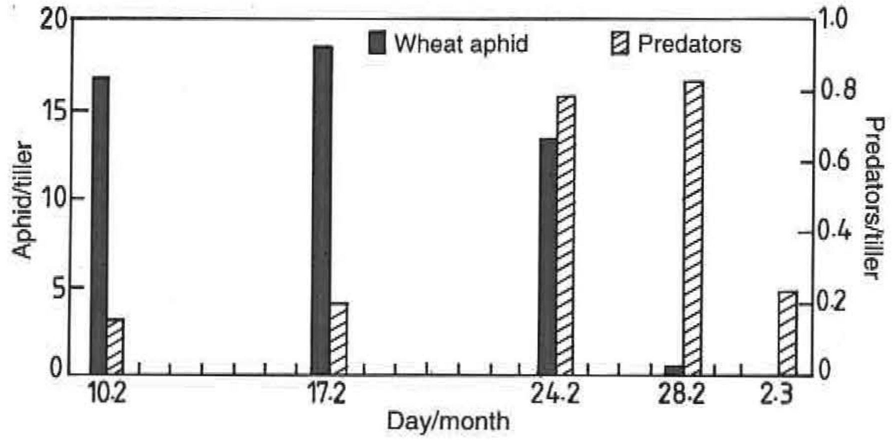

Fig. 1b. Development of medium colonies of aphid and predators on tagged wheat tillers

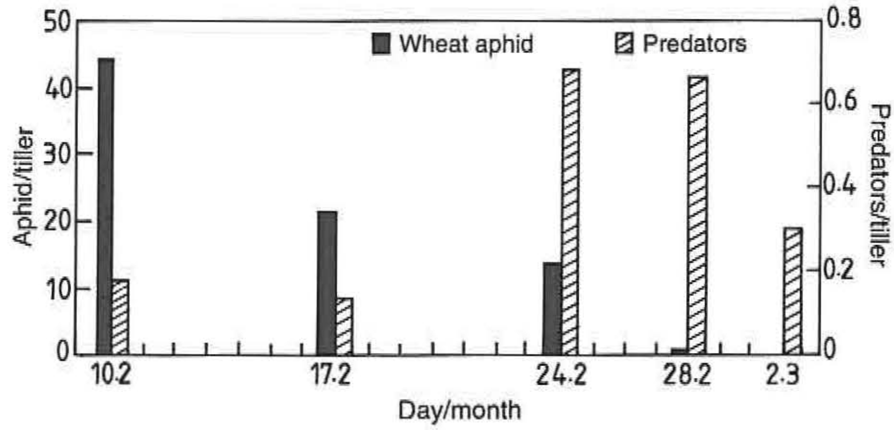

Fig. 1c. Development of large colonies of aphid and predators on tagged wheat tillers

Wheat Weed Control in Northern Sudan

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Until recently, weeds were not considered a threat to wheat production in northern Sudan (Merowe area). However, the use of uncertified seeds and grazing by animals on infested fields disseminated seeds of some serious annual weeds viz. *Sorghum* spp., *Malva perviflora* and *Sinapis arvensis* throughout the region. Some plant protectionists are requesting wide-scale use of herbicides to control wheat weeds.

The studies described in this abstract were undertaken with the objectives of developing an integrated weed control strategy in wheat. The strategy is based on both cultural and chemical methods of control. Cultural methods include the establishment of critical period of weed competition, time and frequency of pre-watering, hand weeding, sowing, inter-row spacing, varieties and seed rates. Each factor was taken as a separate experiment. For chemical control method 2,4-D at 4 rates was used. All trials were conducted for two consecutive seasons.

The average damage inflicted by weeds on wheat was found to be up to 62%, and the critical period of weed competition seems to be between four and eight weeks from sowing date. Pre-watering once or twice during October was ineffective in controlling wild sorghum; however, under domination of *Leptadenia heteropylla*, one pre-watering was adequate to reduce weed density. One hand weeding at 6 weeks from sowing with pre-watering was enough to maximize wheat grain yield (Table 1).

Table 1. The effect of hand weeding and pre-watering on wheat yield, Merowe, northern Sudan

Treatments	No. of weedings	Time weeks	Pre-watering	Grain yield (kg/ha)
1.	1	2	Yes	2,827
2.	1	4	Yes	2,847
3.	1	6	Yes	3,838
4.	1	8	Yes	2,472
5.	1	2	No	2,348
6.	1	4	No	2,616
7.	1	6	No	2,570
8.	1	8	No	1,771
9.	2	2+4	Yes	3,440
10.	2	2+6	Yes	3,935
11.	2	2+8	Yes	3,384
12.	2	2+4	No	2,718
13.	2	2+6	No	3,046
14.	2	2+8	No	2,806
S.E.I		347.3		
L.S.D. (0.05)		984.2		
C.V. %		23.9		

Sowing by broadcasting and ridging almost doubled wheat grain yield in comparison to flat sowing, but densities of wild sorghum were not significantly different between the two sowing methods (Table 2). Inter-row spacing has no effect on weeds; however, there was a slight increase in wheat grain yield as spacing decreased below 20 cm (Table 3). Wadi El Neil and Debeira varieties responded positively to two hand weedings, while Condor and Baladi had negative responses. Condor was the only variety that responded positively to one hand weeding. Increasing seed rate reduced the effect of wild sorghum at 100 kg/feddan, and under the presence of weeds, wheat grain yield increased significantly compared to 25 kg/feddan under the same conditions (Table 4).

Table 2. The effect of wheat variety and sowing methods on wheat yield, Merowe, northern Sudan

Treatments		Grain yield (kg/ha)
1.	Debeira Flat	972.0
2.	Condor Flat	557.0
3.	Wadi El Neil Flat	786.0
4.	El Neilain Flat	558.0
5.	Baladi Flat	1,279.0
6.	Debeira broadcasting and ridging	1,679.0
7.	Condor broadcasting and ridging	1,586.0
8.	Wadi El Neil broadcasting and ridging	1,493.0
9.	El Neilain broadcasting and ridging	629.0
10.	Baladi broadcasting and ridging	1,872.0
	S.E. ±	220.3
	L.S.D. (0.05)	630.3
	C.V. %	38.6

In the first growing season 2,4-D at 0.6 kg a.i./feddan outyielded the unweeded control and eliminated 63% of broad-leaved weeds. In the second season, there was no difference in wheat grain yield among the four rates due to the presence of wild sorghum, but the chemical eliminated 98% of broad-leaved weeds.

Table 3. The effect of hand weeding and inter-row spacing on wheat yield, Merowe, northern Sudan

	Treatments	Grain yield (kg/ha)
1.	10-cm row, clean	2,654.0
2.	20-cm row, clean	3,287.0
3.	30-cm row, clean	3,125.0
4.	40-cm row, clean	2,950.0
5.	60-cm row, clean	2,688.0
6.	10-cm row, weedy	833.0
7.	20-cm row, weedy	1,233.0
8.	30-cm row, weedy	1,146.0
9.	40-cm row, weedy	609.0
10.	60-cm row, weedy	821.0
	S.E.±	242.3
	L.S.D.(0.05)	693.0
	C.V. %	25.0

Table 4. The effect of hand weeding and seed rate on wheat yield, Merowe, northern Sudan

	Treatments	Grain yield (kg/ha)
1.	60 kg/ha weed-free	2,397.0
2.	120 kg/ha weed-free	2,425.0
3.	180 kg/ha weed-free	2,425.0
4.	240 kg/ha weed-free	2,838.0
5.	60 kg/ha weedy	538.0
6.	120 kg/ha weedy	1,008.0
7.	180 kg/ha weedy	1,458.0
8.	240 kg/ha weedy	1,717.0
	S.E.±	254.3
	L.S.D. (0.05)	733.5
	C.V. %	27.5

6 Integrated Pest Management in Cotton

Integrated Pest Management in Cotton Production and Protection

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Cotton is the most important economic crop in Sudan. Traditionally, about 400,000 hectares are sown annually to cotton. In about half of this area, cotton is produced by gravity irrigation while in the other half cotton is produced by rains and flooding. The gravity irrigated cotton, however, accounts for about 80% of the total annual production in the country. Although the average yield of the irrigated cotton is comparatively higher than that of the rain-fed, the profit of the former has always been marginal due to the high inputs used annually . Chemical control is the most important of these inputs because it constitutes 20–40% of the total cost of production, and yet it is the item most prone for reduction.

The major cotton insect pests in the Sudan are the American bollworm *(Helicoverpa armigera* [Hb.]), jassid *(Jacobiasca lybica* [De Berg]), whitefly *(Bemisia tabaci* [Genn]) and aphid *(Aphis gossypii* Glover). In Gezira scheme, the main production area for irrigated cotton in the Sudan, commercial chemical control of cotton pests started in 1950/1951 at one spray per season. The number of sprays increased gradually until it reached 8–9 sprays per season during the 1970s. The yield, however, remained almost stagnant with the exception of the normal seasonal fluctuation which is always associated with agricultural production (Table 1). The large number of aerial applications of insecticides has polluted all the components of the environment, causing significant hazards and damages to the Gezira ecosystem. Unfortunately, the magnitude of these hazards and damages has not been studied properly.

Table 1. Cotton production and protection, Gezira scheme, 1979–1996 (Source: Sudan Gezira Board)

Season	No. of sprays	Yield (kg/ha) LS	Yield (kg/ha) MS	Crop protection cost as % of total production costs
1979/80	8.87	796	1,189	34
1980/81	8.61	696	1,059	32
1981/82	6.78	1,316	887	26
1982/83	5.22	1,410	1,927	24
1983/84	5.45	1,388	2,093	26
1984/85	4.14	1,427	2,476	23
1985/86	8.60	1,112	1,765	33
1986/87	5.20	1,537	1,825	30
1987/88	5.67	1,258	1,862	24
1988/89	5.27	1,420	2,067	22
1989/90	4.34	1,215	1,664	15
1990/91	3.72	930	1,508	10
1991/92	4.75	1,628	1,895	19
1992/93	4.93	1,420	1,069	35
1993/94	3.02	1,469	1,404	30
1994/95	2.85	1,300	1,319	22
1995/96	4.00	1,200	1,456	36

LS and MS, Long-and medium-staple cotton varieties, respectively

Cultural Practices

The impact of cultural practices on cotton protection and production has been investigated in the Sudan by many workers. It has been established that early sowing of cotton *(Gossypium barbadense)* in July increased the risk of infestation by the American bollworm *(Helicoverpa armigera)* (Balla, 1970, 1986; Elamin and Balla, 1983), pink bollworm *(Pectinophora gossypiella)* (Jackson, 1970), flea beetle (*Podagrica puncticollis)* (Schultz et al., 1967)) and bacterial blight *(Xanthomonas campestris* var. *malvacearum)* (Andrews, 1936; Nur, 1970). Recently, it has been observed in the Gezira scheme that a number of farmers sow cotton earlier than recommended, believing that this will lead to higher yield. As a result, cotton reached the flowering stage in late August and early September, attracting female *H. armigera* which developed throughout September during the rainy season when aerial application of insecticides was practically impossible. Reduction in yield in such situations is unavoidable.

Nitrogen fertilization and high plant density was reported by many authors to increase whitefly population (Joyce, 1961; Hassan, 1970; Jackson et al., 1973). The addition of 279 kg N/ha (3N) shortened the life cycle of this species by two days (Abdelrahman and Saleem, 1977). The increase of whitefly population in high plant density conditions is attributed to the extra shelter from the dense canopies against adverse weather and insecticide sprays (Bindra and Abdelrahman, 1983).

Farah and Abdelrahman (1980–1983) demonstrated that stopping of irrigation at the end of November reduced the whitefly population and consequently the fiber stickiness in the medium staple cotton variety, Barac(67)B, without any significant adverse effect on either yield or quality.

The influence of field weeds on cotton pests has received much attention in Sudan. Elamin and Elamin (1979) listed the common weed species which play an important role in the build-up of cotton pests. The practice of weed control by pre-sowing irrigation of cotton which was introduced in Gezira in 1965 (Taha and Musa, 1971) has been recently replaced by pre-emergence herbicide application followed by supplementary hand weeding. The important host weeds, which belong to the family Malvaceae *(Hibiscus* spp.*)*, outside the rotational plots, on no-man's-land, used to be eradicated by plant protection personnel within the framework of a *clean-up campaign* was completely abandoned in recent years. The clean-up campaign comprised a number of phytosanitary operations to protect cotton from pink bollworm *(Pectinophora gossypiella)* and blackarm disease *(X. malvacearum)*. Phytosanitary legislation was issued as The Cotton Regulation in 1926 (Ripper and George, 1965). *P. gossypiella*, although recorded in Gezira since the beginning of the century, has never attained the status of pest. Blackarm disease is now well controlled through the use of resistant varieties and seed dressing. Recommended agronomic practices—sowing date, weeding, thinning and nitrogen fertilization—have a great influence on cotton production and efficacy of insecticide application. Optimizing the cultural practices in cotton growing is one of the important items in the package forwarded for cotton IPM. Apart from the entomological benefits, proper cultural operations could increase cotton yield substantially. This is demonstrated by the marked variability of yield data per farmer within the same cotton number, the smallest production unit in cotton schemes (=38 ha). Table 2 shows the cotton yields in season 1995/1996 per farmer in three randomly selected cotton numbers in Gezira and Rahad schemes, which both received four insecticide applications based on the recommended raised ETLs. Data show differences in yield within the same cotton number between 2-and 4-fold in both schemes. This phenomenon in cotton production schemes is the norm rather than the exception despite the fact that all the plots in the cotton number receive the same inputs; the only variable factor is the tenant farmer. It is evident that in this season (1995/1996), and with the same inputs, the yield could have been at least doubled if some extension efforts to optimize the cultural practices had been executed.

Resistant Cotton Cultivars

Chemical control is widely practised, with the escalating cost of chemicals standing out as the major factor contributing to the high cost of production (20–40%). The use of resistant varieties within the framework of an IPM strategy becomes the durable and reliable solution for control of insect pests and diseases.

The morphological and biochemical characteristics of the cotton plant constitute a

Table 2. Yield (kantar/feddan) variability within the cotton number, Gezira (Derwish Block) and Rahad schemes (Block 8), 1995/1996. The numbers represent the cotton yield of individual farmers

Gezira Derwish Block																		
Canal Hemidan No. 37																		
6.0	5.0	7.8	5.2	3.5	5.4	5.9	4.6	5.1	4.8	5.3	5.7	5.4	4.0	4.8	4.5	5.3	5.1	5.1
Moharm No. 25																		
4.8	5.2	4.6	6.1	6.2	5.1	5.0	5.8	5.9	3.5	2.1	6.2	7.0	4.3	4.4	4.6	5.8	5.2	
Abdel-Daium West No. 15																		
4.4	4.6	4.7	3.9	4.0	4.2	4.9	5.3	5.1	4.7	4.2	3.6	4.2	4.2	4.3	5.0	3.4	4.4	
Rahad Block 8 Canal 8																		
Double - E, Abu XX: 4																		
6.7	4.3	6.5	3.2	5.6	5.4	6.3	6.1	4.1	5.6	5.4	6.9	4.5	3.8	4.9	5.8	5.3		
Double - 3 Abu XX: 4																		
5.0	8.5	5.6	6.0	5.4	7.0	6.5	6.5	5.6	7.6	6.5	4.3	8.3	4.3	6.3	3.6	6.1		
Double - 5 Abue XX: 3																		
6.1	7.2	7.2	6.3	7.3	5.6	6.1	4.7	4.3	3.6	5.4	5.2	9.8	2.5	1.2	4.0	5.4		

(1 kantar = 142 kg seed cotton; 1 feddan = 0.42 ha)

solid base for selecting cotton types resistant or tolerant to insect pests. Such characteristics include frego bracts, okra leaf, gossypol content, hairiness and nectar. Control of whitefly has been achieved through the introduction of okra leaf, glabrousness and gossypol content in the medium staple cotton variety, Sudac-K (Khalifa and Gameel, 1982). The low humidity and high temperature in the microenvironment of the open canopy of the okra leaf variety created an unsuitable condition for the multiplication of whitefly in addition to better penetration of the pesticide and reduced number of sprayings (two versus 4–6 for the normal Acala leaf types).

Further breeding efforts to control the early season pests (jassid) and to allow the build-up of natural enemies to control the late season pests (whitefly and aphids) resulted in the release of the hairy Acala(93)H and its sister line, Acala(93)M (Mursal, 1978). Comparing insect pest pattern on the low hair density variety, Shambat-B, and the high hair density, Acala(93)H, researchers found that Shambat-B favoured a high jassid population and the lowest whitefly and aphid populations, and the opposite was true for Acala(93)H. This implied that two factors need to be quantified: hair distribution (number of hairs per unit area) which appears to be more important in jassid resistance, and hair length which may be an important factor in reducing whitefly and aphid populations. Despite the high whitefly populations on Acala(93)H compared to Shambat-B, stickiness grading showed no significant difference between the two varieties. However, when the combined effect of the insect pest complex was considered, the cultivar Acala(93)H ranked first (Munir, 1992a).

Natural Enemies and Chemical Control

During March and April, when cotton fields start to dry up, cotton pests abandon the cotton plants to the green host plants on the banks of rivers and canals as well as to the trees and gardens where they spend the cotton-free period (April–June) at low population levels. During the rainy season (July–September), the cotton pests first build up on weeds which emerge in July after the first showers of the rainy season. In September and October these pests start to disperse onto cotton (Cowland and Hana, 1950). In all these stages, the natural enemies of these pests follow, yet keeping pace with their hosts/prey (Abdelrahman, 1986). It is evident that heavy insecticide application on cotton early in the season would prevent the establishment of natural enemies in the cotton canopy, and this would entail more spraying (Eveleens et al., 1981). The natural enemies of whitefly and aphid are important in central Sudan, and when cotton is left without spraying throughout the season (Abdelrahman and Munir, 1989) both species are kept below the prevailing economic threshold levels (200 adults/100 leaves and 40% infested plants, respectively). The advantages of delaying the commencement of the insecticide application was further intensified by the recommendation of new raised ETLs for the four key pests (Table 3). To avoid early applications of insecticides against an early infestation of *H. armigera*, the egg parasitoid, *Trichogramma pretiosum*, was introduced from the United States and released in cotton fields in both Rahad (in 1988) and the Gezira scheme (in 1989). Although the parasitoid has been successfully colonized and its initial occurrence during 1989–1992 ranged between 68% and 15% parasitism, this percentage went down to 1–3% in both schemes during the 1995/1996 season (Beije et al., 1996a). Whether this recession in the percent parasitism is temporary or not, remains to be seen. Delaying the initial application of insecticide without affecting the yield was found to be possible through the study of the compensation capacity of the cotton plant. It has been experimentally demonstrated that in central Sudan both cotton types, *G. hirsutum* and *G. barbadense*, can fully compensate 100% simulated damage of *H. armigera* (Abdelrahman, in press). In some dry seasons, the cotton jassid, *Jacobiasca lybica*, infest cotton early in the season and blemish the leaves. Jassid in central Sudan has a limited and ineffective number of natural enemies (Abdelrahman and Munir, 1989). The use of selective insecticides is the only available option, at present, in case of an early attack by this pest.

Table 3. Recommended ETLs for cotton pests, 1993

Pest	Old ETLs	New ETLs
Bemisia tabaci	20 adults/100 leaves	600/100 leaves
Jacobiasca lybica	50 nymphs/100 leaves	70 nymphs in *G. hirsutum* 100 nymph in *G. barbadense*
Aphis gossypii	20% infested plants	40% infested plants
Helicoverpa armigera	100 eggs and/or larvae/ 100 plants	30 eggs or 10 larvae/100 plants No insecticide spraying before advanced flowering

Factors Affecting Cotton Quality

The quality of cotton depends on factors such as seed quality, sowing date, level of fertilization, number and frequency of watering, picking time and insect pest damage. Two factors, however, are worth emphasizing namely, watering and insect pest attack. These two factors were picked out because of their effect on cotton lint stickiness where price discounts amount to 15–25%.

The jassid attack reduces boll size, fibre length and strength. Whitefly and aphid secretions contaminate cotton lint, causing the honey-dew problem. The shortage of irrigation water during boll formation and fibre maturation periods results in fibre immaturity where fibre length and strength are adversely affected.

Discussion and Conclusions

The recommended cultural practices for cotton growing in central Sudan are mostly those instrumental in reducing pest attacks. These recommendations were based on yield data from field experiments, and the impact of pests was one of the main factors determining yield. The incidence of pests and diseases, for example, has been the main factor in determining the sowing dates of different cotton types.

The yield data from Gezira and Rahad schemes has revealed that the production gap among farmers within the same cotton number ranges between two and four folds in almost every cotton number. This is due solely to the human factor, i.e., deviation from the recommended package. Yield data also fully support the new raised ETLs since the yield could be doubled or even tripled with the same inputs and the same number of insecticide sprays (four in 1995/1996). The voices which call for more sprays to increase the cotton yield are invited to consider the option of increasing the yield through optimizing the cultural practices. This entails no more input and causes no pollution. The use of the blackarm and fusarium wilt resistant cotton varieties in Sudan proved to be both effective and reliable.

The impact of the adoption of the raised ETLs in cotton pest control has already shown its invaluable economical benefits and environmental advantages. The indigenous natural enemies of whitefly and aphids are capable of controlling the populations of both pests if permitted to be established in the cotton canopy. The delay of the first insecticide application is the key factor in achieving this goal. Further improvement in the integration of chemical and biological control of cotton pests could be achieved through close supervision of the area application of the insecticides and the use of selective chemicals.

Natural Enemies and Cotton Pest Control in Sudan

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Before the crisis in cotton pest control in the Sudan during the 1960s there used to be only one major cotton insect pest in Gezira: the cotton jassid which caused 'hopper burn' (Eveleens 1983; Abdelrahman and Munir, 1989). For nearly two decades, this pest was controlled with just one spray. In the early days of cotton growing, whitefly was also a problem because it transmitted leaf curl virus, and the pink bollworm had pest status; these problems were overcome by cultural measures and by breeding resistant cotton varieties. Up to 1960, natural enemies were apparently quite effective in keeping other potential pests in check.

This situation changed dramatically when pesticide use increased, reaching an average of 9.3 sprayings during the 1978/1979 season in Gezira cotton. Three previously minor pests (whitefly, African bollworm and cotton aphid) had attained economically damaging levels. Besides the overuse of pesticides, leading to annihilation of natural enemies, the introduction of other crops as well as laxity with legislative and sanitary regulations contributed to these new problems. Compared with 140 predacious species (26 families) recorded from cotton fields in the early days, only 30 predators representing 17 families and including 10 spiders, could be found by Herrera in 1986(b).

In 1978, an FAO project was initiated to promote integrated pest management in cotton. During the first three phases of this project much attention was given to the impact of chemical control and justified raised economic threshold levels (ETLs) for the four main pests (Stam, 1992). Then it was proved that without any spraying, whitefly and aphid could be controlled by their natural enemies (Abdelrahman et al., 1989; Stam et al., 1990). Also, some foreign aphelinid wasps were released against whitefly, and *Trichogramma* was introduced against bollworm.

With good support from the Sudanese government, pesticide use on cotton could thus be reduced, paving the way for a partial re-colonization of cotton fields by indigenous natural enemies (Ahmed, 1993a, b). After some years of testing the new ETLs in pilot areas, their overall introduction took place in the 1993/1994 season, resulting in 4.9 sprays on average that season for Gezira fields.

This paper gives a short history of research on beneficial cotton insects in Sudan and reviews available information on the four major pests and the impact of their natural enemies. An updated list of the main natural enemies of cotton in Sudan is given (Table 1). Available research data are presented on beneficials in cotton after the release of whitefly parasitoids and bollworm egg parasitoids, and after the introduction of raised ETLs. Natural enemies in Gezira are compared with those in other cotton growing areas, in particular the Gash Delta, where cotton is (again) grown without any pesticide application. Finally, recommendations are given for research and monitoring of natural enemies and cotton pest control in Sudan.

Beneficial Organisms and Pests on Cotton in the Sudan

One of the earliest records of natural enemies associated with cotton pests in Sudan was in 1926, when W.H. Bedford stated that *Drapetis aenescens* (Diptera: Empididae), a predacious fly, was very abundant in cotton fields from September until November. Males of Empididae capture small insects and present them to females before mating. The presence of this predator in the Sudan was earlier reported by an Austrian scientific expedition in 1914. H.B. Johnston bred *Uscana johnstoni* (Hymenoptera: Trichogrammatidae) from eggs of the cotton stemborer *Sphenoptera gossypii* (Coleoptera: Buprestidae). He qualified this parasitoid as being very effective in the control of the stemborer. In 1906, an insect collection had been initiated at Khartoum, which expanded over the following decades to become the National Insect Collection at Wad Medani, the most complete and well-kept collection in the country (Ahmed, 1993b).

The period from 1925 to 1945 witnessed many innovations in the field of biological control and many new parasitic species were described. T.W. Kirkpatrick discovered the presence of *Bracon kirkpatricki* (Hymenoptera: Braconidae) attacking larvae of the pink bollworm (*Pectinophora gossypiella*) in Gezira (Ahmed, 1993b). In 1929, about 9,000 specimens of *Bracon brevicornis* were released in Gendettu Pump scheme against the pink bollworm (King, 1929), but no further information is available.

Bedford, Cowland, Cameron and other ARC entomologists devoted much of their time

Table 1. Main natural enemies of the four major cotton pests in Sudan (data mostly from Dr M. Abdalla Musa, National Insect Collection, ARC, Wad Medani; supplemented by recent field observations (Ahmed, 1993a, b, 1995; Munir, 1993a, b and Beije, 1996a,b,c); see also Ahmed, 1978,1990; Herrera, 1986a, b and Abdelrahman and Eveleens, 1979

Pest 1 : *Jacobiasca lybica*			
I.	Parasitoids		
	Hymenoptera:	Mymaridae:	*Anaphes* sp. (1930)
		Dryinidae:	*Aphelopus* sp. (? *melaleucus*) (1949)
II.	Predators		
	Araneae:	Oxyopidae:	*Oxyopes* sp.
		Salticidae:	*Heliophanus* sp.; *Thyene* sp.
		Araneidae	
		Clubionidae:	*Chiracanthium* spp.
		Entelegynae	
		Gnaphosidae	
		Philodromidae:	*Thanatus* sp.
		Thomisidae:	*Thomisus* sp.
	Hemiptera:	Lygaeidae:	*Geocoris* spp.
		Miridae:	*Campylomma nicolasi*
		Berytidae:	*Metacanthus mollis*
	Coleoptera:	Melyridae:	*Laius venustus; Ebaeus nyasanus, E. sudanicus*
		Coccinellidae:	*Cheilomenes propinqua vicina; Coccinella undecimpunctata; Hippodamia variegata; Micraspis striata; Xanthadalia rufescens*
		Anthicidae:	*Formicomus* sp.
	Neuroptera:	Chrysopidae:	*Brinckochrysa* sp. *Chrysoperla pudica, C. zastrowi*
Pest 2 : *Helicoverpa armigera*			
I.	Parasitoids		
	Diptera:	Tachinidae:	*Exorista xanthaspis; E. sorbillans; Goniophthalmus halli; Palexorista imberbis; P. laxa; Peribaea mitis; Pseudogonia rufifrons; Carcella illota*
		Phoridae:	*Megaselia* sp.
	Hymenoptera:	Braconidae:	*Apanteles ruficrus; Bracon kirkpatricki; Cardiochiles* sp.; *Chelonus versatilis; Meteorus laphygmarum*
		Chalcididae:	*Brachymera bottegi; B. kassalansis; Psilochalsis soudanensis*
		Elasmidae:	*Elasmus johnstoni*
		Eulophidae:	*Euplectris laphygmae; Pediobius furvus*
		Scelionidae:	*Telenomus busseolae*
		Trichogrammatidae:	*Trichogramma pretiosum*
II.	Predators		
	Araneae: see list under **Pest 1**		
	Diptera:	Asilidae:	*Dasythrix brachyptera*
	Hymenoptera:	Eumenidae:	*Eumenes maxillosus*
		Formicidae	
	Neuroptera:	Chrysopidae:	*Chrysoperla pudica, C. zastrowi*
	Hemiptera:	Miridae:	*Campylomma nicolasi*
		Lygaeidae:	*Geocoris* spp.
		Anthocoridae:	*Orius albidipennis*
		Reduviidae:	*Coranus aegyptius*
		Nabidae:	*Tropiconabis capsiformis*
	Coleoptera:	Carabidae:	*Calosoma* spp.; *Chlaenius* spp.
		Staphylinidae:	*Paederus sabaeus*
		Coccinellidae:	*Cheilomenes propinqua vicina; Coccinella undecimpunctata; Hippodamia variegata*
Pest 3: *Bemisia tabaci*			
I.	Parasitoids		
	Hymenoptera:	Aphelinidae:	*Encarsia lutea; Eretmocerus mundus*
II.	Predators		
	Araneae: see list under **Pest 1**		
	Neuroptera:	Chrysopidae:	*Chrysoperla pudica, C. zastrowi; Brinckochrysa* sp.
		Coniopterygidae:	*Coniopteryx (Xeroconiopteryx) mucrogonarcuata; Nimboa* sp.; *Semidalis pluriramosa*
	Coleoptera:	Coccinellidae:	*Scymnus levaillanti, S.* spp.; *Coccinella undecimpunctata; Cheilomenes propinqua vicina; Hippodamia variegata; Micraspis striata; Xanthadalia rufescens*

Table 1 Continued next page

Table 1 Continued

		Melyridae: (Malachiidae)	*Laius venustus* *Ebaeus nyasanus, E. sudanicus*
	Hemiptera:	Anthocoridae:	*Orius albidipennis*
		Miridae:	*Campylomma nicolasi*
	Diptera:	Empididae:	*Drapetis aenescens, D.* spp.
	Acarina:	Phytoseiidae:	*Amblyseius aleyrodes; Typhlodromus medanicus; T. sudanicus*
Pest 4 : *Aphis gossypii*			
I.	Parasitoids		
	Hymenoptera:	Aphidiidae:	*Diaeretiella* sp. (? *rapae*)
		Aphelinidae:	*Aphelinus sudanensis*
II.	Predators		
	Araneae: see list under **Pest 1**		
	Neuroptera:	Chrysopidae:	*Chrysoperla zastrowi, C. pudica*
	Diptera:	Syrphidae:	*Ischiodon aegyptius; Paragus serratus*
		Chamaemyiidae:	*Leucopis* spp.; *Chamaemyia* spp.
		Thereridae:	*Psilocephala sudanica*
	Coleoptera:	Coccinellidae:	*Scymnus levaillanti, S.* spp.; *Cheilomenes propinqua vicina; Coccinella undecimpunctata; Hippodamia variegata; Hyperaspis* spp.; *Micraspis striata; Xanthadalia rufescens*
	Neuroptera:	Chrysopidae:	*Chrysoperla zastrowi; C. pudica*
	Hemiptera:	Miridae:	*Campylomma nicolasi*

between 1930 and 1935 to evaluating the impact of naturally occurring mortality agents on cotton pests. They concluded that the parasitoids of the whitefly in cotton (then identified as *Eretmocerus diversiciliatus, Prospaltella* spp. and two other unidentified species), although very abundant towards the end of the season, could not play a major role in checking the pest because they did not become effective until a lot of damage had been done. Cowland (1933, 1934) stated that temperature, humidity and age of the plant were probably the major factors behind the high whitefly "natural" mortality observed after mid-October. In mid-November he found that approximately 25% of four instar nymphs and pupal stages were parasitized. However, circumstantial evidence inferred from what happened after the intensification of spraying during the 1960s, 1970s and 1980s indicated that the role of natural enemies in the pre-insecticide era had been underestimated. The climatic factors, to which early workers attributed most of the mortality of whitefly nymphs and pupae, did not change much, and yet the pest extended its presence on cotton at damaging levels until the end of the season.

After the introduction of chemical spraying in the late 1940s, interest in beneficial insects declined, although large-scale DDT applications induced outbreaks of whitefly and African bollworm (Joyce, 1956a; Ahmed, 1993b). Increased spraying , from one spray before 1963, 5–7 sprays in 1969/1970 to over nine sprays in 1978/1979, only created more problems, in particular stickiness caused by whitefly and the cotton aphid (Stam et al., 1990). In the early 1980s, the Sudanese government adopted a pest management strategy favouring a more judicious use of pesticides which again made the role of beneficial insects and spiders more important (Ahmed, 1993b).

The FAO IPM project for cotton was initiated in 1978. Abdelrahman and Eveleens (1979), Herrera (1986a,b) and Ahmed (1978,1993a) compiled lists of natural enemies found in cotton and other crops. Experimental applications of *Bacillus thuringiensis* against bollworm were unsatisfactory (Eveleens et al., 1981). Observations in large unsprayed areas during the seasons from 1985 to 1989 showed that populations of natural enemies were 2–6 times higher than those in sprayed fields (Abdelrahman et al., 1991; Stam, 1992; Table 8).

The project showed that ETLs for the four main pests could be raised without reduction in profit. A number of posters and booklets were produced to show the hazards of pesticide use and the positive impact of beneficial insects or "farmers' friends". Various predators and parasitoids, some of them new records for Sudan, were identified by specialists abroad. Aphelinid parasitoids against whitefly and *Trichogramma* wasps against bollworm were imported and released in cotton fields.

In 1993, Farmer Field Schools were initiated, their programme including information about major natural enemies. Also, many training sessions on IPM and beneficial arthropods were given for extensionists, FFS trainers, IPM scouting teams, farmers and project staff. With the fourth project phase, emphasis shifted to wheat and vegetable crops. Regular field observations and sweepnet sampling revealed which beneficial organisms were most common in cotton, wheat, sorghum, onion, tomato and eggplant. It was shown that the main predator groups are found in all important crops as well as in border vegetation, but the relative abundance of these groups varies depending on crop/vegetation, location and available prey. The major predacious groups in cotton are *Campylomma* bug (Miridae), coccinellid, green lacewing and spider.

Major Cotton Pests and the Impact of Their Natural Enemies

African Bollworm (Helicoverpa armigera [Hubner])

The African bollworm has received much attention from researchers, both in Sudan and elsewhere (Balla, 1986,1982; Frisbie,.1983; van den Berg, 1993). Yet we still do not know exactly why it is a serious pest in certain seasons and certain areas and less so, or not at all, in other seasons or other locations. Presumably, both abiotic factors (weather conditions) and biotic factors (natural enemies and host plants) play a determining role. Herrera (1986b) mentioned that under normal field conditions in several cotton growing areas, predators frequently prevented outbreaks of bollworm as well as aphid and spider mite. As a matter of fact, before the 1960s, *H. armigera* was only occasionally a problem in Gezira cotton.

Razoux Schultz and Elamin (1965) reported a maximum of 69% parasitism of *H. armigera* larvae from *Dolichos lablab* in March 1964. Balla (1986) mentions that natural enemies, in particular parasitoids, inflicted considerable mortality on African bollworm populations (up to 53% larval mortality in February), but in 1978 the incidence of parasitoids had declined practically to nil. Balla attributes this to the increased use of pesticides on cotton. Also Joyce (1956b) confirmed that spraying of DDT in the Gash Delta induced outbreaks of *Helicoverpa*. Munir (1987b) mentioned that the bollworm was attacked by parasitic tachinid flies and hymenopterous parasitoids of the genera *Meteorus* and *Euplectris*. Bollworm counts in Gezira and Rahad during the 1988/1989 season showed that the pest level was not higher in unsprayed fields compared to sprayed fields (Stam, 1992).

Regarding natural enemies, Herrera (1986a) mentions over 35 predacious species and 20 parasitoids (including egg parasitoids) recorded on cotton in Sudan. Ahmed and Elamin (1977) found six *Helicoverpa* eggs parasitized by undetermined scelionid wasps on 24 September1975 in unsprayed cotton at ARC, out of a total of 60 eggs examined that day; for the season 1975/1976 this meant only 0.7% parasitism.

Munir et al. (1992) stated that there were actually no native egg parasitoids of the bollworm, and a large-scale programme was carried out from 1988 to 1990 to introduce and release *Trichogramma pretiosum* Riley in order to enhance bollworm control (Abdelrahman and Munir, 1989; Munir and Stam, 1992; Munir, 1993b). Initial studies to assess the result of this release programme showed that 45% to 6% of bollworm eggs were destroyed by the introduced egg parasitoid. However, field studies during the 1995/1996 season indicate that parasitism by this wasp dwindled to a mere 1–3% (Tables 2 and 3). Ahmed (1995) mentioned that the braconid wasp, *Meteorus laphygmarum*, destroyed about 20% of bollworm larvae in fields where early chemical application was avoided. As for predators, adults and nymphs of

Table 2. Average number of bollworm eggs on 100 cotton terminals and parasitism by *Trichogramma* in Gezira and Rahad, 1986–1996; data from Munir, 1986–1993 and Beije, 1996c

	Rahad			Gezira		
	Eggs/100 terminals		par.%	Eggs/100 terminals		par.%
Season	Oct. + Nov.	all season	all season	Oct. + Nov.	all season	all season
1986/87		8	–		18	–
1987/88		14	–		6	–
1988/89	63	39	31		10	–
1989/90	9	8	30	1	3	45
1990/91	5	4	6	1	1	11
1991/92	14	11	15	20	11	20
1992/93		17	32		30	23
1995/96	49	36	3	20	26	1

Table 3. Bollworm egg mortality on cotton in Gezira and Rahad, monitored by tagging; all fields were sprayed, but in 1992 only a few times; data from Munir, 1993a; Munir and Mohamed, 1992, and Beije, 1996c

	Seasons 1989–91 (Gezira+Rahad)	Oct.–Nov. 92 (ARC)	Oct.–Dec. 95 (near ARC)
No. of eggs observed	168	77	378
% of eggs hatched	22	21	76
% of eggs parasitized	38	14	3
% of egg predation	40	65	4
% of eggs disappeared	–*	–*	17

(*) apparently Munir either discarded disappeared eggs or considered them preyed upon

Campylomma spp. were found to prey readily on bollworm eggs (Herrera, 1986b). Laboratory experiments showed that green lacewing larvae ate as many as 50 bollworm eggs per day (El Magid Ali, 1977).

Herrera (1986b) reported that most spider families considered as important predators of bollworms were found in Sudan. Regarding ants, two species (*Messor barbarus* and *Paratrechina longicornis*) were mentioned as bollworm predators in Sudan, the first one feeding on bollworm eggs, the second attacking big caterpillars which enter the soil for pupation (El Amin, 1977; Elamin and Balla, 1983). Munir (1992a) found an average of 70% of bollworm eggs destroyed by predators and the introduced *Trichogramma*. It should be noted that one needs to be a very experienced observer to distinguish predator-induced egg mortality from other mortality factors. In particular, there are two occasions when identification of the mortality factor is difficult: when eggs have completely disappeared (by wind, by some predator or normally hatched with the egg shell eaten by the young caterpillar), and when the egg is "dead" (infertile, by pesticide application, by weather conditions, by predator, or first by parasitoid and then by predator). The natural enemies that we now consider most important for the control of *H. armigera* in Sudan are listed in Table 1.

Generally, available research data on natural enemies of the bollworm mainly deal with parasitoids; data on predators are rather scarce. Compared to 21 parasitoids reported from Sudan, there are 25 from Senegal, only four from Nigeria, but 49 from Tanzania and not less than 71 from South Africa. Most of these parasitoids belong to Tachinidae, Braconidae and Ichneumonidae (van den Berg, 1993). In Kenya, bollworm parasitism was found to be relatively unimportant, but ants (*Pheidole, Myrmicaria* and *Camponotus*) and Anthocorid bugs (mainly *Orius* spp.) played an important role in suppressing bollworm populations, as did other, unknown factors. On cotton in Kenya they found 61–97% "background" mortality, attributed to host plant conditions (especially as cotton matured), while total mortality from egg to late larval stage was 96.4–99.7%. Predator exclusion experiments in Kenya showed that there were 4–6 times more bollworm larvae on cotton in the absence of predators (van den Berg, 1993). It is known that also heavy rain and wind can drastically reduce bollworm egg populations (Nuessly et al., 1991; Mabbet and Nachapong, 1983). In Sudan, rains are not frequent and only occur early in the season, but stormy winds are probably an important mortality factor. However, in general mortality fluctuates considerably within and between seasons and between different locations, and the correlation between the number of eggs and the subsequent number of larvae is often poor (van Hamburg, 1981).

In South Africa, ground dwelling ants were observed to have a great impact on bollworm pupae in the soil. In Kenya, up to an average of five ants per cotton plant were counted, in addition to three Anthocorid bugs/plant (with a maximum of 16 Anthocorid nymphs and adults/plant). In cage experiments, less than five predator specimens (mostly ants and Anthocorids) per plant were found to keep the bollworm population at 0.2 larvae per plant, compared to one larva/plant in predator-free cages (van den Berg, 1993). Bollworm egg mortality studies on cotton in Kenya revealed that 2 days after oviposition 12–65% of eggs were sucked by Anthocorids (average 38%), 8–27% were destroyed by other predators and abiotic factors and 0–13% of eggs were parasitized. On average, 41% of eggs survived in this field study (van den Berg, 1993).

Research in the United States showed that more bollworm eggs were destroyed by piercing and sucking beneficials (lacewing larvae and true bug) than by chewing predators such as coccinellids (Bell and Whitcomb, 1962). Field exposed and monitored second instar larvae were mostly killed by spiders, followed by ants (Delucchi, 1975). The importance of spiders, particularly at pre-peak pest densities, was confirmed by Sterling (1983) in Texas. Out of 16 key predators of cotton bollworm and budworm there, half of them were spiders, which fed on all stages of the pest. Sack spiders could destroy 14 eggs per day when eggs were abundant, or three young larvae per day. Jumping spiders, another group commonly found in Sudanese cotton, could eat five eggs/day, while large spider specimens attack large bollworm larvae (Sterling,1983). In studies with caged cotton plants, indigenous predators were found to destroy 66% to over 90% of *H. zea* (Delucchi, 1975; Wilson and Gutierrez, 1980). The last mentioned authors found cotton in California on which 67% of egg and larval mortality of *H. zea* was due to *Orius* spp., while green lacewing and *Geocoris* caused important additional mortality; adults of *H. zea* were commonly killed by dragon fly. In South Africa, *Orius* has been known to destroy as much as 40% of *H. armigera* eggs (Pearson, 1958). In Peru, main predators of *Heliothis* eggs were found to be Mirid bug (Herrera, 1977). Although species composition and abundance of predators can vary greatly from region to region, similar species of predators seem to affect *Heliothis* pests (Frisbie, 1983).

Cotton Jassid (Jacobiasca lybica *[de Berg]*)

A comprehensive world literature review about cotton jassid and its enemies was made by Klerks and van Lenteren (1991). Razoux Schultz and Elamin (1965) reported levels of parasitism of the jassid in Sudan below 1%. They mentioned *Anagrus* sp. (Mymaridae) attacking jassid eggs and *Aphelopus* sp. (Dryinidae) as parasitoids of jassid nymphs. Research by Munir and Abdelrahman (1987) and Munir (1993b) led them to conclude that there were actually no egg parasitoids (Mymaridae) of jassids in cotton. They considered the natural control of jassid extremely weak. Moreover, investigations in 1995 to find possible jassid egg parasitoids on eggplant, another important hostplant, did not yield any parasitoid (Beije, 1996c). Yet, Allan and McKinley (1957) reported that Mymaridae adults observed during early November in Gezira were probably responsible for the low jassid population that season.They mentioned chrysopid and ladybird as jassid predators. Razoux Schultz and Elamin (1965) mentioned three coccinellids, *Chrysopa* and spider as predators of jassid. Munir (1987b) found that the only natural enemies of *Jacobiasca* on cotton seemed to be spiders. In 1990 he reported that only the spider *Oxyopes* sp. was actually observed feeding on cotton jassid. Field observations during the last 2 years added two other species to the list of predators not mentioned by Klerks and van Lenteren: *Metacanthus mollis* (a facultative predator belonging to the Berytidae) and *Formicomus* sp. (Anthicidae)(Beije, 1996c). The indigenous beneficial arthropods that we actually consider most important for the natural control of jassid in Sudan are given in Table 1.

In Aroma, Gash Delta, *Formicomus* was found to be abundant on cotton, while the jassid population there was very low; this leads us to think that this predator is possibly the most important biological control agent against jassid, followed by spider and Melyrid beetle. In Gezira, jassid are very abundant during most seasons (Table 6) and the forementioned predators occur at much lower levels during the cotton season.

Most of the predators known to feed on jassid are generalist feeders: chrysopids, coccinellids, nabids and anthocorids (Klerks and van Lenteren, 1991). It is a good thing that they are able to survive on other prey, but they may also attack or even prefer insects other than leafhopper. These generalist predators have been found to prefer aphid to jassid.

Whitefly (Bemisia tabaci *[Genn]*)

Cowland (1933,1934), Joyce (1955), Gameel (1969), van Gent (1982), Abdelrahman (1986) and Munir (1986a,b,1987a,b) studied the impact of whitefly parasitoids in Gezira cotton. In the early years, *Eretmocerus diversiciliatus* and *Prospaltella* spp. were named to be most important. Joyce (1955) found 90–100% parasitism of whitefly nymphs by *Eretmocerus*. This is in line with the fact that up to the 1960s whitefly was not an economic problem. After that it did become a serious pest, which is attributed to the increase in pesticide applications and the subsequent elimination of whitefly parasitoids (Eveleens and Abdelrahman, 1980; Eveleens, 1983; Abdelrahman and Munir, 1989). However, Cowland and also Razoux Schultz and Elamin (1965) reckoned that the observed high 'natural' mortality of whitefly after mid-October was due to temperature, humidity and age of plant rather than to parasitoids.

Early data indicated that whitefly was essentially an early and mid-season occasional pest, and until 1962 peak populations of whitefly were confined to September and October (Abdelrahman, 1986). Peak parasitism in sprayed fields reached 44% in 1966/1967 (Gameel, 1969) and 37% in the season 1983/1984. In the latter season, parasitism in an unsprayed plot, however, reached 77% (Abdelrahman, 1986). Van Gent (1982) found that three little wasps belonging to the Aphelinidae were important in Gezira: *Eretmocerus mundus*, *Encarsia lutea* and another, unidentified *Encarsia* species. Weeds were observed to be important alternative host plants: on *Ipomoea cordofana*, van Gent found 34% whitefly parasitism in September, while Munir (1986b) reports during April–August an average of 37 % parasitism on this weed. On *Sida alba*, whitefly parasitism was found to reach 80% during the early season (Munir 1986a). Okra grown during the "off-season" showed 31% of whitefly pupae parasitized. Munir mentioned *Sida*, *Abutilon* and *Lantana camara* as other important host plants on which the parasitoids survived.

Munir (1987b) found 28% parasitism of whitefly pupae in sprayed cotton fields and 42%

in unsprayed fields (Table 4). Earlier, van Gent (1982) reported 86% pupal parasitism in unsprayed plots in January, and a comparable rate of parasitism was attainable about a month earlier in fields receiving well-timed selective spraying. Abdelrahman (1986) observed in 1983/1984 a maximum of 77% parasitism in untreated fields in mid-December, compared to 37% in sprayed fields in January. He and Munir state that early in the cotton season there is a niche devoid of whitefly parasitoids due to the absence of suitable host stages and the early pesticide applications. Both Gameel (1969) and Abdelrahman (1986) concluded that under the given circumstances, parasitoids alone could not sufficiently control the whitefly pest.

Munir (1986b) constructed a life table of whitefly with the following mortality figures: 50% of whitefly eggs were destroyed by predators, 41% of subsequent nymphs were destroyed by *Encarsia lutea* and *Eretmocerus mundus* and 41% of remaining pupae were killed by various causes.

In October 1986, Munir introduced and released two aphelinids from Pakistan, which he claimed to be two strains of *E. lutea* and *E. mundus*, in order to enhance early season whitefly control. He later concluded that this venture was successful (Munir, 1993a,b). With regard to predators, Herrera (1986b) mentioned that *Campylomma*, the most numerous predator that year, was observed to feed on whitefly immatures.

Large-scale experiments with unsprayed cotton fields in Gezira during the 1986/1987 and 1987/1988 seasons clearly showed that whitefly can be satisfactorily controlled by its natural enemies (Abdelrahman and Munir, 1989; Abdelrahman et al., 1989; Stam, 1992; see Table 4). The results of their research eventually led to acceptance of a substantially raised threshold level for control of whitefly. In the Gash and Tokar deltas, whitefly does not have a pest status, but it is present; apparently it is kept at low levels by natural enemies.

Hafez et al. (1979) described the impact of *E. mundus* on cotton whitefly in Egypt, while Azab et al. (1969) gave earlier data on whitefly parasitism in that country. Frisbie (1983) and Gerling (1990) gave overviews of whitefly natural enemies. The latter mentions seven predacious arthropod families, all of which occur in Sudan: Coccinellidae, Anthocoridae, Miridae, Empididae, Chrysopidae, Coniopterygidae and Phytoseiidae. The first and last mentioned families are best represented worldwide, with 10 and 12 species, respectively;seven Chrysopid species have been reported as whitefly predators. In Brazil, *B. tabaci* is reportedly controlled by four parasitoids, mostly Aphelinid wasps (Frisbie, 1983). This author writes that predators tend to be more effective at lower pest densities, while parasitoids, if given a chance, are effective once whitefly levels increase.

Cotton Aphid (*Aphis gossypii* Glov.)

The cotton aphid gained pest status only after the advent of pesticide sprayings. Abdelrahman and Munir (1989), Stam et al. (1990) and Stam (1992) described how in large, unsprayed cotton fields aphids were again controlled by their natural enemies. In sprayed fields, there were five times more aphid colonies (Munir, 1987b). Earlier Munir (1986a) observed on unsprayed cotton at ARC, Wad Medani, that 58% of aphid were killed by predators, with an additional 11% destroyed by the parasitoid *Aphelinus*

Table 4. Some data about seasonal abundance and parasitism of whitefly in cotton in Gezira and Rahad from 1983 to 1990; data from Abdelrahman, 1986; Munir, 1986b,1987b; Stam, Munir and Abdelrahman, 1988; Abdelrahman, Stam and Munir, 1991; Abdelrahman et al., 1990

Season	Location	Period	Spraying	Whitefly adults/ 100 leaves	% leaves infested	Average % parasitism
1983/84	Gezira	Oct.–Jan.	–			30
1983/84	Gezira	Dec.–Feb.	+			7
1985/86	?	Oct.–Feb.	–		40	88
1986/87	N'diana,G.	Season	–	82	33	42
1986/87	N'diana,G.	Season	+	475	53	28
1987/88	N'diana,G.	Oct.–Feb.	–	61		55
1987/88	N'diana,G.	Oct.–Feb.	+ (6x)	357		72
1987/88	Rahad, V	Oct.–Jan.	–	291		66
1987/88	Rahad, V	Oct.–Jan.	+ (6x)	192		74
1988/89	Dolga, G.	Oct.–Feb.	–	105		
1988/89	Dolga, G.	Oct.–Feb.	+ (6x)	399		
1988/89	Rahad, V	Sep.–Jan.	–	125		
1988/89	Rahad, V	Sep.–Jan.	+ (4x)	117		
1989/90	Amara K,G.	Oct.–Feb.	+ (4x)	402		
1989/90	Rahad, IV	Sep.–Jan.	+ (3x)	429		

sudanensis. In early January 1993, Munir found 5% of cotton aphid to be parasitized by this wasp.

The best known specialist aphid killers are ladybird, hoverfly larvae and chrysopid larvae. Hoverfly are usually less important in cotton than in other crops such as wheat or sorghum. In the 1985/1986 season, the small *Scymnus* ladybird were found to be most numerous, representing 78 % of all coccinellids (Herrera, 1986b). The importance of this ladybird in Gezira (and Gash) was confirmed during the 1995/1996 season (Beije, 1996c; Table 8). The *Cheilomenes* ladybird is rated second. In Chad, the *Scymnus* genus is also considered more important than *Cheilomenes* (pers. comm., B.Verhoek). Coccinellids also have their natural enemies. Munir reported that an encyrtid wasp (*Homalotylus* sp.) killed 73.5% of *Cheilomenes* larvae (in Stam, 1992).

Observation experiments in the laboratory indicated that the ladybird *Xanthadalia rufescens* larvae ate an average of 83 individuals of the cotton aphid during their larval development, which took 9.1 days (Munir, 1992a). *Hippodamia variegata* ladybird larvae and *Chrysoperla* larvae were found to eat an average of 9.7 and 15.4 cotton aphids per day, with a larval duration of 9.3 and 6.3 days, respectively (Munir, 1993a). This suggests that lacewing larvae, each of them potentially killing nearly 100 aphids, are more important to control aphid in cotton than the ladybird species tested. However, with coccinellids, both larvae and adults are predacious, while with *Chrysoperla* only the short-lived larvae are carnivorous.

Ahmed (1990, 1992) reported from Tokar Delta that the cotton aphid there was effectively checked by natural enemies, in particular by the predators *Chrysoperla* spp., hoverfly (*Ischiodon aegyptium*), the ladybirds *Scymnus levaillanti* and *Cheilomenes propinqua vicina* and the parasitoid *Diaretiella rapae*.

Under field conditions, aphid are highly vulnerable to attack by natural enemies. This is mainly because they lack defense mechanisms, and their presence in clusters spares predators the toil of hunting for food.

Natural Enemies in Cotton After the Introduction of IPM

Available research data on beneficials in cotton in Sudan generally lack a systematic, quantitative and accurate approach. This makes it difficult to compare findings. Although Herrera (1986b) gave as his first recommendation the establishment of efficient monitoring procedures and the need for quantitative assessment of predator impact, this appeal has not so far been heeded. Research data were obtained during different periods, in different locations and using different methods. At times whole plants were sampled; other times counts were done per metre row. Sometimes only a certain number of leaves or terminals were examined; or data were obtained by the use of a sweepnet, pitfall trap or light trap. Frequently, the description of methods used is vague, or the extent of data collection in space or time is not clear. Sometimes it is not mentioned what insect stages were monitored.

Research carried out during the last three seasons (reports Abdelrahman, 1994, 1995, 1996) does make an attempt to use standardized data collection in the same areas of Gezira and Rahad, but unfortunately no consideration is given to the impact of pesticide applications on the beneficials and the pests counted. Also, only three groups of natural enemies (*Chrysoperla* spp., coccinellids and whitefly parasitoids) were observed for only one developmental stage (only predator larvae, and parasitism in whitefly advanced pupae). Given the fact that there are currently at least 10 more or less important predator genera alone (Beije, 1996a), and that different observers usually have a different level of training, it is clear that the available data on the impact of natural enemies on cotton pests are far from complete.

Data from Ahmed (reports 1988–1995) have mostly a qualitative character. This author stated that prior to and after the introduction of *Trichogramma* and aphelinids, no proper field and laboratory studies were done (Ahmed, 1993a).

Many taxonomic data are still based on old identifications kept at the insect collection at ARC. However, recent taxonomic reviews may have changed a number of names, as was realized with the common green lacewing *Chrysoperla* species, which was referred to in previous reports as *Chrysopa carnea*. Finally, unavailability of reports formed a drawback for the compilation of this report.

The four most common predator groups in cotton observed during the 1985/1986 season were *Campylomma*, *Scymnus*, *Chrysoperla* and spiders (Herrera,1986b). The following section shows to what extent the introduction of natural enemies (aphelinids against whitefly in 1986/1987, and *Trichogramma* against bollworm from 1988 to 1990) was successful. It also looks at available, recent data about incidence of major predator groups after the introduction of raised ETLs for the four major cotton pests in 1993/1994 which led to a reduction in pesticide applications.

Bollworm Egg Parasitoids

Although Ahmed and Elamin (1977) and Herrera (1986a) reported *Helicoverpa* egg parasitism, Munir et al. (undated, but probably 1992b) deny the occurrence of egg parasitoids. At any rate, the parasitism percentage reported by the first authors was extremely low (0.7% for the season).

Millions of *Trichogramma pretiosum* Riley were released in 1988 in Rahad, in 1989 in Gezira and in 1990 in New Halfa scheme. In his final report, Munir (1993b) concluded that this little wasp was established as an important addition to the natural enemy complex of the bollworm. Alternative hosts (*Earias* and *Trichoplusia*) on alternative host plants helped the egg parasitoid to survive the off-season. Munir (1992b) mentioned 28% parasitism by *Trichogramma* of *Trichoplusia* eggs on *Sonchus* weed and 36% parasitism of *Earias* eggs on *Abutilon*.

Munir stated that *Trichogramma* in collaboration with native natural enemies destroyed an average of 70% of bollworm eggs, of which 30% were due to the introduced egg parasitoid (Abdelrahman, Stam and Munir, 1991). Literature from Kenya (van den Berg, 1993), reported total natural mortality up to 99% (all bollworm stages and including abiotic factors). In Table 2, figures are given of bollworm egg abundance and parasitism by *Trichogramma* in the years before and after the release of the egg parasitoid. As mentioned before, bollworm has not always been a serious problem; for example during the1986/1987, 1989/1990 and 1990/1991 seasons egg numbers generally remained far below the threshold of 30 eggs/ 100 plants which was later adopted. At this point it seems noteworthy to mention one of the inaccuracies that was encountered. The number of bollworm eggs in many of Munir's reports is given as *number per plant*, although in fact *number per terminal* is meant because that is what had been counted. Obviously, there is a big difference between plant and terminal, and for the sake of comparison with literature from elsewhere only, it is absolutely necessary to be precise about these kinds of things. In the years after the release of *Trichogramma* in Rahad and Gezira, Munir found seasonal egg parasitism on cotton terminals of between 6 and 45% (Table 2), with fluctuating bollworm abundance. When we compare this to countings on collected terminals during the 1995/1996 season, there is a sharp decline in parasitism to 1–3% only. Although *Trichogramma* is still present, its effect seems to be minimal. Continued sampling in the coming seasons must prove whether the figures of last season were indeed representative of the actual situation. Using another method, namely tagging and monitoring of bollworm eggs in the field, 3% parasitism was again found only from October to December1995, compared to 38–14% by Munir (1989–1992) (Table 3). Compared with literature data, the percentage of egg hatching found during last season (in just one sprayed Gezira field) is very high, while predation appears extremely low.

It can hardly be surprising to notice that the effect of *Trichogramma* has dwindled: nearly all literature data about biological control with this egg parasitoid deal with inundative, repeated releases, not with inoculative releases.

Whitefly Parasitism

As already mentioned, Munir (1986b,1987a,c) introduced and released at N'diana, Gezira, two Pakistani aphelinids, claimed to be strains of *Eretmocerus mundus* and *Encarsia lutea*, two nymphal-pupal parasitoids which already occurred in Sudan. The idea was to fill the 'niche for parasitoids early in the season', but no reference is made to the period of their occurrence in Pakistan. In total, probably not more than 125 specimens of them were released. There was also a third species (Munir, 1986b), but this has been omitted in later reports, presumably because its identity was not clear and/or numbers obtained for release were low. The maximum whitefly parasitism reached at the release site in December 1986 was 17.9% compared to 15.2% in the sprayed control (Abdelrahman and Munir, 1986).

In order to prove that the introduced parasitoids established themselves, complicated serological tests would probably have been necessary because morphologically the introduced species could not be distinguished from the indigenous ones. Such tests were not made, but Munir (1993b) observed a general decline in whitefly population levels, which he attributed to the introductions made. However, data presented in Table 4 do not support this statement.

There are some indications that the whitefly infestation level has dropped during the last few years; however, available data on percentage of parasitism do not show an increase in parasitism; on the contrary, parasitism percentage rather seems to decrease (Tables 5 and 6). This can possibly be explained by an increased predation by the more numerous predators.

When one looks at periods of high parasitism (Table 5), then it is noteworthy that during the seasons 1993/1994 and 1995/1996 peaks occurred as early as October (but at low whitefly densities), which could mean an improvement compared to the situation of late parasitoid arrival described by Gameel (1969), Abdelrahman (1986) and Munir (1986a).

Data on Chrysopid and Coccinellid Larvae

Abdelrahman (reports 1994,1995,1996) monitored, on a weekly basis, population levels of chrysopid and ladybird larvae and whitefly parasitism, as well as population numbers of the main pests (Table 6). Unfortunately, no attempt was made to investigate interactions between pest populations and populations of beneficials, nor was impact of pesticide applications considered. In fact, from these data no

Table 5. Population levels of whitefly and whitefly parasitism in cotton; average number of whitefly per 100 leaves and percentage of red-eyed pupae parasitized over 3 seasons (1993–1996); Gezira and Rahad; counts were made weekly, September–January; data from Abdelrahman, reports 1994,1995,1996

Season	Cotton variety	No. sprays	Whitefly no. Adults	Whitefly no. Pupae	Whitefly parasitism% All season	Sep.	Oct.	Nov.	Dec.	Jan.	Peaks	Date
Gezira												
1993/94	Shamb	3.2	1,150	875	43		**49**	39	**47**		76 52	Oct .11 Dec. 13
1994/95	Shamb	2.2	86	317	15	5	5	11	30	**39**	38 41	Dec. 18 Jan. 2
1995/96	Shamb	4.0	85	369	29	7	**48**	21	27	**36**	91 80	Oct. 4 Oct .11
Rahad												
1993/94	Acala	4.0	679	611	45		20	**47**	**52**		59 57	Oct .13 Dec. 1
1994/95	Acala	5.0	153	621	37	8	19	35	**47**	**55**	60 49	Dec. 28 Jan. 11
1995/96	Acala	4.2	146	532	28	–	**46**	26	28	15	81 75	Oct. 8 Oct . 22

Table 6. Cotton pests and three of their natural enemies; Gezira and Rahad schemes, Sept.–Jan.; data from Abdelrahman, reports 1994–1996 and Abdelrahman et al., 1990

Season	Cotton variety	Av.no. sprays	Av. yield	Pests: Jass. nymph	Bollworm E	Bollworm L	Aphid % inf.	Wh.fly N+P	Wh.fly A	Natural enemies: Chrys. larv.	Cocc. larv.	Wh.fly paras. %
Gezira												
1989/90	Barak	4	5.7	15	2	2	15		402			
1993/94*	Shamb	3.2	3.6	21	2	5	28	875	1,150	1.9	1.7	43
1994/95	Shamb	2.2	3.3	60	5	3	**51**	317	86	**3.2**	**1.7**	15
1995/96	Shamb	4.0?	4.0	17	1	1	47	369	85	1.8	1.5	29
Rahad												
1989/90	Shamb	3	5.2	12	3	3	30		429			
1993/94*	Acala	4.0	4.1	48	7	2	26	611	679	1.5	3.0	45
1994/95	Acala	5.0	5.2	3	3	5	**74**	621	153	**3.5**	**3.2**	37
1995/96	Acala	4.2	4.9	5	1	1	52	532	146	1.6	1.3	28

(*) Sampling in 1993–1994 was from October to December only
Jass=Jassid, Wh.fly=Whitefly, Chrys=*Chrysoperla*, Cocc.=Coccinellid, E=Eggs, L=Larvae, N=Nymphs, P=Pupae, A=Adults

conclusions were drawn about any impact of natural enemies.

Population peaks of the two predators, lacewing and ladybird larvae, were found to vary between the end of October and early January. Over the last three seasons, the maximum number of lacewing larvae per 100 leaves and per sampling date was 11, while for ladybird larvae this number was 15.4. The data in Table 6 seem to indicate that high predator populations are related to high aphid populations. The data on pest numbers particularly show a large variability which can hardly be accounted for, especially when there are no accurate data on pesticide applications.

With better training, the quality of data collection could be improved so as to get more consistent data. It is also believed that there is a general underestimation of predator numbers, depending on the level of training and experience of the observers, as well as their attitude. Compared to a peak of 5.5 lacewing larvae per 100 leaves on 29 November 1995 in Gezira (report Abdelrahman, 1996), others found 6.5 chrysopid larvae per 100 cotton terminals from the same fields that same day, in addition to 64 lacewing eggs and 2.5 pupae; the latter count of larvae was a definite underestimation, since the terminals were collected by hand in the field and only later examined in the laboratory. Lacewing larvae are known to be shy and difficult to count (Fye, 1971). During chrysopid peaks in some fields at Wad Medani in October/November 1995, estimates of the number of chrysopid eggs per cotton plant reached 100, equivalent to nearly one egg on every cotton leaf, but lacewing egg mortality can be 50% due to the action of *Telenomus* egg parasitoids (Munir, 1990). Basheir (1996) collected data on the control of aphid and bollworm by *Chrysoperla* on cotton, alfalfa, faba bean and tomato in Rahad scheme. He considers this common predator a promising biological control agent, because it is easy to rear in large quantities (Basheir, 1996).

General Data on Predator Abundance and Sweepnet Samples

Ahmed (1992) mentioned that Gezira cotton was being recolonized by important natural enemies of which cotton fields were devoid for over two decades; he named in particular *Ischiodon aegyptius* (Syrphidae), *Nabis capsiformis* (Nabidae) and *Aphelinus sudanensis* (Aphelinidae). During the period 19 November 1995 until 10 January 1996, on weekly collected cotton terminals from Gezira and Rahad an average of one chrysopid individual (including all stages, also eggs) was present on every third and fifth terminal, respectively.

From 12 October to 14 December1995 regular sweepnet samples were taken from a few cotton fields in central Gezira; the results are given in Table 7.

The same four most numerous predator groups were found as reported by Herrera (who used visual counting) at ARC in 1986(b): in descending order these were *Campylomma*, coccinellids, *Chrysoperla* and spiders. Within the group of ladybird, *Scymnus* (mainly *S. levaillanti*) is the predominant one, in particular after mid-November. *Cheilomenes* is the second important ladybird. Unfortunately, from these data it is difficult to compare absolute predator numbers, since different methods for counting were used. The average number of all predators per m^2 counted by Herrera from November to January amounts to 18.5. Sweepnet samples during October and November found 32.6 predators (excluding ants and wasps) per ten sweeps (Table 7).

Table 7. Natural enemies in cotton in Gezira, October–December 1995, according to sweepnet samples

			Natural enemy groups**, numbers per sweepnet sample (10 sweeps)										
Date	Field*	n	Chrys.	Camp.	Metac.	Orius	Nabid	Spid.	Cocc.	Melyr.	Syrp.	Ant	Hym.
1.10	all fields sprayed												
12.10	a	4	2.5	8.5	–	–	0.8	–	2.0	–	–	–	0.3
15.10	a, b fields sprayed												
19.10	c	2	4.0	4.5	–	–	–	0.5	3.0	–	–	–	–
22.10	c, d fields sprayed												
26.10	c	4	1.3	4.8	0.3	–	–	–	11.0	–	0.3	–	–
2.11	a	4	3.8	44.3	–	–	–	1.3	9.8	–	–	1.5	0.3
9.11	c	4	3.8	45.0	–	–	–	0.8	6.0	0.5	–	–	–
	d	4	2.3	87.8	–	–	–	1.0	8.8	–	–	–	–
15.11	a, b fields sprayed												
19.11	a	4	3.0	18.0	–	–	–	0.5	4.5	0.3	–	0.3	0.5
23.11	a	4	3.5	37.3	–	0.3	–	0.8	2.5	–	–	–	–
26.11	a	4	3.3	28.0	–	–	–	–	2.3	0.3	–	–	–
30.11	a	4	3.0	27.0	–	0.3	–	–	1.3	–	–	0.3	0.5
	c	4	0.8	7.3	–	–	–	0.3	0.3	–	–	–	1.5
7.12	a	4	1.8	27.3	–	–	–	2.8	1.5	0.3	–	–	0.5
	d	4	1.3	4.0	–	–	–	–	0.8	–	–	–	0.3
14.12	a	4	1.0	23.8	–	–	–	0.5	1.5	–	–	–	0.8
ave.season			2.6	24.9	–	0.1	0.1	0.6	4.2	0.1	–	0.2	0.3

(*) Locations: a: Abdeldaim E12 (four sprayings: 11.9, 1.10, 15.10, 15.11); b: Abdeldaim E8 (same four sprayings); c: Haj Mustafa 3 (sprayings on 15.9, 1.10 and 22.10); d: Haj Mustafa 1 (same three sprays).
(**) Chrys.=*Chrysoperla*, Camp.=*Campylomma*, Metac.=*Metacanthus*, Spid.=Spider, Cocc.=Coccinellid, Melyr.=Melyrid beetle (mostly *Laius* sp.), Syrp.=Syrphid, Hym.=Hymenoptera

From the seasons 1987/1988, 1988/1989 and 1989/1990 there are sweepnet data from Abdelrahman et al. (1990) and Abdelrahman, Stam and Munir (1991) taken in Gezira and Rahad, but their method was slightly different: they made 50 sweeps per sample and swept one cotton row only, while the recent study made ten sweeps per sample (this is more practicable), and technicians swept at a right angle across the rows, while walking along rows. Table 8 gives a summary of these data. Regarding the four main predator groups only, during 1987/1988 and 1988/1989 an average of 29 predators were swept per 50 sweeps in unsprayed fields. In sprayed fields (data from 1987 to 1990), this figure was 6.5 only. When this is compared with the 161 predators over 50 sweeps in 1995/1996 in sprayed fields (Table 8), there is a happy note: if recent data are representative of the current situation, it must be concluded that the general population level of the major predator groups has increased more than 20 times over the last five years, which is indeed very good news. It is likely that the main factors behind this apparent increase are generally reduced pesticide use and possibly the use of chemicals which are less toxic to beneficials.

The increase in numbers of green lacewing in Gezira during the last few years is confirmed by different entomologists (personal observations). The ratio of main predators relative to *Chrysoperla* (Table 8) also suggests that in particular the group of *Campylomma* has become much more abundant.

Comparison of Natural Enemy Fauna in Gezira, Rahad, Gash and Tokar

While cotton fields in Gezira and Rahad were always sprayed, cotton in Tokar Delta was only sprayed from about 1968 to 1978, and cotton spraying in Gash Delta also stopped a long time ago. After that, cotton was not grown in Gash for some 20 years, until they planted it again a few years ago, without any pesticide application. Unlike the production system in the Gezira and Rahad schemes, in the deltas, crops are grown seasonally on remaining soil moisture after vast floodings during the rainy season; there is no additional irrigation. There is neither herbicide nor fertilizer input.

These rather isolated deltas constitute a special habitat. Unfortunately, a systematic inventory of the arthropod fauna, and in particular a comparison of this between Gash and Tokar and Gezira and Rahad, has never been made. However, there are a number of entomological reports from these delta areas (Snow, 1948; Anon., 1949; Joyce, 1956b; Ahmed, 1990,1992; Beije, 1996a,b). Interesting agronomical and other data are found in Tothill (1952). From 1925 until 1940, average yield in Tokar was 5.3 kantar/feddan (with 10.7 kantar in one good season), compared to below 2.5 in the Gash during that period. In Gash, grasses were a major problem. Recent yield data for Gash show over 3 kantar/feddan, reaching over 6 kantar in well-irrigated areas.

Table 8. Main predators in cotton during different seasons in different fields, according to sweepnet samples and visual countings

Season	Location[1]	Period	Spray	Predator numbers per 50 sweeps				
				Chrys.	*Camp.*	Spiders	Cocc.	Nabid
1987/88	N'diana, G.	Nov.–Dec	–	3.4	17.2	0.8	6.4	0.2
	Block 5, R.	Nov.–Dec.	–	1.8	34.0	2.2	3.3[2]	
1988/89	Dolga, G.	Oct.–Dec.	–	7.9	17.9	2.0	5.0[3]	0.9
	Block 5, R.	Oct.–Dec.	–	2.1	10.2	1.1	1.1[3]	1.6
1987/88	N'diana, G.	Nov.–Dec.	6x	1.1	4.3	0.1	0.3	0.05
	Block 5, R.	Nov.–Dec.	6x	0.5	5.2	0.1	0.8[2]	
1988/89	Dolga, G.	Oct.–Dec.	6x	1.2	9.2	0.5	1.0[3]	0.1
	Block 5, R.	Oct.–Dec.	6x	1.3	4.4	0.7	0.9[3]	0.2
1989/90	A.Kassir,G.	Oct.–Dec.	4x	7	1.4	0.3	1.6[3]	
	Block 4, R.	Oct.–Dec.	3x	9	1.8	0.2	0.4	
1995/96	A.Hakam, G.	Oct.–Dec.	3–4x	13*	124*	3*	21*[3]	
				Ratio of predator numbers (visual count):				
1985/86	Gezira ?	Oct.–Feb.	+ ?	1 :	0.5 :	0.4[3]		
1985/86	ARC, G.	Nov.–Dec.	–	1 :	3.4 :	0.2 :	2.4[3]	
	ARC, G.	Nov.–Jan.	–	1 :	2.0 :	0.3 :	1.5[3]	

(¹) G = Gezira, R = Rahad (²) Scymnus ladybird only (³) mostly *Scymnus*, Chrys=*Chrysoperla*, Cocc.=Coccinellid, Camp.=*Campylomma*
(*) converted from 10 sweeps to 50 sweeps

Tothill (1952) mentions that pests and diseases in Tokar were generally less serious than elsewhere in Sudan. Aphids, leaf curl transmitted by whitefly, blackarm disease, termite and weeds were main problems at that time. Bollworm and shedder bug were reported to migrate to cotton from sorghum and millet. *Heliothis* was found to be attacked by tachinid parasitoids at the end of the season.

Cotton from Gash was of very good quality. In Gash Delta, damage by aphid (after December/ January), locust, cricket, bollworm, thrips and jassid was reported in some years or locations only. Whitefly levels were low, but leaf curl disease was transmitted (Snow, 1948; Anon., 1949). Regarding bollworm, the Sudan bollworm was found to be the biggest pest, with 2,000–14,400 damaged bolls per feddan reported during the period 1944–1949 (Anon., 1949).

Joyce (1956b) reported the pest inducing effect of large-scale DDT spraying on *Helicoverpa* outbreaks in the Gash. Other old ARC files also reported whitefly problems after using DDT. Ahmed (1990), visiting Tokar Delta in January 1990 (after chemical pest control had stopped around 1978), mentioned that pest incidence was low, except for the cotton aphid. That season, *H. armigera* and other bollworm infestation was light, while populations of jassid and whitefly were very low. Termite reportedly caused substantial damage, though. Important beneficial insects mentioned were green lacewing, hoverfly and *Cheilomenes* ladybird. Ahmed found that hymenopterous wasp were poorly represented in Tokar. In 1992, Ahmed concluded that natural enemies of aphid (namely *Ischiodon, Chrysoperla, Scymnus, Cheilomenes* and the parasitoid *Diaretiella rapae*) were capable of controlling *A. gossypii* in the Tokar Delta, but leaf worm and bollworm thrived unchecked. This author found that the agro-ecosystems of central Sudan, being more permanent, support a more diverse insect fauna than the one in Tokar Delta. Yet, jassid and whitefly seemed to pose no problem in Tokar.

Beije (1996a,b,c) paid three visits to unsprayed cotton fields near Aroma, Gash Delta (February1995, January and March 1996). He confirmed that jassid, whitefly and aphid were not problematic, although aphid were abundant. Bollworm (mostly *Earias vittella* and *E. insulana*, and some *H. armigera*), though very common, seemed to be considerably controlled by natural enemies (probably mostly spider and *Orius*), given the fair number of healthy bolls counted. Other potential pests frequently observed were cotton seedbug and flea beetle. Regarding natural enemies, Beije observed a wide range of predator groups and also parasitic wasp (visual countings on plants chosen at random). In addition to ant and mantid, spider, lacewing (chrysopids and coniopterygids), hoverfly, ladybird, melyrid beetle, anthicid beetle and true bugs (mainly *Orius*, some *Campylomma*) were found to be very common. Compared to sprayed Gezira cotton,that in Aroma had strikingly more spider, coniopterygid, anthicid beetle (*Formicomus* sp.) and melyrid beetle (*Laius* sp.).

Since spider were encountered hiding on most of the cotton bolls, they are suspected to play a major role in bollworm control. *Formicomus* (together with spider) is possibly an important factor in controlling leafhopper, while two different *Scymnus* species (beside green lacewing and hoverfly) are probably largely responsible for aphid control.

Given the observation that neither pest nor natural enemy complex in the Gash seems to be basically different from those in Gezira and Rahad, and the fact that pests in Gash and Tokar are largely controlled naturally, it is surprising that so far not more attention has been given to studying the arthropod fauna and in particular the impact of beneficials in these different cotton areas. Comparison of population dynamics of both pests and their natural enemies, and a detailed study of the different habitats in Gash/ Tokar and Gezira/Rahad could well provide a key for better use of existing natural enemies in cotton.

Concerning possible differences between natural enemy populations of Gezira and Rahad schemes there seem to be only few data available. Basheir (1996) found that *Chrysoperla* populations from Gezira were less susceptible to two insecticides (Endosulfan and Dimethoate) than populations from Rahad, which is explained by the longer period of pesticide use, and hence development of tolerance in the green lacewing in Gezira.

Conclusions and Recommendations

Natural enemies are very important for cotton pest control in the Sudan. Before the intensification of pesticide spraying in the 1960s, there was only one major pest, the jassid. Other minor or potential pests were kept in check by their natural enemies. Research in large unsprayed cotton areas at N'diana in Gezira in 1987/1988 showed that at least two pests (whitefly and aphid) could again be satisfactorily controlled by their natural adversaries. Cotton in Gash and Tokar deltas is again grown without spraying, and most cotton pests are largely or completely maintained below harmful levels.

The adverse effects of indiscriminate cotton spraying have been clearly demonstrated by the appearance of "new" pests and the elimination of many beneficial organisms. Before 1960 there were 140 predators recorded from cotton in Sudan; but in 1985/1986 only 30 predators could be found.

After the introduction of cotton IPM, in particular, the banning of DDT and package deals with chemical companies, and the introduction of higher ETLs for all major cotton pests, the number of sprays were reduced and a number of important natural enemies again recolonized cotton fields (Ahmed, 1993b). Sweepnet samples taken from sprayed cotton fields in central Gezira in 1995 showed 10–40 times greater numbers of the four main predator groups, compared to similar samples taken between 1987 and 1989 (Table 8).

The identities of the four most common predator groups have not changed since 1986. These are, in descending order: *Campylomma* bug, coccinellid (mostly *Scymnus*), green lacewing and spider.

The release programme of *Trichogramma pretiosum* egg parasitoids against the African bollworm (1988–1990) seems to have lost its effect. Compared to approximately 30% bollworm egg parasitism observed between 1988 and 1992, only 1–3% was recorded in 1995/1996 (Tables 2 and 3). The impact of the release of two aphelinid parasitoids from Pakistan against whitefly (1986/1987) is not clear, but positive results are doubtful (Tables 4 and 5).

Recent observations on unsprayed cotton in Gash Delta suggest that spider are important bollworm enemies, while anthicid beetle (*Formicomus* sp.) could be a key factor in jassid control. An updated list of major natural enemies for the four main cotton pests is given in Table 1.

Although a number of beneficial groups have not been sufficiently investigated (see Herrera, 1986b; Ahmed, 1993b; Beije, 1996c), it is concluded that the existing indigenous beneficial fauna in the cotton agro-ecosystem can play a major role in cotton pest control in the Sudan whenever pesticides are used judiciously. In particular the timing of application and the choice of pesticides are important, so as to conserve key natural enemies as much as possible.

It is recommended to pay more attention to the promotion of insecticides that are less harmful for major beneficial organisms such as spider, *Campylomma* and nabid bug, coccinellid, anthicid and melyrid beetle, green lacewing and coniopterygid, and whitefly parasitoids (see Mullin and Croft, 1985; Hassan et al., 1991). The use of selective or less toxic chemicals could have a tremendous effect on abundance of natural enemies and, hence, on the need for further crop protection measures.

All major mortality factors for the main cotton pests should be determined. There is also a strong need for quantitative, standardized and reliable sampling of pests and natural enemies, as already mentioned by Herrera (1986b) and King and Jackson (1989). Such sampling should be done seasonally by well-trained technicians in order to monitor improvements or deteriorations in the beneficial cotton fauna. It is known that the impact on pest levels of natural enemies, other biotic factors and abiotic factors is variable. Therefore, it is imperative to count regularly both pest and natural enemy populations. For successful IPM it is essential to estimate and predict the impact of the beneficial complex as well as possible losses caused by pest insects. Comparative studies of the pest and natural enemy complex and their habitat in the Gash/Tokar deltas and in the Gezira/Rahad schemes may well provide a key for better understanding of the role of individual predator groups and may thus lead to better use of natural enemies in cotton pest control.

Since major beneficial groups are, to a large extent, the same for cotton and other important crops such as sorghum and wheat, and because migrations occur from one crop that is ripening and drying to another in the vegetative growth stage, it is recommended that more research be directed towards using rotational crops (including alfalfa) for "field rearing" of natural enemies. This seems all the more possible since these crops have different planting dates, harbour relatively few cotton pests and are not or are rarely sprayed. Aphid populations on other crops are a boost for lacewing, coccinellid, hoverfly and predacious bugs. Sorghum or alfalfa sown north (from where winds mainly blow) of a cotton field will likely serve as a source of beneficial cotton insects, more so than being a source of pest insects. Medium aphid population levels in the cotton crop should be tolerated as long as they are below the ETL, so as to favour the build-up of general predators such as green lacewing, predatory bug and ladybird.

It is hoped that decision-makers will sustain further development of cotton IPM, based on conservation of the existing natural enemies, as well as on proper practices of cultivation and crop protection, in order to avoid another crisis such as the one that occurred during the 1970s, when overuse of pesticides virtually wiped out the farmers' friends.

The Effect of Various Cultural Practices on Cotton Pest and Disease Control

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Cotton has been grown commercially in the Sudan since 1867 in Tokar Delta. In 1911, it was sown in central Sudan in the Gezira scheme under gravity irrigation. The average annual grown area is 400,000 hectares. Cotton ranks first among the main cash crops in the Sudan and ranks second in the export of long staple cotton in the world after Egypt.

Cotton is sown during July to mid-August. The length of the season for long staple cotton is about 240 days; for medium and short staple 180 days. Cotton attracts a large number of insect pests. Their attack has resulted in substantial yield losses and significant increase in the cost of chemical control since 1961. The economic production of cotton with reasonable net profit depends on satisfactory and reliable methods of controlling insect pests, diseases and weeds.

During the period 1915 to 1945 prior to the introduction of chemical pesticide (DDT), the strategy of cotton pest control was based mainly on non-chemical measures. These measures included cultural, legislative and physical methods of control as well as breeding resistant varieties. Attention was also paid to field sanitation, proper tillage practice, crop rotation, strict adherence to recommended agronomic practice related to sowing date, plant population, weeding fertilization and watering. Legislative control measures were strictly enforced to prevent the carry over of insect pests and diseases from one season to another.

With the advent of cotton growing in the Gezira scheme, agricultural, entomological and pathological research was mainly concerned with solving cotton pest and disease problems. Of the early 1935 achievements in this field are the initiation of several legislative and cultural control practices during the cotton growing and 'dead' (closed) season to reduce the carry over of pests and diseases, e.g., pink bollworm (*Pectinophora gossypiella* [Saund]), bacterial blight caused by *Xanthomonas malvacearum* and cotton leaf curl virus. These laws are still enforced to date.

Until 1945, cultural and legislative measures were the only methods used for reducing the damage of the major cotton insect pests, e.g, pink bollworm, flea beetle (*Podagrica puncticollis* Weise), jassid (*Empoasca lybica* [de Berg]) and termites (*Microtermis thoracalis* Sjost). Other insect pests of minor importance recorded on cotton since 1915 were American bollworm (*Helicoverpa armigera* [Hbn]), whitefly (*Bemisia tabaci* [Genn]), cotton aphid (*Aphis gossypii* Glover) and cotton stemborer (*Sphinoptera gossypii* Cot). However, research findings in the late 1940s disclosed that spraying cotton with DDT produced significant increase in yield (Snow and Taylor, 1952). The use of insecticides has become one of the main factors in cotton production ever since (Joyce, 1955). In the late 1950s, the need for chemical control of insect pests increased as a result of heavier losses in cotton yield caused by jassid (Fig. 1).

Immediately after Sudan independence in 1956, the Government made an ambitious agricultural development plants which included expansion of the cultivated area under cotton; introduction of new crops (namely groundnuts and wheat) in the Gezira scheme; increase of vegetable and horticultural crops in Gezira and intensification of rotation. These factors caused major changes in the insect pest complex, especially on cotton (Hassan, 1970). *Helicoverpa* bollworm and whitefly, which were minor pests before 1956, have become major pests. *H. armigera* have 3–4 generations,which attack cotton during bud and boll formation from September to early December. Whitefly have no less than seven generations breeding in cotton from October to February every season. Jassid, on the other hand, was a major insect pest before 1960 but has now become a minor pest. Due to these facts the number of cotton sprays has gradually increased from one spray before 1960

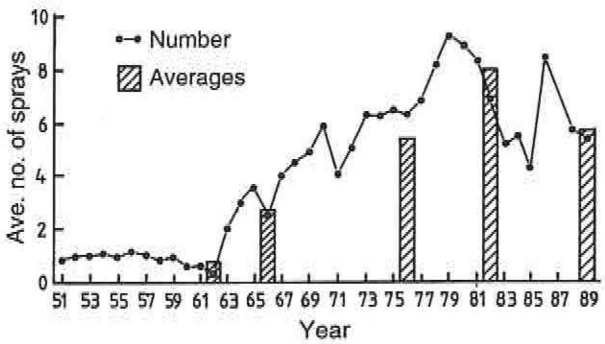

Fig. 1. Number of insecticide sprays on cotton in the Gezira scheme between the 1950/1951 and 1988/1989 seasons (records of the Sudan Gezira Board, Barakat)

to five sprays at the end of the 1960s and to an average of seven sprays during the 1970s. The strategy of control of agricultural pests, particularly that of insect pests of cotton, has gradually shifted from reliance on cultural and legislative methods to over-reliance on pesticide application after 1960 (El Bashir, 1986a and b). No remarkable yield increase per hectare was obtained (see El Tigani M. Elamin, this volume).

Because of the rising costs of insect pest control without any increase in yield of cotton per hectare, the farmers' unions called for a return to the old system of pest control, namely the cultural and legislative measures.

Cultural Control Measures for Cotton Pests and Diseases

Non-chemical pest control practices include cultural, legislative, biological and physical practices. They can be manipulated in such a way as to effectively reduce or eliminate the pest and disease attacks. Schmutterer (1969) wrote that cultural control measures are all indirect preventive methods which are intended to prevent the build-up of large pest populations by modifications or removal of factors which favour them. The success of such measures cannot be assessed exactly as is the case with direct chemical control measures. Furthermore, their applications necessitate a good knowledge of the life history and behaviour of the pest to be controlled. Cultural control methods are often rather cheap, and they are recommended agricultural operations which have to be carried out in order to grow a successful healthy crop.

In the Sudan, control of cotton pests and diseases has been dependent from 1911 to 1945 on strict field sanitation, proper cultural practices and resistant crop varieties. Insect control on cotton with chemical insecticides started after 1945 to combat jassid. The cultural methods or practices reported to be useful in the reduction of insect pests and diseases are discussed below.

Several cotton insect pests, like flea beetle adults, spend time in the soil in a resting stage. Some insect pests pupate in the soil; these include American and Sudan bollworms *(Diparapsis watersi)*, cotton leaf worm *Spodoptera littoralis* and cutworm (*Agrotis* sp).Tillage operations such as deep ploughing help as an indirect measure to bury the insects in the soil or expose them to the sun and predatory birds.

Results of all cotton sowing date trials showed that sowing cotton in June and July gives the highest yield compared with August sowing. To escape the damage of flea beetle in June and blackarm disease in July, the recommended sowing dates for cotton during 1920 to 1972 were 1–15 August. Sowing after August exposes cotton plants to attack by pink bollworm late in the season. Since 1970, after the release of the blackarm-resistant variety (Barakat), the new recommended sowing date for medium and short staple cotton is during July and for long staple from late July to 10 August.

Many weeds are known as hosts of cotton pests. Cotton fields free of weeds are less infested with jassid, whitefly; thrips or aphid compared to badly weeded cotton fields. The effect of insecticide application on insect control in weeded cotton fields is greater than in unweeded fields (Elamin and Elamin, 1980). Good weed control is advisable, not only in the cotton fields but also in the immediate vicinity and in rotational crops to prevent pest migration and infestation of cotton fields.

Heavy watering or flooding has been known to control bacterial blight disease since 1935, but it was not adopted due to restriction in the use of Nile waters from April to June. Flooding for 2–3 days after land preparation results in oxygen deficiency in the soil and causes the death of some insects, e.g., flea beetle adults and pupae of *H.armigera, Diparapsis watersi* and *Spodoptera littoralis.* Flooding as a measure for the control of diapausing larvae of pink bollworm in the soil was investigated. The results showed that the rate of larval mortality increased with the increase in flooding time with a maximum of 60 hours. Flooding for 24 hours was insufficient to destroy all pink bollworm larvae. Although it may be impractical or very difficult to flood large areas, this method could be used in places showing high infestation (Kisha, 1966).

For good crop establishment, a balanced application of plant nutrients is of primary importance. A balanced fertilizer may increase the compensatory ability of plants to the damage caused by pests and diseases. Elamin (1961) found that any deficiency in plant nutrient content shortens the life cycle of the sucking insects. Other entomologists reported that the increase of N-fertilizer causes increase of egg laying by many insects due to the increase of amino acids in the plant.

Balla (1970), Topper (1978) and several other field and research entomologists reported that the main possible cause for the outbreaks of *H. armigera* and *Bemisia tabaci* is the intensification of rotation and the introduction of new crops which favour the development of these pests, e.g., groundnut, sunflower and vegetable. To prevent build-up of insect pests in rotations which include fallow, the practice of clean-fallow (which began in 1937 but later stopped) must be enforced.

Developing cotton varieties resistant to insect pests has been achieved by modifying plant morphology in order to make the microclimate unfavourable. Cotton plants with hairy leaves are resistant to jassid, but they encourage build-up of whitefly (Mound, 1965). On the other hand, glabrous are not attractive to whitefly.

Preliminary results have shown that cotton plants with red leaves are resistant to whitefly and are generally less attacked by insects that like cotton plants with green leaves.

There is a lot of scientific information in the ARC Cotton Breeding Section on breeding cotton varieties resistant to jassid and whitefly in the Sudan.

The important diseases of cotton in the Sudan are bacterial blight, leaf curl and cotton wilt. Bacterial blight caused by *Xanthomonas malvacearum* is the most serious cotton disease. It was first reported in the Sudan in 1922. It is controlled by breeding resistant varieties (since 1970), sanitary measures and flooding or heavy watering (Abu Salih and Khalifa, 1978). The cotton variety Barakat, grown commercially in the Gezira scheme since 1973, is virtually immune to the disease (Siddig, 1973). Leaf curl virus is a whitefly-borne virus disease of cotton. It is carried over from season to season in infected cotton ratoons and out-of-season okra and other alternate hosts. The control measures are planting resistant varieties and eliminating ratoon cotton and alternate hosts, these have kept the disease under control since 1973 (Abu Salih and Khalifa, 1986). Cotton wilt is caused by *Fusarium oxyspsorum F. vasinfectum* (Snyd and Hans). It affects the leaves and plant growth and reduces yield. Cotton wilt is controlled by sowing resistant varieties. Recent ARC research showed that Gezira selection GS-75 was resistant to wilt. Crop rotation seems to be the most important factor in reducing *Fusarium* wilt of cotton; however, the present policy of intensification of rotation in irrigated cotton schemes may lead to a build-up of the disease.

In the Gezira scheme, the rate of infestation of cotton by the pink bollworm *(Pectinophora gossypiella)* has remained at a constant low level since 1936. This has been affected by the enforcement of phytosanitary and cultural control measures. Cotton clean-up has been practised throughout the Gezira scheme since 1935. Yearly, after the end of cotton picking, the cotton fields are usually grazed by goats, sheep and cows. Afterwards, the cotton stems are uprooted, all cotton is swept and burnt together with the cotton stems. These measures, which are completed by 31 May, destroy the pink bollworm larvae in cotton seeds and also control bacterial blight disease.

The potential danger of pink bollworm was demonstrated in some seasons in localized areas, where the clean-up campaign was not done properly.

It is prohibited by law to grow certain plants from 1 June to 15 September because they harbour insect pests of cotton, e.g., flea beetle, jassid, thrips, whitefly, bollworm and cotton aphid. Prohibited plants are okra (*Hibiscus esculentus), kerkade* (*Hibiscus sabdarifa)* and *kenaf (Hibiscus canabinus)*. It is also prohibited by law to store cotton stalks, unginned cotton or cotton seeds in the villages or the fields in the Gezira scheme. These operations and laws are intended to suppress the carry-over of insect pests and diseases to the new cotton crop (Ripper and George, 1965).

Cotton seeds are important sites for diapausing larvae of pink bollworm. Cotton seeds stored in the Gezira scheme as sowing seeds or in the oil mills must be treated before the end of May with hot air at a temperature of 60°C for two hours to kill the diapausing larvae. In the Nuba Mountains, the cotton sowing seeds are spread out on the ground in the sun for 2–3 days during hot summer. This operation also kills the pink bollworm larva and prevents the carry-over of the pest to the new crop.

Economic Threshold Level for Jassid on Long and Short Staple Cotton

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This was the third season for these investigations. Results from the 1993/1994 and 1994/1995 seasons indicated the possibility of increasing the former ETL of 50 jassid/100 leaves to higher levels if the prices of cotton can either be predicted fairly well or can be assumed to remain stable. One certain thing is that the prices of inputs, i.e insecticides and application costs, are fairly stable. This should enable applicators, therefore, to adjust to the new ETLs with a fair degree of certainty.

Materials and Methods

Cotton var. Barakat was sown in the Gezira research farm on 15 July 1995 in Hosha 229 in subplots of 20 x 11.2 m. Jassid infestation was allowed to progress to the following levels before spraying with Talstar 10 E.C (bifethrin) at 0.15 l/feddan. Levels of infestation were included as follows:

1 = free of jassid (achieved by routine spraying)
2 = 50 jassid /100 leaves
3 = 100 jassid /100 leaves
4 = 150 jassid /100 leaves
5 = 200 jassid /100 leaves
6 = unsprayed control.

Other agronomic practices were as per standard practices on the Gezira research farm.

Results

The various treatments received five sprays for both the free of jassid and 50 jassid/100 leaves treatments, and then four sprays, three sprays, one spray and no spraying for the 100, 150, 200 jassids and the unsprayed control respectively. Though the first spray was unduly delayed for treatments 1 and 2, the effect on jassid build-up and yield was quite obvious. The build-up of jassid on various treatments is shown in Table 1 together with the yield in kantars/feddan.

A simple budget analysis was calculated on the following assumptions:

- Each spray will cost about US$10 per feddan for the insecticide and US$1.8 for application;
- Barakat grade 1 will fetch around US$120 per kantar;
- An average free market exchange rate of US$1 =1,300 Sudanese pounds for both input and crop value.

It is clear from results in Table 2 that the net benefit obtained on the higher ETLs almost halved the additional benefit of spraying compared to the unsprayed control. The yield from 200 jassid treatment was even lower than the unsprayed control. Another example of a simple budget analysis was based on assumptions of :

- A 50% increase in cost of application;
- A 2% increase in cost of insecticide;
- A 30% drop in the price of cotton;
- No change in free market exchange rate.

Data presented in Table 3 indicate that the ETL lies between 50 and 100 jassids/100 leaves. The results of this season are in slight disagreement with last season's results which indicated that up to 100 jassid on Barakat could be tolerated without undue loss in financial benefits. This season's result indicated that the ETL should be less than 100. Yet this is exactly what the applicators should consider in making their decision, i.e., no fixed ETL can hold true year after year, and the whole question should be annually reviewed considering the prevailing cotton prices and stability of the market demand for each variety.

Table 1. Cotton jassid on various treatments on var. Barakat, 1995/1996

Tr.	No. jassid/ 100 leaves	11/10	14/10	17/10	1/11	4/11	18/11	22/1	9/12	12/12	19/12	Yield K/feddan
1	0	113	72 a	16 a	111 a	19 a	158 a	7 a	87 a	190 a	35 a	3.66
2	50	111	64 a	17 a	140 ab	26 a	175 a	22 a	85 a	32 a	42 ab	3.72
3	100	126	56 a	57 b	138 a	28 a	147 a	8 b	88 a	72 b	45 ab	2.71
4	150	141	63 a	80 ab	142 ab	35 a	146 a	29 b	102 a	82 bc	81 bc	2.17
5	200	133	52 a	61 b	161 ab	176 b	164 a	173 c	122 ab	116 cd	74 bc	1.36
6	Unsprayed	120	212 b	261 c	219 b	271 c	220 b	233 d	186 b	131d	100 c	1.41

Table 2. Cost/benefit analysis (S£) of using various levels of jassid ETL on var. Barakat

Tr.	Jassid / 100 leaves	No. of spray	Cost of insecticides	Cost of application	Total cost	Yield (K/feddan)	Value cost	Net benefit over control	Net benefit
1	0	5	65,000	11,700	76,700	3.66	570,960	494,260	+274,300
2	50	5	65,000	11,700	76,700	3.72	580,320	503,620	+283,660
3	100	4	52,000	9,160	61,160	2.71	422,760	361,600	+141,640
4	150	3	39,000	7,020	46,020	2.17	338,520	292,500	+72,540
5	200	1	13,000	2,430	15,430	1.36	21,216	196,730	-23,230
6	Unsprayed	0	0	0	0	1.41	219,960	219,960	0

Table 3. Cost benefit analysis (S£) of using various levels of jassid ETL on var. Barakat assuming price changes for both inputs and crop value

Tr.	Jassid /100 leaves	No. of sprays	Cost of insecticides	Cost of application	Total cost	Value of yield	Net benefit (value-cost)	Net benefit over control
1	0	5	78,000	17,550	95,550	399,672	304,122	+150,150
2	50	5	78,000	17,550	95,550	406,224	310,674	+156,720
3	100	4	62,400	14,040	76,440	295,932	219,492	+65,520
4	150	3	46,800	10,530	47,330	236,964	189,634	+35,662
5	200	1	15,600	3,510	19,110	148,512	129,402	-24,570
6	Unsprayed	0	0	0	0	153,972	153,972	0

Controlling the Cotton Jassid with Lower Insecticide Doses

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The possibility of using lower doses of insecticide in cotton pest control has continously aroused interest for two reasons. Using lower doses of insecticides should theoretically prove to be milder on the beneficial fauna and the environment as a whole. Secondly, lower dose application should achieve a cheaper and more feasible control of jassid without significant losses in yield.

Opponents of this approach have continually raised two questions, however. One pertains to the effects of sub-threshold levels of jassid infestation on the build-up of jassid populations and consequently yield. The second asks: What effects would the application of lower doses, thus subjecting jassid to sub-lethal doses of insecticide, have on the future of jassid control? There is a fear that such exposures may induce more resistant populations by inducing an hormolygosis reaction of some sort as in established cases of whitefly and mites resistance to DDT. The answers to both questions are beyond the scope of this study which was undertaken to primarily indicate the practicability of using lower doses, without drawing any final inferences from such an investigation. Both questions are of course legitimate, and especially the second one needs intensive laboratory work. Furthermore, there is no general rule of thumb that would apply for all insecticides or even for groups of insecticides. The picture is complicated even more by the fact that insecticides applied in the Sudan are usually mixtures targeted against a complex of pests and not only jassid. Such mixtures invariably contain insecticides belonging to two different groups of compounds, different in composition, mode of action, metabolism and degradation pathways. Application of mixtures of insecticides have been hailed as the most important measures delaying the appearance of resistance, and by the same token one should expect less of a problem from using lower doses of mixtures rather than single insecticides, but final conclusions have been screened.

Material and Methods

Cotton variety Acala 67B was planted in the second week of July in Hosha 228 in Gezira scheme in plots of 14 x 15 m in RCB design. Periodic counts were taken, and insecticide application was started when jassid levels reached or exceeded thresholds of 100 jassid/ 100 leaves. The insecticides applied and their dosage rates are shown in Table 1. Each insecticide was applied at the recommended rate, 25% and 50% and lower than the recommended, except for Gaucho which is a new insecticide and is still in the large-scale testing programme.

Table 1. Jassid control with lower doses of insecticides

Insecticide	Dose rate litre/feddan	
1. Talstar (bifenthrin)	10 E.C.	0.15
2. Talstar	10 E.C.	0.1
3. Talstar	10 E.C.	0.075
4. Dursban + Endosulfan (chorpyrifos methyl + Endosulfan)		0.75 + 0.75
5. Dursban + Endosulfan		0.5 + 0.5
6. Dursban + Endosulfan		0.375 + 0.375
7. Fastac/Birlane (alphacypermethrin chlorfebvinophos)		1.0
8. Fastac/Birlane		0.75
9. Fastac/Birlane		0.5
10. Gaucho (imidacloprid) SL		0.2
11. Gaucho		0.175
12. Gaucho		0.15
13. Danitol 20 + Marshal 80 E.C. (esfenvalerate+carbosulfan)		0.25 + 0.5
14. Danitol 20 + Marshal		0.187 + 375
15. Danitol 20 + Marshal		0.125 + 0.25

Results

The build-up of jassid population on the various treatments is shown in Table 2. Pest count data was resubjected to the appropriate transformation for the ANOVA, but only actual figures are shown in Table 2. No significant differences were detected between dose rates of the same insecticides either in the pre-spray counts (indicating persistence) or in the post-spray counts, indicating efficacy or immediate knockdown effects, and even for the mean jassid numbers throughout the season (mean of all pre- and post-spraying counts)

However, the only significant differences detected in yield (kantar/feddan) were in the lowest rate of Fastac/Birlane treatment and the intermediate dose of Danitol + Marshal treatments, suggesting that both were more sensitive to dose reduction than other insecticides. There were also slight differences between different insecticides, the highest yield obtained from Gaucho (imidacloprid), and the lowest from the Dursban + Endosulfan, and Fastac/Birlane treatments.

These results are in agreement with the last two season results which indicated that for some insecticides and insecticide mixtures, the application of lower doses to control jassid could certainly be tried without undue fears of failure to control jassid or loss in yield. It has not been possible to assess the effect of lower doses on beneficial fauna, nor on the susceptibility of subsequent jassid populations to the tested insecticides. The importance of both questions cannot be overlooked but for practical limitations could not be investigated here.

Table 2. Selective use of insecticides to control jassid with lower doses

Treat-ment No.	Date of application								Yield K/feddan	Mean throughout season
	16/10/95	19/10	11/11	14/11	26/11	29/11	2/12	10/12		
1.	122a	38b	438b	18ab	163ab	19a	30a	51ab	3.424cde	110
2.	117a	35ab	390ab	19ab	146ab	28ab	29a	51ab	2.801abc	102
3.	120a	29ab	383ab	19ab	116a	27ab	34abc	64b	3.024abc	100
4.	126a	32ab	396b	14a	186b	29ab	42ab	50ab	2.871abc	109
5.	131a	36ab	446b	21ab	182b	33b	41abc	55ab	3.224cde	118
6.	134a	36ab	424ab	21ab	193b	23ab	52bc	70b	2.728abc	119
7.	154a	19a	384ab	22ab	152ab	27ab	39abc	61ab	2.364ab	107
8.	142a	27ab	332a	17ab	154ab	25ab	60c	49ab	2.326a	100
9.	131a	36ab	384ab	19ab	195b	27ab	49bc	65b	3.164cde	113.0
10.	111a	23ab	477b	19ab	187b	24ab	37ab	57ab	4.330f	117.0
11.	113a	23ab	330a	24b	189b	23ab	44abc	51ab	4.506f	97.0
12.	133a	32ab	416ab	17ab	156ab	32b	42abc	71b	3.843def	112
13.	137a	20ab	441b	21ab	174ab	23ab	51abc	47a	3.115cde	114.0
14.	127a	23ab	414ab	22ab	187ab	27ab	55bc	69b	3.959ef	115.0
15.	146a	35ab	374ab	22ab	171ab	28ab	55c	52ab	2.938abc	110.0

* See Table 1 for treatments

Cotton Farmer Field Schools

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The IPM Farmer Field Schools (FFSs) were first implemented in the Sudan in the season 1993/1994 among vegetable farmers in the Gezira region. The success of the FFSs among the vegetable farmers in increasing knowledge and yields during the period 1993–1996 has led to the idea of extending the system to field crops namely, cotton and wheat. Most of the farmers in both Gezira and Rahad schemes grow these field crops as well as vegetables. The cotton FFS is a step towards widening the scope of FFSs to address all the agricultural problems which might confront the farmer in all crops handled. The philosophy behind the FFSs is to provide farmers with the knowledge that helps them to become experts in their own fields (Dabrowski et al., 1994a,b; Alsaffar et al., in this volume).

The cotton FFS was established in the Rahad scheme (Block 8) covering an area of 450 feddans planted with Acala variety (189 ha), involving 40 farmers living in the same village. The FAO/ARC IPM team was helped by scientists from ARC, University of Gezira and Gezira scheme in the training sessions. Weekly training was conducted in the field through three steps: discussion of the training subject of the week in a shaded place adjacent to the cotton plots; visit to a cotton field for observation, identification, comparison, analysis and decision making; return to the shade for discussion of the topic, summarizing and agreeing on a topic for the following week. Farmers' training ran for 15 weeks in the field at about two hours per week. The attendance of the farmers ranged between 40% and 90%. The training sessions covered the following curriculum:

- What is the IPM and FFS?
- Cotton optimal cultural practices (impact on production and protection)
- The life history, identification of stages, economic importance and natural enemies of the main pests—*Helicoverpa armigera*, *Aphis gossypii*, *Bemisia tabaci* and *Jacobiasca lybica*
- Cotton stickiness and advantages of early picking
- Pesticides: hazards and safe handling
- Technical packages for cotton production
- Proper management of irrigation water
- Cotton preparation to obtain high grades.

The post evaluation of the school conducted by the extension personnel shows that the farmers in the school gained a lot of technical information. They recognize now that they can achieve a substantial increase in yield through optimizing cultural practices and not through more insecticide spraying. The area under the FFS yielded 5.92 kantar/feddan, whereas formerly the average for Block 8 was 4.41, which means 34% increase in the FFS "numbers". The farmers now are also capable of identifying the key pests of cotton and their important natural enemies (Table 1).

Table 1. Evaluation of cotton FFS, Block 8, Rahad scheme (Saadabi, 1996)

Response	Pre-training	Post-training
	(% FFS farmers)	
Knowledge of cotton pests		
Know one pest	–	–
Know two pests	40	–
Know three pests	20	40
Know four pests	–	60
Know five pests	–	–
Know six pests	–	–
Did not respond	40	–
Insects which secrete honey-dew		
Know	80	100
Don't know	20	–
Did not respond	–	–
Damage caused by delayed picking		
No effect	20	–
Expose cotton to dust	60	100
Expose cotton to insects	–	–
Did not respond	20	–
Cotton pests and their natural enemies		
Could differentiate	40	100
Could not differentiate	40	–
Did not respond	20	–
Effect of pesticides on natural enemies		
Know	40	100
Did not know	40	–
Did not respond	20	–

7

Sustainability of Integrated Pest Management in the Sudan

Institutional Responsibilities for Developing and Implementing Integrated Pest Management in Developing Countries

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Institutional responsibilities for IPM vary from country to country. They are assigned by national IPM programmes that are implemented within the framework of the national plant protection policy. Government policies relating to plant protection have drastically changed in many countries during the past decade.

Policy Changes

In the second half of the 20th century pesticides became in general use in Europe and North America with the support of a booming pesticide industry. Pesticides were cheap and allowed the farmer to produce crops without the risk of pest damage while the consumer became accustomed to a produce that was free from any sign of attack by pests or diseases. Soon the use of pesticides was considered essential for crop production. Gradually, the use of pesticides was also introduced into the developing countries. In many countries policy instruments were devised to make pesticides better accessible to the farmers. Such instruments included:

- Subsidies of up to 100%;
- Direct government purchases that reduced the prices farmers paid for pesticides;
- Distribution systems through government-supported marketing outlets;
- Government marketing and promotion efforts through agricultural extension systems;
- Preferential tariffs to importers of pesticides versus importers of other inputs;
- Policy messages that greater consumption of pesticides was essential for greater crop production.

In many countries, lack of pesticide management combined with aggressive pesticide advertising led to an ever increasing use of various and often very toxic pesticides that were also applied by small-scale farmers, women and children. Pesticide usage was further stimulated by donor organizations that provided pesticides directly or included them as essential in their development programmes. During the last decade, in particular, perceptions on the use of pesticides have drastically changed because of environmental and economic concerns. In many countries, policy changes have been or are being introduced to reduce the dependency on pesticides and to promote IPM.

A strong stimulant for policy changes is a national commitment to IPM. An increasing number of countries in South-East Asia and also in Africa have officially declared IPM the national strategy for plant protection. Specific policy instruments have been introduced in certain countries to stimulate the adoption of IPM (Table 1).

In South-East Asia it was demonstrated by various FAO projects that pesticide use in rice could drastically be reduced without loss in yield. This finding stimulated governments to gradually reduce pesticide subsidies. This not only promoted IPM but resulted in substantial annual savings for the governments. Pesticide subsidies are presently being removed in many countries because of the high cost for the governments.

Indonesia and some other Asian countries have banned the use of certain insecticides on rice for various reasons. Insecticides of toxicity class 1A and 1B are considered too toxic to be used by rice farmers, in particular because the spraying is often done by women and children. Broad spectrum insecticides in general have a large negative impact on natural enemies of the key rice pests. The same applies for persistent insecticides. The insecticide endosulfan was found very detrimental for fish and shrimp farming. The restriction stopped the advertising and legal sales of these insecticides for use in rice. Farmers were trained in Farmer Field Schools not to use the restricted insecticides any more. In addition, the importation and sale of certain persistent broad spectrum insecticides, in particular organic chlorines, has been banned in many countries.

Sales tax for pesticides has been recently introduced in India. This tax generates funds for pesticide management and related IPM activities.

Institutional Responsibilities for IPM Implementation

FAO's experience in South-East Asia shows that for effective IPM development and implementation, an IPM Steering Committee or National IPM Coordinating Committee is required that represents the main IPM stakeholders. It should have direct access to the highest level of the relevant ministries, in particular the Ministry of Agriculture, Ministry of Environment and Ministry of Finance and Planning or their equivalents and sometimes also the Ministry of Health and the Ministry of Commerce.

The mandate of this committee is, in general, planning, formulation of IPM policies, coordination of activities and setting of priorities. It should be instrumental in obtaining national or external funds. This committee has strong links with structures that regulate the distribution and use of pesticides, in particular, the Plant Protection Service.

Research institutions and universities normally provide the technical knowledge on which IPM options and strategy are based (agronomy, resistant varieties, biological and chemical control strategies). These strategies are field validated and adopted to local situations in close collaboration with the farmers. Various entities can be involved; researchers, Plant Protection Service, the Extension Service, NGOs.

Once sufficient IPM options have been identified, a training of trainers' programme is launched. The trainers to be trained are normally the extension personnel; the training itself is conducted by the extension staff with support from researchers and subject matter specialists. The effectiveness and appropriateness of the IPM options and their adoption rate should be monitored on a regular, permanent basis. Various institutions can be involved in this.

Responsibilities for IPM Development and Implementation in the Sudan

Much interest and support for the implementation of the fourth phase of the Project has been received from the Minister of Agriculture, Natural Resources and Animal Wealth and from the Minister of Agriculture of Gezira State. It is suggested that support for IPM be formalized in a policy statement. Such a statement can facilitate the release of national funds, help to obtain external funds and give a strong signal to the relevant institutions and organizations to direct their activities towards IPM development and implementation.

In Sudan, there are several committees that play a role in IPM: National IPM Committee, the IPM Coordinating Committee, the Pests and Diseases Committee and the Pesticide Regulation Board. These committees were formed some years ago, and the question arises as to whether they still meet present-day needs for IPM support. In reviewing the functions of the various committees, the following questions could be asked:

Table 1. Policy instruments explicitly used to support IPM

Remove direct subsidies for insecticides		Annual saving
Indonesia	1986/89	US$150 million
Philippines	1987/88	US$12 million
India	1992	US$35 million
Restrict legal use of pesticides		Number of pesticides
Indonesia	1986	57
Philippines	1989/94	3
India	1992/95	20
Ban import or sale of pesticides		Number of pesticides
Philippines	1992/94	3
Viet Nam	1993/95	12
Sri Lanka	1995	2
Tax pesticides "Polluter Pays Principle"		Annual revenue
India		US$65 million

- Does the National IPM Committee truly represent the many IPM stakeholders?
- Is there a need to update its mandate to facilitate the obtaining of national and external funds and to promote policy change in favour of IPM?
- Is there a need to enlarge the IPM Coordinating Committee and to update its mandate?
- Is it necessary to revise the control measures, approved by the Pests and Diseases Committee to better meet the needs of the small farmer and to better support IPM? This applies, in particular, to the use of very toxic broad spectrum pesticides.
- Are pesticide recommendations accompanied with realistic waiting periods and residue levels in view of human safety and export of produce?
- Is adequate attention given to the International Code of Conduct on the Distribution and Use of Pesticides and the Prior Informed Consent clause when pesticides are registered?

The overall responsibilities of the collaborating institutions were rather clear during the FAO/ARC IPM project implementation, although not well-defined. After the recent redistribution of responsibilities between the federal and local governments and the transfer of the extension directorate to the ARC, there is a need to clearly define the responsibilities for IPM research, field validation, training of trainers, training of farmers, monitoring and evaluation to prevent duplication of effort and to facilitate the mobilization and use of national and external funds.

Sustainable Integrated Pest Management by the Ministry of Agriculture

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Gezira State is considered the most important state in vegetable production in the Sudan;thus the State Ministry of Agriculture has always considered the IPM programme as a top priority (see Saoud M. Saad Eldin in this volume). The Ministry of Agriculture introduced IPM into the extension and training programmes in the 1991/1992 season. The rationale was that many problems had arisen from the heavy dependence on chemical control of vegetable pests in Gezira State. These problems can be summarized as follows:

- Overuse and misuse of pesticides;
- Cost of production greatly increased due to high number of sprays;
- Repeated pesticide use in certain vegetable crops and development of resistance by various pests;
- Alarming cases of pesticide-related poisoning (acute and residual effect);
- Increased pesticide use due to farmers' belief that pesticides were an essential component of modern agriculture;
- Pollution of environment.

Implementation Steps in the IPM Programme in Gezira State

At the beginning of implementation, the general sessions were the main training activities to make the public aware of pesticide hazards. Since the 1992/1993 growing season, the Gezira State Ministry of Agriculture in cooperation and coordination with the FAO/ARC IPM Project and ARC researchers has been implementing the IPM programmes as an integrated part of extension, communication and training. The main objective has been to reduce the effect of pesticides on public health, natural enemies and production costs by training and motivating farmers to concentrate on non-chemical means of controlling pests.

In the 1992/1993 season, staff started to organize and conduct specific sessions for farmers and others to provide them with more in-depth information on IPM and related issues. The first application of the Farmer Field School (FFS) concept in the State was during the 1993/1994 season. The 1995/1996 season was considered to be the third year for application of IPM through the FFS in Gezira State. The idea of IPM Rural Women Schools (RWS) was applied in the Sudan for the first time during the 1995/1996 season in Gezira State. Seventeen FFSs and five RWSs were established in the last three seasons in the State.

The performance of FFSs and RWSs have been regularly monitored and evaluated during all seasons through observations and attendance as well as change in participants' knowledge, skills and attitudes towards the IPM principles and practices. Indicators showed that the implementation of FFSs and RWSs in Gezira State is considered successful by all measures.

The FFSs and RWSs have been acknowledged as having significant success by the State Government and the Farmers' Union, and they have been recommended for adoption as participatory approaches which implement new and effective extension and research work in the farming community. Therefore, the State Ministry and Farmers' Union decided to support the FFSs and RWSs financially during the last season by providing about one million Sudanese pounds to guarantee sustainability.

Workplan for the 1996/1997 Season

Based on the last three years' experience, the developed model of FFSs and RWSs in Gezira State will be expanded, assuring continuity through collaborations, cooperation and coordination of all concerned sectors (ARC, State Ministry and Farmers' Union). The FFSs and RWSs workplan for the 1996/1997 season in Gezira State is considered as a continuation of the previous seasons. Weekly field training sessions, demonstration plots, nurseries, general training sessions and field days will be continued and supported by available funding from the State and the Farmers' Union. Additional funding will be requested from UNDP for national programmes.

The aim of the RWSs is to provide rural women with basic knowledge and skills related to establishing IPM vegetable nurseries and home gardens; cultural practices of the main crops; safety measures of pesticide application; child care; home economics; healthy environment; health education; preparation of processed food from vegetables and fruits, sanitation principles. RWS activities will be extended to new areas, including Managil Province and continue in Gezira, Kamleen, Botana and Hassaheisa provinces where there are eight RWSs. Twelve new RWSs will be established accordingly to the available resources. The number of schools will increase by 25% each season. This will be achieved through training of twenty extensionists; promotion of farmers' group leaders as trainers; utilization of every extensionist to organize more than one school per area.

Participants will graduate but are expected to maintain communication with the FFS through monthly meetings. Thirty farmers will be selected to be involved in activities for each school. Table 1 shows location, number of schools, number of farmers, number of cadres of FFS during the 1996/1997 growing season, and Table 2, various school activities. A proposed modified curriculum is shown in Table 3. The organizational structure which was created by the FAO/ARC IPM Project should be sustained (Table 4). Gezira State expects that the established IPM Research and Training Centre at ARC will assist in designing and carrying out training programmes for FFS trainers, participate in monitoring and evaluating schools; and organize the IPM FFS National Coordination Committee.

The running costs of the FFSs and RWSs include transportation, fuel, school preparation, demonstration plot requirements, production of needed training materials and field days. This budget will be available as follows: 50% from the Ministry of Agriculture through its developing budget and the general budget for local councils, 25% support from Farmers' Union and 25% from FFS and RWS participants.

The IPM Research and Training Centre should play a main role in continuity of training and qualifying of IPM FFS and RWS cadres (extensionists, horticulturists etc.) in order to enable them to run the schools effectively. To meet the diversified needs of the small-scale

Table 1. Planned locations, number of schools and number of cadres in FFSs and RWSs, 1996/1997

	No. of schools		Locations				
Province	FFS	RWS	FFS	RWS	No. of participants	No.of cadres	Cadre specialization
Gezira	4	3	Hantoub Hantoub Abu Sugra	Fadasi Hantoub Abu Sugra	120 F+150 RW	9	7 Extensionists, 1 Horticulturist, 1 Plant Protectionist
Kamleen	2	3	El Kasamber Um Dagarsi	El Kasamber Alti	60 F+100 RW	6	4 Extensionists, 1 Horticulturist, 1 Plant Protectionist
Botana	2	1	Rufa'a El Erebab	Banat	60 F+50 RW	5	3 Extensionists, 1 Horticulturist, 1 Plant Protectionist
Hassaheisa	3	2	Ganib Abu Usher Arbagi	El Sadaga Abu Frou	90 F+100 RW	7	5 Extensionists, 1 Horticulturist, 1 Plant Protectionist
Managil	1	–	Managil	–	30 F	3	1 Extensionists, 1 Horticulturist, 1 Plant Protectionist
Total	12	9			360 F + 400 RW	30	20 Extensionists, 5 Horticulturists, 5 Plant Protectionists

Table 2. Workplan for FFSs and RWSs in Gezira State, 1996/1997

Activities	No. of activities	Beneficiaries
FFS	12	12 x 30 = 360 farmers
RWS	8	8 x 50 = 400 RW
Weekly training sessions in FFSs	9 month x 4 x 12 = 432	415 farmers
Weekly training sessions in RWSs	11 months x 4 x 8 = 352	460 RW
Demonstration plots	12 schools x 2 = 24	750 farmers
Nurseries	12 x 2 = 24	850 farmers
Field days	12 x 1 = 12	1,200 farmers
Home garden	8 x 5 = 40	150 RW
Follow up and evaluation visits	20 schools x 2 = 40	760 farmers and RW
Data collection	20 schools x 2 staff x 4 visits = 160	200 farmers and RW

farmers in Gezira State, training materials will be needed regarding FFS establishment; *Orobanche* control; occurrence, distribution and control of nematodes; natural enemies of main pests of vegetables; pests of main fruit trees; pests of main fodder crops and health education.

Regular monitoring and evaluation will be executed through observations, farmers' and RWSs' attendance and changes in participants' knowledge, skills and attitudes towards IPM objectives.

Table 3. New subjects in the 1996/1997 FFS and RWS curricula (for basic curriculum, see Saoud M. Saad Eldin in this volume)

1. Cultural practices of banana, mango and citrus production
2. Cultural practices of main fodder crops
3. Identification of main pests and natural enemies of banana, mango, citrus and fodder
4. Identification of main diseases of banana, mango, citrus and fodder crops
5. Identification of banana nematodes
6. Identification of weeds and their control
7. Maintaining a healthy environment
8. Energy substitution
9. First aid
10. Poultry
11. Forestry

Table 4. Institutional structure and responsibilities of the IPM FFS and RWS network in Gezira State

FFS or RWS Organizer (memberships):
Extensionist or horticulturist in FFS and female extensionist in RWS based in the local extension centre.

Responsibilities:

1. Organizing 1–2 FFS or RWS in the area.
2. Conduct weekly training sessions.
3. Prepare monthly report.
4. Responsible for organization and execution of all IPM FFS or RWS activities.

FFS/RWS Coordination Committee Composition:

1. Farmers' Union —Chairman.
2. Extensionist member.
3. Horticulture Department — member.
4. Representative of Plant Protection Department — member.

Responsibilities:

1. Planning of the schools' programmes and supervision of their execution.
2. Monitoring and evaluation of the schools.
3. Provide requirements and coordinate with different concerned services.

State Coordination Committee Memberships:

1. Senior staff of IPM Research and Training Centre.
2. Members of the FFS Committees.
3. Area representatives of Agricultural Research Corporation.

Responsibility:
Exchange experiences and opinions among members on programme planning, supervision and execution.

Sustainable Integrated Pest Management and Integrated Services for Vegetable and Fruit Farmers in the Sudan

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Vegetable and fruit production comprises more than 12% of the total agricultural output compared to 21% contributed by grains, 15% by cotton and 9% by oil seeds in the Sudan. The main vegetables produced are tomato, onion, eggplant, potato, okra, cucumber, sweet potato and leafy vegetables; while the fruits grown are banana, orange, grapefruit, lime, mango, guava and date. The main production area is along the Nile River in the north and its tributaries in the central and eastern part of the country.

The introduction and expansion of artificial irrigation along the Nile River has not only increased the acreage under vegetable and fruit production but also extended the growing seasons for crops. This factor, together with intensive land use change in agricultural practices and the problem of pests and diseases, has assumed added significance since considerable damage and reduction in yield are evident. Although a limited number of diseases e.g., powdery mildews, attack the horticultural crops, several species of insects of economical importance thrive well under the local climatic conditions. These include whitefly, jassid, aphid, borer and scale insects. Thus, due to the pest and disease problems, farmers prefer to apply pesticides preventively, especially against pests. These chemicals became very expensive recently, and they are now unaffordable to some farmers. Also, not all the recommended chemicals for vegetables and fruits are available. This situation has encouraged farmers to search for other ways to supply themselves with unregistered products of unknown quality, in improper containers and packages from illegal markets.

Due to the fact that the vegetable and fruit sector contributes much to the national gross income from agricultural products, it was vital to look for assistance. To improve the situation, Sudan and Germany agreed to organize and execute a joint project (1986–1994) to increase yield, improve the quality of the product and make production more efficient, considering the increasing demand for these commodities due to population growth and increasing urbanization. Financially, it was agreed that the German Government would supply equipment and inputs while the Sudanese Government was to meet the running cost. This agreement was implemented smoothly between the two partners (Guddoura and Sonnenschein, 1992; Guddoura, 1993).

The Sudanese/German Project "Integrated Services for Vegetable and Fruit Farmers" (ISVFF) was a joint cooperation until 1994 between the Sudanese Ministry of Agriculture and Forestry and the German Ministry of Economic Cooperation (BMZ), represented by the German Agency for Technical Cooperation (GTZ). Presently, the ISVFF is fully supported by the Government of the Sudan.

The ISVFF Project started in 1986; activities were concentrated mainly along the Nile Valley in three states: Khartoum State, Northern State and Gezira State. Fifteen service field stations were established during the 1986–1992 period as follows:

- Five stations in Khartoum State: Karrari, Halfaya, Kadaru, Isailat and Saggi;
- Six stations in Northern State: Berber, Darmali, Kitayab, Elmahmya, Jubarab and Wad Hamid;
- Four stations in Gezira State: In-bagear, Um Dagarsi, Branko and Wad El Hadad;
- One bio-control station in Karima.

Opening of additional stations is planned. The project also aims at strengthening the concerned institutions, mainly the central and state departments of horticulture, extension and plant protection, in their efforts to improve the production of fruits and vegetables, and to transfer knowledge to the target groups. The major target groups of the project are small-scale vegetable and fruit farmers and their families, consumers, government and non-governmental field advisors and date palm farmers in Northern State.

Methodology applied by the project followed modified farming system and problem-solving approaches in its extension and training activities. This means that the farming system, the physical, biological and socioeconomic factors that affect the farmers; their production methods, goals, requirements and constraints were assessed for planning and evaluation and were considered in the implementation of the integrated services work. The practical part of this extension concept concentrated mainly on the process of problem solving from the farmers' point of view and not on the transfer of ready-made series of advice.

The ISVFF Headquarters is based in Khartoum North in the Plant Protection Department. Three committees were created to foster cooperation between the institutions: National Steering Committee, National Technical and Management Committee and National Training Committee. The Steering Committee is chaired by the Under-Secretary of the Ministry of Agriculture, and the Deputy Chairman is the Director General of the Plant Protection Directorate. On the state level, coordination committees were established, one for each state under the chairmanship of the State Director of Agriculture. Four units—Training Unit, Field Unit, Plant Nutrition Unit and Inputs Unit—were established for coordinating project activities with the concerned institutions.

IPM Approach

The surveys conducted in all project areas by the 15 field stations before the initiation of the ISVFF activities revealed that pest control is the main problem facing vegetable and fruit farmers. Accordingly, plant protection activities have comprised approximately 50–60% of the work of the project. However, the misuse of available pesticides by the farmers, lack of knowledge about the dangers of pesticides, limited awareness of correct agricultural practices which reduce pest damage and lack of foreign exchange to purchase pesticides resulted in a challenge to develop an integrated pest control strategy that depends mainly on the resources actually available to the majority of farmers.

The following techniques and methods of IPM were included in training of trainers and farmers and were used in developing crop-specific recommendations:

- Physical methods: Reduction of crop losses through destruction of infected plant parts, pruning as well as regular weeding;
- Cultural methods: Carrying out proper ploughing and levelling, recommended sowing date, adjustment of irrigation and fertilizer application, adjustment of crop density and topping in citrus intercopping;
- Biological control: Introduction of predators and preservation of natural enemies;
- Chemical control: Use of proper, selective pesticides with limited or no effect on beneficial organisms, recommended dosage rates, foliar fertilizers;
- Neem products: Integration of neem products in the IPM programme (Siddig, 1991);
- Training of farmers: Organization of farmers' meetings, provision of technical advice and field days, develop farmer skills and awareness in production and protection of horticultural crops;
- Application of the technical packages: Demonstration of research findings and recommendations in both the field demonstration trials and during the training of farmers.

Project IPM strategy was applied in 15 field stations located in three states and serving 18,000 farmers. The well-trained field advisors are aware of the IPM strategy and its application on different vegetable and fruit crops in their areas. Several crops were selected as a priority in implementing the IPM strategy as described below.

Selection and Proper Use of Pesticides

Vegetables and fruits are consumed by poor and rich people. Proper applications of safe, recommended pesticides is of vital importance. Due to the difficulties in obtaining proper pesticides, farmers often use products for other crops, e.g., cotton pesticides are sold below their commercial value and repacked in unsuitable containers for use on fruit and vegetables. Some farmers apply these chemicals whenever they see any pest attack. In many cases, they use pesticides almost every 2–3 days. For insecticides application, surveys show that about 40% of the farmers use a bundle of grass dipped in a bucket of pesticide solution or a piece of sack filled with powder pesticides for dusting. In addition, farmers use high concentration formulations which pose further health hazards to the users.

The IPM project invented a number of measures to secure safer pesticide management by well-skilled farmers. To begin with, small packaging was introduced. One litre, half-litre, one kg or half-kg amounts in proper containers encouraged smaller purchases of a chemical. The farmers immediately accepted these containers and could afford to buy and use them. Secondly, high toxicity pesticides, such as monocrotophos, dirulfen and methomyl, were absolutely not recommended for use by small-scale farmers. Likewise, there was the introduction of pesticides with reduced concentrations of the active ingredient, e.g., Carbofuran 5% g or 3% g instead of 10% g. The extension station began renting sprayers to farmers which enabled them to use the proper equipment for pesticide application.

Comprehensive training programmes were organized for farmers and included group meetings, open days and field days. These have resulted in considerable reduction in the number of sprays—two per month instead of ten. In addition, farmers now use lower dosage rates and follow the precautions against pesticide hazards. For using neem (*Azadirachta indica*) products, farmers were trained how to prepare neem water extract and powder by themselves. This information along with application method was presented in a simplified pamphlet on neem which was written and distributed to them. Similar pamphlets containing research findings and recommendations for each crop from sowing to harvesting time were also made available.

These measures have created a high level of awareness among farmers. They started to deal with pesticides properly and safely. Subsequently, soil samples and plant parts of vegetables and fruits were taken from areas where the project activities were located. The main purpose was to ensure that fruits and vegetables produced within the project areas and based on the advice given by trained staff do not exceed the international WHO/FA standards set for pesticide residues. Evaluation of pesticide residues was done according to various international regulations (German, FA and EEC guidelines) for maximum residue level (MRL). Results showed that pesticide residues were below the maximum residue level on vegetables and fruits grown in the ISVFF supervised areas.

The project staff has summarized available information on pest and disease control published by researchers of the Agricultural Research Corporation and universities, mainly by staff of Khartoum University. Simple on-farm experiments were also carried out by the project staff in various locations.

Production and Protection of Potato

Potato is gaining increased importance in the Sudan. This crop is subject to severe attack by tuberworm (*Phthorimaea opercullela*). Other pests of potato are the leafhopper (*Empoasca* spp.), cotton aphid (*Aphis gossypii*) and cotton whitefly (*Bemisia tabaci*). Tuberworm damage results in great yield losses. The farmers were very willing to use pesticides whenever the crop was subjected to attack in the field or stores. However, since potato is a tuber crop, chemical control against its pests had to be avoided.

The IPM project applied a package of recommended treatments for the control of potato pests as follows:

- Sowing in the second half of November instead of the first half of December;
- Sowing at a depth of 3 inches instead of one inch;
- Harvesting in early March instead of late March;
- Applying manure and use of foliar fertilizers instead of nitrogen fertilizer which became very expensive and difficult to obtain;
- Spraying with water extract of neem seeds (1 kg seed powder per 20 litres water) instead of using harmful and expensive pesticides. Field results showed significant reduction of potato pests and sound increase in yield.

Production and Protection of Onion

Onion is the most widely used vegetable in the country. The main pest attacking the crop is the onion thrips (*Thrips tabaci*) which is responsible for low yield in many areas. Other serious local pests are the lesser armyworm (*Spodoptera exigua*) and the cotton leaf worm (*S. littoralis*). Thrips attack on onion is heaviest during January–February. Since the insect is very small in size and stays between the leaf sheath and the stem, the farmer cannot recognize it. It is difficult to know when to treat the crop; thus, farmers spray onion even when there are no thrips on it.

The IPM project strategy has depended mainly on teaching farmers about pests as well as the recommended cultural practices to control them. The project field station staff were well acquainted with the ETL for onion thrips which was fixed at 20 insects per plant. The field staff used this figure to distinguish between high and low population densities. This was taught to the farmers who then started to check their fields by themselves. This simple technique has enabled farmers to understand the relationship between the insect and the damage to the crop. They became confident and aware of biological processes and were able to eliminate unnecessary prophylactic sprays. In addition, this showed that such techniques could be taught to farmers, and they can follow through with application.

Onion transplanting should take place during October and November instead of December. This enables the plants to be well established before thrips infestations occur. Spraying with foliar fertilizer should be done the second week after transplanting. Likewise, regular irrigation every 3–7 days according to the temperature and good weeding are necessary. The application of these irrigation and weeding recommendations in one of the field stations resulted in no use of pesticides on the crop.

Production and Protection of Tomato

Tomato is one of the most important vegetable crops in the Sudan. The increasing market demand for fresh and processed tomato has encouraged many farmers to increase production of this crop. The high infection with tomato yellow leaf curl virus (TYLCV), which can result in great reduction in yield, threatened the production of the crop. Farmers failed several times to have good yields. Field experiments to grow tomato in shady houses had limited effect on TYLCV infection. Also, repeated spraying with pesticides to control the whitefly, the main vector of the virus, was not economical. Treatment in seedbeds gave no solution to the problem. However, it was observed that tomato was very rapidly, heavily infested when grown close to other plants which served as host to the virus vector. The project staff observed in the TYLCV infested areas in central Sudan that a number of host plants of the virus vector were found in the tomato-growing areas and served as the source of infestation throughout the year. It was also observed that although some farmers used the vector host plants for intercropping, the main purpose was to grow a shelter of animal fodder.

In 1985, the Nile river annual flood reached such a high level that large agricultural land areas were submerged. There was complete destruction of all remaining plants. After the flood, farmers planted large areas with tomato, no TYLCV infections were observed and a good yield was harvested. This led to the conclusion that the farmers, through their own experience, developed their own IPM approach and used it to solve the problem of the TYLCV. It is clear that the flood destroyed all host plants in the area and eliminated the virus reservoir. Before the vector had time to build-up the infestation, tomato were grown without significant virus infection.

A second high level flood occurred in 1988 and farmers again produced tomato without serious virus attack. The result of these observations could be extended to farmers who grow tomato in the desert under well irrigation where virus vectors are eliminated between cropping seasons. It was also observed that TYLCV was reduced when selected plants were intercropped with tomato (Yassin and Abu Salih, 1972). In an on-farm intercropping demonstration trial, cowpea, lubia and haricot were planted within the tomato area. These crops are known as attractive host plants to the whitefly. The result showed that the infestation of tomato plants was lower and the need for chemical spraying was less than in monocropped tomato.

Biological Control of Date Palm Scale Insects

In the north, along the Nile Valley where millions of date palms are grown, the leaves and fruit were heavily infested with the date palm scale insect (*Parlatoria blancharidii*). Losses were estimated at about 10%. Due to the large infested area, control through the use of chemicals was very expensive and presented health hazards.

The periodical survey made by the project technical staff revealed the presence of indigenous predators—*Chrysoperla carnea*, *Cybocephalus deduchi*, *Pharoscymnus* spp., *Scymnus* spp., a phytoseiid mite and a parasite *Archenomus arobicus*. The successful biological control of the date palm scale insect in northern Africa encouraged project staff to introduce a coccinelid predator (*Chilochorus bipustulatus*) from the INRA institute in Antibe, France. Mass rearing was established on the purple scale (*Chrysomphalus ficus*) grown on pumpkins. Releases were carried out directly in the field where the beetle found large populations of scale insects. Releasing was repeated and the predator established populations in some localities. However, in time, the predator gradually disappeared from the fields, and no permanent establishment could be achieved. After observation of the life cycle of the scale insect *Parlatoria*, it was evident that under Northern State conditions and within various tested biotops, micronatural enemies have a better chance of survival because they seek refuge under the scale cover which offers a suitable microenvironment. Such environment is physically congenial and confers protection against enemies, particularly local migrant birds. This was not possible in the case of *Chilochorus bipustulatus*.

Use of Foliar Fertilizers

The project introduced and tested foliar fertilizers on both vegetables and fruits. Farmers in the project areas applied these fertilizers in their fields. Observations have indicated that treated crops showed reduced damage by insects compared to the untreated plants. This resulted in the decrease of the amount of pesticides required against pest infestation and was proved by a clear tendency to decrease usage of pesticides per unit area and cropping season.

Discussion

The most important problems of vegetable and fruit production in central Sudan were related to pests. Due to misuse of the available pesticides and the high prices of chemicals, alternative approaches were urgently needed. The ISVFF project implemented IPM to contribute to the solution of the problems. Different methods and techniques were adopted and implemented in various localities. The aim was to minimize the amount of pesticides used, encourage safe handling of these chemicals and promote and adopt suitable alternative ways and means of plant protection.

The training programmes organized and implemented were met with farmers' interest, and positive practical results were obtained. The results of the field demonstration trials convinced farmers who later introduced them on their farms and gained benefits. The application of the technical package reduced the infestation of pests and increased the yields (Table 1). The participating farmers showed that they were able to understand and adopt the IPM approaches. The acceptance of this approach by the target group, the small-scale farmers, encouraged the project to continue and extend its activities to

Table 1. Percentage increase in production through IPM implementation in selected areas

Locality	Crop	% increase
Darmali	tomato	25
Darmali	onion	20
Issailat	potato	30
Issailat	eggplant	35
Halfaya	onion	16
Saggi	potato	20

other areas, adding and updating the techniques. Another important point is that farmers, through IPM, gained self-confidence and better understanding of the processes in their fields. Also, IPM can be used as a teaching tool for economic and biological principles. In today's changing world, IPM can enable the farmer to cope better in order to survive under such conditions.

This is a contributory paper.

Research Priorities for Increasing Vegetable Production in the Sudan

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Vegetable production in the Sudan is drawing increasing interest because of the potential high returns per unit area. A wide variety of vegetables are cultivated in various parts of the country, under both irrigation and rain. The popular and widely grown vegetables are tomato, onion, potato, eggplant, okra, hot pepper and cucurbits. In addition to production for local markets, specialized farming for export to Europe and nearby Arab countries is expanding. Melon, sweet and hot pepper, eggplant, okra and snapbean are exportable crops and can fetch high prices in foreign markets. Growing vegetable crops between November and April for export is economically sound, but many technical and production problems prevail. Product availability, harvest season, minimum pesticide residues, damage by pests and diseases, shape, colour and size need to be addressed to ensure continuous supply of good quality produce.

The vegetable production area has increased considerably in the Sudan, but productivity has remained low in comparison to neighbouring countries (Baudoin, 1994). The low yield problem is compounded by the recent increase of input prices. Increasing yield/unit area can be attained by adopting improved technologies and rational use of inputs. Back-up to generate new technologies and adaptive research to verify the technologies under farmers' conditions will ultimately increase yield on a more sustainable basis than in the past.

Environmental Problems

Climatic factors determine the season of the produce. The most important factor is temperature. Vegetables are classified into cool and warm season crops according to their optimum thermal requirement. They are divided into winter and summer crops. This seasonality affects the availability of the produce— abundant in the main season and rare in the off-season, e.g., tomato and okra. There are some advancements in the selection of varieties adapted to adverse environmental conditions.

Usually the best soils are devoted to vegetable production in the Sudan. These are mostly along the river banks and valleys and are characterized by good physical and chemical characteristics. Sandy soils are optimal for root and tuber vegetable production provided that they are well-irrigated and fertilized. Heavy clay soils are not preferred for vegetable production. The pH of the soil is important in determining the availability of nutrients. Neutral pH favours healthy plant growth and balanced nutrient absorption. Excessive alkaline soils cause micronutrient deficiencies, particularly of Fe, B, Zn and Mn.

Vegetables in the Sudan are grown mainly under irrigation, but some are grown under rain, e.g., okra and watermelon in Kordofan plains. To avoid water shortage during growth, vegetables are mostly grown close to a water source. Amount of required water depends on the prevailing environmental conditions and the stage of crop growth. In summer more water is needed than in winter.

Production Problems

Vegetables are mainly grown by small-scale farmers where the land has been fragmented into smallholdings. This renders mechanization for land preparation difficult and economically not feasible. No grower co-operatives exist to group the smallholdings into large ones for easy and efficient use of machinery. Beladi ploughs are frequently used for leafy vegetables.

Weeds can cause damage to crops and can lead to total loss if not controlled. They compete with the crop for light, nutrients, water and space. They interfere negatively with cultural and harvest practices, may be poisonous and act as reservoirs or alterant hosts for insects and diseases. Perennial weeds such as *Cynodon dactylon* (L), *Cyperus rotundus* L. and *Ishaemum afrum* are some of the most serious weeds. Annual weeds such as *Panicum hygrocharis*, *Setoria* sp., *Brachiaria erncíformis* can cause serious yield reductions if not weeded. Serious parasitic weeds like *Orobanche ramosa* and dodder, *Cuscusta*, are spreading fast. *Orobanche* attacks the solanaceous crops but now has a wide range of hosts.

Weed control in vegetable crops should be done as early as possible. Methods of control include ploughing and discing before sowing, hand weeding, earthing up and chemicals (Walter et al., 1984; Babiker et al., 1993 and Babiker, this volume). Hand weeding is good if labour is cheap, otherwise it is expensive and time consuming. If chemical control is used, care should be given to dose, timing, mode of application and its consecutive effects on successive crops. The use of herbicide followed by a supplementary hand weeding could be a good weed control strategy.

Irrigation shortage causes serious reductions in yield and quality. Irrigation water is becoming more and more expensive and scarce due to the high cost of spare parts for pumps, petrol and high evaporative conditions. The quality of water should be considered when irrigating from wells as many have high concentrations of soluble salts that limit its use, especially on land already containing high levels of soluble salts.

The availability of good, reliable, true to type seeds is the initial step in successful vegetable production. The bulk of most vegetable seed is imported from abroad. Apart from the hard currency involved in the importation of seeds, there are problems of viability and purity. The seed locally produced has poor quality because it is usually produced from rejected material. Research on seed production is minimal. There is large scope for improving vegetable seed production in the Sudan because of its suitable climate. Areas like Jebel Marra should be explored for seed production of biennial crops and potato seed.

Losses from insect pests, diseases and weeds constitute one of the major constraints facing vegetable production in the Sudan. Estimated losses have been encountered by the pests roughly at 25% in the Sudan (Guddoura et al., 1984). Tomato suffers from the incidence of whitefly, American bollworm, tomato yellow leaf curl virus, early and late blight and such weeds as *nageel (Cynodon dactylon)*, *sida* (*Cyprus* spp.) and *halouk (Orobanche ramosa)*. The onion crop is exposed to thrips, pink root rot, *nageel* and *sida*. Eggplant is damaged by jassid, whitefly, aphid, tingid bug, mosaic virus, *nageel* and *sida*. Major pests attacking potato are whitefly, jassid, aphid, cutworm, tuberworm, virus diseases, early blight and *halouk*. Okra and cucurbits are both exposed to whitefly, jassid, aphid, virus diseases, powdery mildew as common pests. Egyptian bollworm attack okra, while fruit fly and beetle attack cucurbit.

Vegetables and other common crops are also attacked by different major pests and diseases, reducing their yield to poor levels.

Harvest and Post-Harvest Handling Problems

Good harvesting involves the recognition of optimum time to harvest, correct handling, use of suitable harvesting containers and careful selection during harvesting (Delvague, 1988). The optimum time of harvest is important as it affects subsequent physiological processes. In view of high perishability of vegetables, careful handling during harvest is required, and diseased or damaged fruits should not be mixed with good ones. The use of suitable harvesting containers is an essential element in preserving the quality of the crop (Delvague, 1988).

Proper packing and grading of vegetables is important in keeping produce in a good condition until it reaches the consumer. In export markets, packing constitutes a major problem due to the high cost of imported cartons as the ones produced locally are of inferior quality. Cartons should be strong enough to protect the produce during transport and handling and reach the consumer in a fresh and attractive form. In the local market, not much attention is paid to packing and grading, and often produce like potato, eggplant, okra and cucumber is put into sacks, or tomato is put in tins. Operations of clearing or grading according to quality and size are rarely done.

Storing is usually done for vegetables which are harvested in one operation like potato and onion. They are stored to spread marketing over a period of time, thereby ensuring a reasonable profit. Potato is stored in pits dug in the ground and shaded on top by mats *(rakouba)*. It can be stored in pits up to 2–3 months, and losses amount to 12–15%. Onion is stored also in well shaded and ventilated *rakouba*. This type of storage could last up to 4–5 months, but losses could amount to 40% depending on the variety and the prevailing climatic conditions.

Cold storage is expensive and is usually done for high paying crops like potato. Lack of cold storage at the export terminals for storing vegetables along the route from producer to consumer in case of flight delay or cancellation results in large losses. In the central markets, devices should be worked out to preserve vegetables from dehydration and deterioration.

Although export of vegetable crops started in the early 1970s, the amounts exported are still low and in the best years seldom exceed 3,500 tons. The problems that hinder the export of Sudanese vegetables are infrastructural, production, technical and administrative (Kahil, 1983). Vegetables are mainly exported by passenger planes which charge prohibitive freight rates and only small amounts are shipped due to limited space per flight. Lack of proper handling and cold storage facilitates predisposes perishable vegetables to quality deterioration, sometimes resulting in the rejection of the consignment.

Production and technical aspects include planting varieties in demand in the export market, availability of inputs and, most important, knowledge of exporters with quality standards and specifications. Improvement of cultural practices for maximum yield, improvement of quality and control of pests and diseases using IPM techniques will definitely make Sudanese vegetables competitiveness in exporting markets, and this would ultimately fetch high prices.

Research Contributions to Vegetable Improvement

Vegetable research started in the Sudan in the mid-1960s on the most economically important and popular vegetables grown at that time: tomato, onion, okra, eggplant, pepper, potato and cucurbits. Research commenced by introducing foreign varieties which were compared with various cultivars in various agro-ecological zones. The introduced varieties of tomato, eggplant, potato and melon showed higher yield and better quality than the local cultivars. Tomato varieties Early Pack, Ace, Strain B, Pearson, Peto 86 and U.C. 97-3; eggplant varieties Black Beauty, Early Long Purple and Wizzo; sweet pepper California Wonder; watermelon varieties Congo, Charleston Gray and Early Mexican; and potato varieties Alpha, Draga, Spunta, Ajax, Famoza and Nicola have gained popularity among farmers and are now widely grown.

On the other hand, local cultivars of onion, okra and hot pepper demonstrated better performance than the introduced ones. In the case of onion, most of the cultivars grown are of local origin. The breeding work on onion culminated in the release of white, yellow and red varieties which have high dry matter content, pungency, good storage ability and low percentage of premature bolting incident. Okra varieties suitable for winter production were also released.

In the area of developing disease resistant varieties, two tomato varieties, Sennar 1 and 2, resistant to TYLCV were released by the Agricultural Research Corporation; another variety, Giha, was released by the University of Gezira. Other resistant lines are under final field testing (see Sadig Omara in this volume).

Research on cultural practices on vegetables was simultaneously carried out with the breeding work. A lot of information was generated regarding sowing dates, methods of planting, nutrition requirements, plant population, irrigation, ridge and bed orientation for the important vegetable crops. This on-station research was later followed by on-farm research to verify these technologies in cooperation with extension and develop packages and demonstrate them to farmers.

The list of insecticides and fungicides approved by the National Pests and Diseases Committee for commercial use, includes 49 chemical compounds. The recent identification of IPM packages for tomato, onion, eggplant, potato, okra and cucurbits is a sizable achievement in the field of vegetable crop protection (Dabrowski, 1994).

Major Problems and Research Strategies

The main problems of tomato production are high temperature in summer, occurrence of diseases (TYLCV, powdery mildew), a parasitic weed (*Orobanche ramosa*) and lack of nutritional and agronomic studies for the newly released varieties, e.g., Sennar 1 and 2. Hence, future research should concentrate on breeding for heat tolerance, resistance to TYLCV, powdery mildew and *Orobanche ramosa* and selection of suitable varieties for processing. The agronomic aspects of the newly released tomato varieties should be studied. It is also important to develop and improve nursery techniques for growing healthy tomato seedlings to reduce damping-off disease and protect seedlings against the whitefly which transmit TYLCV.

The released onion varieties have already deteriorated with regard to premature bolting incidence, colour, pungency and uniformity. Onion Yellow Dwarf Virus and thrips constitute major problems in onion. Pink root rot is spreading in areas of intensive onion cropping. Weeds cause serious losses in nurseries and where onion is grown from direct seeding. Purification and maintenance of released onion varieties is a research priority. The search for resistant varieties to pink root rot and thrips is important. It has been noticed that the open leaf varieties are tolerant to thrips while the compact ones are susceptible. The Onion Yellow Dwarf Virus is transmitted by aphids. Use of neem extracts to repel aphid vectors is a possible control method. Onion is a poor competitor to weeds during the initial stage of development. Hand weeding is difficult and time consuming. The use of selective herbicides followed by supplementary hand weeding could be a good practice for weed control in direct seeded onion.

Research priorities for potato include continuation of testing of introduced varieties and production of planting material ('seed' tubers) with adaptation to heat, early maturity and disease resistance. Varieties resistant to *Orobanche ramosa* should also be investigated. Local production of planting material is of utmost importance as the price of imported "seed" is prohibitively high. It is necessary to improve existing "seed" potato multiplication procedures and pave the way for implementation of a national seed programme based on available basic research data.

In okra, the following research areas need to be studied: purification and selection of resistant varieties to powdery mildew and TYLCV; collection, evaluation and conservation of okra genetic resources and improvement of cultural practices for newly released varieties.

The sweet melon *galia* is an important export vegetable. Wilt disease complex causes serious losses and needs intensive research work. The second problem is the high cost of hybrid seed. Research to produce hybrid seeds locally should be considered.

Minimal research has been done on improvement of seed production.Study on cultural practices to improve seed yield of the most important vegetable crops is needed. Intensive research on exportable vegetable crops is greatly needed to determine varieties that can be grown for foreign markets. Post-harvest handling, packing, grading and marketing problems should be studied.

A survey conducted in 1990 showed that over 80% of vegetable farmers were regularly using insecticides on vegetables (Siddig and Sharaf Eldin, 1990). A number of cases of overused pesticides was noted. Consequently, the outcome of this irrational use of pesticides was the development of resistance in pests like the whitefly, followed by pest resurgence leading to even more intensive pesticide use and thus to higher production costs and limitations to the export of vegetables. Further, the misuse of pesticides has led to the destruction of natural enemies and exposure of vegetable producers and consumers to risks of poisoning.

Based on this situation, the need for practising IPM on vegetable crops became obvious. Since 1993, the FAO/ARC IPM Project has initiated training of farmers on integrated control measures with the following components: cultural control measures; preservation of natural enemies; chemical treatment on need bases only with emphasis on the use of selective chemicals applied in a safe manner for producers and consumers (Dabrowski, 1994).

Traditional extension methods have also proved not to be very effective. Instead, it was recommended that farmers should be provided with the necessary knowledge and understanding of the local agrosystem that enables them to analyze options and take their own decision instead of receiving packages of technology for implementation (Dabrowski et al., 1994a).

Thanks to the FAO/ARC Project, IPM systems, including Farmer Field Schools, were practised during the last three seasons on vegetable crops. However, as the FAO IPM Project will cease in October 1996, government commitment to the IPM system, including funding and pesticide policies in support of IPM, is greatly needed.

Research to Improve Integrated Pest Management Options for Vegetables in the Sudan

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There is little doubt that the IPM approach is accepted worldwide for the management of agricultural pests. In Sudan, the concept as well as some IPM options have already found their way to the farmers through the Farmer Field Schools (FFSs), an activity of the FAO/ARC IPM Project initiated in 1993.

For a sound IPM programme, the basic elements as well as main and potential components must be studied first. These include natural control, pest biology and ecology, sampling and economic levels; cultural, biological and chemical control; host-plant resistance and pest management. The sound components are the ones that will find their way to farmers' fields as IPM options. Research priorities regarding these options and their further improvements, which involve a dynamic process, have been identified and based on field observations, discussions with farmers during the FFS activities and literature reviews. Most of those priorities have already been taken care of in the Crop Protection Research Centre's future programme of work. Some of the IPM options have already been tried with farmers by ARC researchers. Further improvements of these options and others will lead to more sound IPM technology. In every case, the main objective is the reduction of pesticide use in vegetable crops. For ready adoption by farmers, IPM options should be cheap, within reach of farmers' hands, easily applied and able to increase yield or decrease cost of production.

Insect Pest Control

The implementation and perfection of the recommended cultural practices will continue to be the core activity of IPM in vegetable crops. Mohammed (1995c) compiled the recommended cultural practices for vegetable production in central Sudan. The expected results of the implementation and perfection of these cultural practices will be less insect pest incidence due to the removal of the alternate host plants or more crop tolerance to insect attack. Elamin (1996) found that well-established, irrigated and fertilized onion plants withstood as high as 62 thrips per plant without showing the expected silvery appearance symptoms of damage. However, Kannan (1996) reported that 30 thrips/plant led to complete destruction of onion plants under water stress conditions.

The use of sesame oil to combat whitefly, the vector of TYLCV on tomato was recommended by Yassin et al. 1982 after three seasons of field experimentation. Sesame oil at 2–3% as oil water emulsion + Agaral (or liquid soap) as detergent, proved to be effective, safer, leading to significant decrease in TYLCV and significant increase in yield. However, to give such results, sesame oil should be applied to well-established tomato plants where irrigation water is not a limiting factor (Elamin, 1995).

Siddig (1991) recommended using neem leaf and seed water extracts against the insect pests of okra and potato. The application of the neem extracts should be extended to insect pests on other crops such as onion, eggplant and cucurbits. Gasm Elseed (1995) obtained good results with neem extract against the whitefly on tomato at Fadasi village.

Abdelrahman et al. (1995b) recommended the stoppage of insecticide application against the whitefly on tomato at 50% fruit setting. This recommendation was violated by the application of insecticides to control American bollworm after the 50% fruit setting. Now there is a need to find a biocontrol agent such as *Bacillus thuringiensis* or an insect growth regulator or a plant extract to control the American bollworm on tomato fruits to have a vegetable product free from any insecticide. Additional work should be initiated to increase IPM options against insect pests as follows:

- Using *H. armigera* sex pheromone trap and the bacterium, *B. thuringiensis*, for monitoring and managing *H. armigera* in tomato fields during the reproductive phase of the crop;
- Expanding the use of the large yellow sticky traps, especially in small vegetable holdings, to minimize the number of whitefly, jassid, aphid and leaf miner;
- Use of the yellow sticky traps in large vegetable holdings to monitor the first appearance of whitefly, jassid, aphid and leaf miner and their subsequent build-up, i.e., as a forecasting system and hence to aid in the timing of chemical application;

- Testing the efficiency of the insecticidal soap such as Savon Insecticide of Safer Ltd (K salts of fatty acids) which controls aphid, whitefly, mealy bug and soft brown scale;
- Application of granular formulations of insecticides for the management of insect pests of vegetable crops since such formulations are less toxic to natural enemies than spray forms;
- Mixing lower doses of recommended insecticides with oils.

Development of IPM Strategies for Plant Diseases

Damping-off disease is important in small-seed crops, e.g., tomato, onion, eggplant, sweet and hot pepper. Causal pathogens are soil-borne fungi that prevail in the Sudan soil. These are non-specialized pathogens with wide host range. The factors affecting disease development are poor land preparation, excessive irrigation (quantity and watering interval), farmers' attitudes towards the use of untreated seeds and high seed rate. The disease is known to cause economic losses in tomato and onion nurseries established on flats. IPM strategies have already been effectively used by farmers to control the disease. These include fungicide seed dressings, by proper land preparation, establishing transplants on flat ridges, sowing seeds thinly in groves and light watering.

The epidemic of TYLCV in the Sudan has become very serious. The virus is transmitted by the whitefly *(Bemisia tabaci* [Genn]). Transmission is higher in hot months than in cool ones. The vector transmits the disease from tomato to tomato and other host plants among the solanaceous vegetable crops and some weed flora (Yassin1975; Yassin and Abu Salih, 1972, 1977; Yassin et al., 1982).

A number of resistant tomato varieties such as Sennar 1 and 2 and Giha were released to be augmented by cultural and chemical methods in a system of integrated disease management. However, these varieties are only available as breeder seeds and are not yet commonly available to farmers. The only practical management options to successfully contain the disease to an acceptable low level of infection is by using cultural and chemical methods in a complementary approach. Thus, advice on control may combine intercropping with coriander *(Coriandrum sativum)* as a repellent to the whitefly, removal of weed alternative hosts to the disease (e.g., *Datura stramonium, Acalypha indica* and *Solanum dubium)* as well as spraying soft insecticides when necessary. This IPM approach successfully contained TYLCV in winter tomato to an economically acceptable level. Coriander is a winter crop and cannot be intercropped with summer tomato when the disease is more serious.

In the Sudan, powdery mildew (PM) is widespread, affecting all vegetable crops especially in winter and resulting in high economic losses in tomato and cucurbits. There can be little doubt about the leading role of chemicals in controlling PM in tomato and cucurbits. Fungicides are the main or even the only useful and economically acceptable means for effective and reliable control at present. Their role is realized by farmers despite the problems they pose and the limitations in view of the needs for integrated management approach. Resistance to fungicides is one of the major problems caused by the exclusive and continuous use of fungicides. To prevent this, a wider variety of technically high grade systemic fungicides was made available to farmers to replace less protective fungicides and to meet IPM objectives (Ahmed, 1995). The potency and systemic nature of these compounds can allow novel application methods to be used. Systemic fungicides are widely used by tomato farmers who strongly believe in the use of calendar spraying to improve plant vigour and health. Farmers have not yet learnt to make full use of the systemic mode of action and curative action of these fungicides. However, farmers participating in the Farmer Field Schools (IPM Project) know how to make proper field diagnosis of PM in tomato and cucurbits and how to manage it in the season before great losses are encountered.

Blossom end rot is a physiological disease that negatively affects the quality of tomato fruits. Research findings by the FAO/ARC IPM Project and collaborators indicated that the disease in Sudan is created totally by the excessive use of inorganic fertilizers (urea), i.e., 29 kg N/ha combined with long watering intervals. One of the IPM options for the control of this disease is to use only 86 kg N/ha in split doses at 4–6 weeks after sowing and at flowering stage to make use of its maximum nutritional benefits.

Bacterial spot of tomato and pepper is an economically important disease affecting both the quantity and quality of crops. The disease is caused by *Xanthomonas campestris* pv. *vesicatoria.* The bacterium may survive between seasons on infected plant debris but disappears from soils as plants decompose. Phytosanitary measures to reduce initial inoculum have little effect on the subsequent development of the disease. Attempts to contain or eradicate disease outbreaks by rotation were not successful as the causal bacterium spreads readily from diseased to nearby healthy soils by rain water. Dispersal occurs more efficiently and covers large areas especially when the rainy season starts early, before any crop establishment.

Prospects of Future Research

Earlier research in the 1980s revealed that summer tomato could be intercropped with *Dolichos lablab* to reduce TYLCV. *Dolichos* is an attractant to virus vector, *B. tabaci*, and non-host to the virus. This will break the virus cycle and consequently reduce incidence of TYLCV. Thus research findings need to be verified and validated in a participatory approach with farmers. Also, the effects of some other crops that can grow in summer and have a repelling effect on the whitefly will be studied to supplement IPM options to control TYLCV in summer tomato. Research at ARC should continue to focus on breeding varieties with resistance to TYLCV.

Although no major problems have so far arisen from misuse of fungicides in the Sudan, training will be intensified to educate farmers to make more intelligent use of systemic fungicides and to change their attitudes towards the use of fungicides without running the risk of losing profits.

An area that calls for more attention in basic and applied research programmes is the spraying application techniques on vegetables. A high percentage of the products applied never reach the final target. Accordingly, improvement is needed to reduce the number of sprays and pollution to the environment. Knowledge of the epidemiology and ecology of PM will enable exploitation of some cultural measures which can improve the efficiency of chemical control. Diagnosis of the causal agents of PM attacking vegetable crops and weed flora are essential to know the alternative hosts of tomato PM and therefore the integration of cultural practices to facilitate inoculum reduction. Efficient of chemical control of PM greatly depends on the correct time of spraying. It is often thought that the job of a plant pathologist is to predict with accuracy the occurrence of a disease so that control can be achieved with minimum application of fungicides. However, with changing climatic conditions and sowing dates, it seems unlikely that there will be a reliable forecasting system soon. Alternative methods of PM control will be encouraged. One such method is the use of inorganic compounds such as potassium, sulphur and magnesium salts as foliar sprays to be integrated with a single well-timed fungicide spray. Another alternative is the use of neem extract to replace fungicides.

Crop residues and debris serve as major sources of inoculum of *X. campestris* pv. *vesicatoria*. Consequently, burning infected tomato plants can eradicate the disease and have an impact on the soil ecosystem. This is a high priority in disease management in an IPM approach.

Sustainable Weed Control in the Sudan

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The Sudan is the largest country in Africa. It extends from latitude 5⁰ N to 23⁰ N and thus comprises a diversity of ecologocal zones. Agriculture is the mainstay of the Sudanese economy. About 10 million hectares are under cultivation. Expansion of the cultivated area is continuous in both the irrigated and rainfed sectors (Hamdoun, 1979). Many marginal lands have been brought under cultivation. Intensification and diversification of cropping (and hence weeds) have become the main features of Sudanese agriculture.

Weeds, which could be terrestrial, aquatic, annuals, perennials, free living or parasitic, constitute a major biotic factor that constrains crop production. Weeds cause more crop losses in the tropics and sub-tropics than in any other part of the world. It is here that weeds determine how much land a farmer can bring into cultivation (Akobundo, 1991). Weeds compete with crops for natural resources. Furthermore, they may exude toxins or toxins may be produced as decomposition products (Rice, 1984). They also harbour insect pests and disease-causing organisms. The mere presence of weeds may further result in lowering of the quality of the harvested product and in making agricultural production more difficult. In Sudan, unrestricted weed growth invariably causes from 18% to over 80% loss in crop yields (Ishag, 1979).

Examination of the list of weeds published in 1977 by Holm et al., showed that the main species on the list are predominant in Sudan. Those include the perennial grasses (*Cynodon dactylon* and *Ischaemum afrum*), the perennial sedge (*Cyperus rotundus*), the annual grasses (*Setaria pallide-fusca*, *Panicum hygrocharis*, *Sorghum arundinaceum* and *Brachiria eruciformis*), the broad-leaved weeds (*Ipomea* spp., *Corchorus* spp. *Digera alternifolia*, *Osmuim basilicum*, *Heliotropium sudanicum* and *Phyllanthus niruri*, Table 1) as well as *Striga hermonthica*. Aquatic weeds are a major problem in Sudan. The water hyacinth (*Eichhornia crassipes*) is a serious weed in the White Nile. The total water loss due to the presence of the water hyacinth could be equal to 7,000,000,000 m^3. This represents one-tenth of the average yield of the Nile (Hamdoun and Tigani, 1977).

The most troublesome species in irrigation and drain canals are the submerged weeds (*Chara globularis*, *Najas pectinata*, *Ottelia alismoides* and *Potamogeton* spp.), and the emergent weeds (*Echinochloa stagnina*, *Ipomoea* spp., *Phragmites australis*, *Typha angustata* and *Vossia cuspidata*, Table 2). They impede water flow, encourage siltation and harbour disease-causing organisms harmful to humans.

Table 1. Predominant weeds in field crops

Central Sudan:	*Cynodon dactylon* *Ischaemum afrum* *Cyperus rotundus* *Setaria pallide-fusca* *Panicum hygrocharis* *Sorghum arundinaceum* *Brachiria eruciformis* *Ipomea* spp. *Heliotropium sudanicum* *Phyllanthus niruri* *Xanthium brasilicum* *Rottboellia cochinchinensis* *Prosopis chlinensis* *Striga hermonthica* *Orobanche ramosa*

Table 2. Weeds in irrigation canals

Submerged weeds:	*Chara globularis* *Najas pectinata* *Ottelia alismoides* *Potamogeton* spp.
Emerged weeds:	*Echinochloa stagnina* *Ipomoea* spp. *Phragmites australis* *Typha angustata* *Vossia euspidata* *Desmostachya bipinnata* *Imperata cylindrica* *Dieanthium annulatum*

A recent survey in Northern State revealed the dominance, mainly in orchards and irrigation canals, of the perennial grasses, *Desmostachya bipinnata*, *Imperata cylindrica* and *Dicanthium annulatum* (Babiker, 1994). A close examination of the history of infestation by these weeds suggested an inland movement from the Nile bank. Field crops are predominated by *Amaranthus graecizans*, *Chenopodium album*, *Convolvulus arvensis*, *Gynandropsis gynandra*, *Malva parvifora*, *Melilotus indica* and *Sinapis arvensis* (Table 3). *Prosopis chlinensis*, which was introduced into Northern, Nile and Eastern states

Table 3. Predominant weeds in field crops

Northern Sudan:	*Desmostachya bipinnata*
	Imperata cylindrica
	Dicanthium annulatum
	Amaranthus graecizans
	Malva parviflora
	Chenopodium album
	Melilotus indica
	Sinapis arvensis
	Prosopis chilinensis

has encroached into the nearby irrigated schemes. The weed has become a problem in Tokar Delta, New Halfa and the Zeidab schemes. *Xanthium brasilicum*, once confined to Tokar Delta, has become problematic all over the country, especially on canal banks and uncultivated areas. *Rottboellia cochinchinensis* constitutes a threat to sugar cane in Kenana area. The parasitic weeds, *Striga hermonthica* and *Orobanche ramosa*, on sorghum and tomato, respectively, are wide-spread in the Sudan and have caused these two crops to be abandoned in many areas.

Weed Control Practices in the Sudan

In most areas of the Sudan, except the irrigated schemes within the Central Clay Plain, hand weeding is the sole weed control method. The recommended practice is two to three weedings during the first 60 days after crop emergence. However, because of labour shortage and the competition for labour, for which the peak demand coincides with the rainy season, timely removal of weeds is virtually impossible, and considerable yield losses are often encountered.

Since the 1960s, the weed research programmme at the Agricultural Research Corporation has been working towards the development of an integrated weed management (IWM) system. It has been the understanding that weed management should involve successful weed control while maintaining good resource and environmental stewardship. A field abandoned to weeds represents the highest level of resource depletion and is contradictory to the concept of sustainable agriculture. The programme is based on utilization of cultural, manual, mechanical, chemical, biological and ecological methods of weed control in various combinations. At present, weed management systems, based on herbicides, supplementary weeding and manipulation of the crop environment, have been recommended for control of annual weeds in most major crops in central and northern Sudan (Hamdoun and Babiker, 1978; Hamdoun, 1979). However, financial and logistics difficulties restricted the use of these programmes to irrigated cotton and sugar cane.

Two programmes encompassing resistant varieties, fertilizers and herbicides have been developed for control of *Striga* on sorghum. A successful biological control programme using the weevils, *Neochetina eichhorinae* and *N. bruchi*, was developed for the water hyacinth on the White Nile (Beshir, 1979). A combination of biological and chemical control may, however, be more rewarding. For irrigation canals, manual and mechanical weedings are the predominant practices. Herbicides for controlling emergent and bank weeds were used to a limited extent and were later abandoned. Some chemicals showed promise for control of submerged weeds. However, they were considered too risky. In Sudan, canal water is used for domestic purposes. Introduction of the grass carp or white amur (*Ctenopharyngodon idella*) may be more appropriate.

Future Prospects

More emphasis is needed on weed identification guides, weed population models and a system for designing and testing programmes that are tailored to the weed spectrum, stage of growth, density, local environment, fertility level and cropping patterns, while providing environmentally-sound and cost-effective weed control. There is also a need to transfer available weed management technologies, especially recently developed *Striga* management practices, to farmers' fields. Short- and long-term impacts of technology on yield of crops within the context of sustainable agriculture should be demonstrated to farmers and policy makers.

A weed management strategy should be developed for Tokar and El Gash deltas. In these areas, where flood irrigation is practised, a management strategy based on pre-emergence soil-applied herbicide is not suitable. A survey to determine the key weed problems together with farming systems should be undertaken and a suitable management programme worked out.

For aquatic weeds, a management system based on periodic drying of canals, burning or grazing, manual and mechanical weedings and shading should be developed for submerged species. However, for emergent and bank weeds, mechanical weeding should be followed by herbicide as spot treatment. It has to be borne in mind that most of these weeds (e.g., *Typha angustata* and *Phragmites australis*) are perennials with extensive rhizome systems. Mechanical weeding does not provide a solution to these weeds as they regenerate from rhizome buds. Use of herbicides particularly under the monocropping system of sugar cane has led to the development of perennial weeds such as *C. dactylon*. Mechanical weeding followed by herbicide as spot treatment may provide a partial solution to this problem.

Some weeds—*D. bipinnata, I. cylindrica, X. brasilicum, R. cochinchinensis, P. chlinensis, Vernonia pauciflora, O. ramosa* and *S. hermonthica*—are on the increase. These weeds are difficult to kill once established. The seeds of these weeds spread over long distances with crop seeds and planting materials. Phytosanitary measures should be invoked to prevent spreading. A vigilant eye should be kept on imported seeds or seeds obtained from infested areas. Soil movement from infested areas should be discouraged.

Conclusions

The high incidence of weeds is a consequence of vegetation mismanagement. Whatever method of weed control adopted, farmers should be educated on the following:

- The detrimental effects of weeds on crops, particularly during the first 4–8 weeks after crop emergence and hence the importance of timely weeding;
- Importance of proper crop husbandry practices on weed management;
- The crucial role of seeds and vegetative propagules in spread and multiplication of weeds;
- The seriousness of infestation by perennial weeds, particularly on irrigation canals and pumping sites;
- The limitation of hand weeding and/or burning as sole means for control of perennial weeds;
- Weeds such as *D. annulatum* should not be allowed to grow on Abu VIs, Abu XXs or fruit orchards; their establishment could be curtailed by planting of cover crops.

Participatory Approach in the Curriculum of the Agricultural Extension Department, University of Gezira

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Participation Approach

People's participation in rural development was formulated in the mid-1970s amid growing awareness that development efforts were having little impact on poverty. The conventional strategies have seen development primarily as a series of technical transfers aimed at boosting production and generating wealth. In practice, conventional projects usually target medium-to large-scale"progressive" producers, supporting them with technology, credit and extension advice in the hope that improvements will gradually extend to more "backward" strata of rural society. The basic fault in the conventional approach was that the rural poor were rarely consulted in development planning and usually had no active role in development activities. The lesson was clear: unless the rural poor are given the means to participate fully in development, they will continue to be excluded from its benefits. This realization has provoked new interest in an alternative rural development strategy, that of people's participation through organizations controlled and financed by the poor (FAO, 1990a,b).

The basic elements of the new strategy are: *Equity* and *Self-Reliance* which should release the energies of rural people and guarantee that they share fully in the fruits of their efforts. This can be achieved only by enabling the rural poor to take charge of their lives, to make full use of their productive resources and to manage their own activities (Chambers et al., 1989; FAO, 1990a).

Implementation of the participatory approach needs different kinds of field staff than the traditional extensionists. The group promoter is a key agent in any participatory project; the task is to facilitate the development of the group's capacity to organize and manage their own activities. Unlike the "traditional" extensionists, group promoters do not see their "clients" as passive recipients of new technical knowledge: their aim is to work side by side with the poor, building up confidence in their own abilities and promoting their self-reliance. Since this must be done without creating patron-client dependencies, the group promoter's function is essentially that of an intermediary, with three basic roles:

1. Group adviser, strengthening the group's leadership, organizational and planning capacity;
2. Participatory trainer, teaching groups basic technical, literacy and problem-solving skills;
3. "Link person", facilitating communication between groups, government and NGO development services (FAO, 1990).

The participatory approach has been included also in some pilot plant protection strategies, mainly in integrated pest management.

New Challenges in Extension in Pest Management

A number of authors have emphasized that IPM is not a technology and is therefore not something that can be transferred using conventional approaches. Rather, a holistic approach should be used with due attention to production and protection. IPM development should be done in close collaboration with farmers. Their needs should be well known. Traditional extension methods such as classroom training and visit systems in general have not been very effective. This type of training has an objective to teach a farmer a number of technologies, but the inter-relationships between these technologies is often not clear (Schulten, 1994).

Fulfilling the new aims of IPM presents three particular difficulties to extension workers. First, decision tools which will improve farm level pest management are complex, often requiring new cognitive skills as well as new factual and procedural knowledge. Threshold-based spraying, for example, requires a basic ability to work out projected costs and returns, which in turn demands an understanding of the economics of crop production beyond that which a farmer has needed previously. Without this, no amount of teaching the procedures of sampling and pest recognition will help the farmer make appropriate decisions. In the case of still more complex practices, the difficulty is multiplied (Garforth, 1993).

Second, extension workers are often faced with having to contradict earlier advice, as with a move from calendar to threshold-based spraying, or with the removal of a particular product from the list of recommended or permitted pest control chemicals. This can have a damaging effect on the credibility of extension workers.

Third, effective pest management, especially in smallholder agriculture, may require collective activity. Most agricultural extension focuses on individual holdings, with extension workers encouraging farmers to adopt changes on their own farms which will benefit them whatever their neighbours choose to do. However, many pests do not conveniently confine their attention to a single holding. Extension workers therefore find themselves trying to promote collective decision-making and action.

These three difficulties highlight the fact that extension for pest management cannot be reduced to the provision of information and the encouragement of individual farmers to adopt new practices. Examples of extension objectives in pest management are listed in Table 1 (Garforth, 1993).

The FAO/ARC IPM Project in the Sudan has demonstrated that the model developed by the FAO Inter-Country Rice Integrated Pest Control Programme in south and southeast Asia based on participatory approach in their IPM Farmer Field Schools could be implemented also in Africa. The prime emphasis was on implementation of existing knowledge through training, rather than on new research. The extension activities do not focus on transferring specific technologies or bits of information in the Farmer Field Schools. They rather seek to capacitate farmers to take sound decisions by providing some basic principles (Dabrowski et al., 1994a,b; see also Alsaffar et al. in this volume).

The new paradigm of rural development projects needs new kinds of trained people who can meet challenges of the participatory approach by emphasizing, illustrating and exploring the abilities of resource-poor farmers to experiment, adopt and innovate; to give priority to farmers' agendas and knowledge; and who will be able to offer a range of practical approaches and methods for farmer participation in research (Chambers et al.,1989; Scones and Thompson, 1994). The role of extensionist is moving from transfer of technology to animation, facilitation and problemization (Table 2). The Extension Department of Gezira University has already incorporated the participatory approach in undergraduate and postgraduate courses; students' research projects and group training courses for extensionists, field inspectors and subject matter specialists employed by large agricultural schemes.

Extension Education Programmes at Gezira University

The management of the FAO IPM Programme has inspired and mobilized mutually productive cooperation between the IPM team and

Table 1. Examples of extension objectives in pest management (Garforth, 1993)

Objective	Examples
Provide education to develop farmers' knowledge and understanding or teach them new decision rules and criteria.	Life cycle of key pests The concept of economic threshold
Give information to help make immediate decisions, or to store for use in future decision making.	Literature on different equipment Lists of recommended chemicals Current pest incidence in the area
Advise what action to take in present circumstances.	Check pest and damage level in the crop now
Create awareness of new ideas, products or practices.	Concepts of "predators", "beneficial insects", "resistance to disease" Checking pest damage, as a routine activity
Develop cognitive skills needed to handle new kinds of information.	Calculation of pest incidence Calculation of chemical application rate
Train farmers in new practical skills, or carry out existing practices more efficiently.	Sampling within a field Calibration of sprayer Preparation and placement of bait
Facilitate formation of groups for mutual support, economies of scale or more effective action.	"Scouting" groups, to share information on pest levels Rat control groups' for joint action
Encourage farmers' confidence in their ability to adopt new practices.	Show that other farmers in similar circumstances now routinely and successfully use threshold-based decision making

Table 2. New extension activities and responsibilities related to the participatory approach (Anon., 1987)

Terminology	Activities
Animation	Assisting people to think, reflect and act autonomously by helping to build up their intellectual capacities and knowledge base.
Conscientization	A process in which people achieve a deepening awareness both of the reality which shapes their lives and of their capacity to transform that reality.
Facilitation	Assisting people to acquire practical skills, to improve their access to material resources, and to undertake actions.
Participatory rural development	A process of creative change initiated by organized, self-conscious rural people acting in response to their own deprivation.
Praxis	The interplay between action and reflection and the systematic reflection on actions.
Problemization	The posing of reality to the people as a problem for critical reflection.
Self-reliance	An expression of a person's faith in regeneration of powers lost through dependence and exploitation.

Agricultural Extension Department at the University of Gezira. The Extension Department currently offers both undergraduate and postgraduate degrees: Bachelor of Science with extension as a major option, Master of Science in Agricultural Extension and Doctor of Philosophy (PhD) in extension. There has been active cooperation and interaction of department staff and students in these three degree programmes on one side and the IPM programme on the other. A fourth programme is a series of short training courses offered for workers in major agricultural production corporations such as Gezira, Rahad and New Halfa schemes.

The Extension Department also coordinates short-term training for students of various agricultural specializations offered by the departments of Crop Science, Soil Science, Environmental Sciences, Agricultural Economics, Plant Protection, Horticulture, Agricultural Rural Engineering, Animal Production, Food Science and Agricultural Extension and Training.

Students graduate with a Bachelor of Science honours degree after successfully attending ten semesters at the faculty. A semester comprises 15 weeks of study. In the first six semesters, all students take basic agricultural sciences. In the last four semesters, students select options. Each department provides an option. During the seventh to tenth semesters, students take extensive courses in extension and related subjects. Extension courses emphasize involvement of farmers in different stages of problem-solving and the participatory approach.

A Master of Science in extension is awarded either by courses and research or by research only (Table 3).

Table 3. Requirements and number of credit hours for the MSc degree in agricultural extension at the University of Gezira

Requirements	No.of credit hours
1. Rural sociology	3
2. Communication process and diffusion of innovations	3
3. Comparative agricultural extension systems	3
4. Introduction to continuing education	3
5. Administration of extension and training	3
6. Group and participatory extension methods	3
7. Rural community development	3
8. Research methods in educational and social sciences	3
9. Statistics applied to educational sciences	3
10. Thesis	6

Research and preparation of a PhD thesis is the only requirement in the PhD degree programme. PhD candidates could be helped by taking some courses if supervisors recommend the provision of "deficiency courses".

The Extension Department is currently developing a one-year Postgraduate Diploma in 6-extension for field inspectors of the Gezira, Rahad and New Halfa schemes. The objective of the new programme is to equip field inspectors with knowledge, attitudes and skills that would enhance their proficiency in implementing the participatory approach. No student is involved in this programme yet since it is not finalized. It is intended to meet the needs of the field workers working with farmers rather than university teaching and/or research.

The Department has offered regular short courses on extension and other agricultural subjects to agricultural scheme staff from 1988 to 1991. Since 1993, the FAO IPM Project has again extensively involved the department teaching staff in courses given to the Gezira and Rahad field inspectors on the participatory approach through a series of workshops.

The department also accepted an offer from the management of the Gezira scheme to prepare a series of short training courses (3 months) for field inspectors aimed at promoting the proficiency of these trainees on extension methods based on the participatory approach. This training course is designed to cover the following areas:

- Theoretical, philosophical, social and economic foundations of extension work to promote change in the attitudes of inspectors towards the participatory approach as opposed to an authoritarian approach;
- Extension systems and methods with emphasis on farmers' participation;
- Communication, diffusion and adoption;
- Principles of programme planning and evaluation.

Undergraduate Student Projects Related to the FFS Approach

Three out of the group of six students graduating this year with a Bachelor of Science, major extension, have prepared graduation projects related to IPM Farmer Field Schools. The first report was written by Maha El Zein who evaluated the use of live specimens as a teaching tool in the IPM field training of farmers in the FFS at the village of Fadasi. This study aimed at assessing the effectiveness of presenting live samples and site drawbacks as a teaching tool by identifying the level of farmers' knowledge before and after they were trained in the fields; assessing the amount of added knowledge; identifying the percentage of change in farmers' knowledge after joining the FFS and evaluating using live insects in weekly training sessions.

A questionnaire was developed for gathering data from participating farmers on the use of live samples in practical training on tomato and onion crops and on identifying "farmers' friends" at Fadasi El Halimab FFS area. The author concluded that the scientific knowledge of farmers about pests of tomato and onion was higher among school participants compared to those who did not join the school. The FFS participants secured higher grades in precise knowledge on the location of pests, symptoms of diseases and the optimal method used in management of pests and/or diseases of onion and tomato (Table 4). FFS participants also collected higher yield and return from their crops (Table 5). The FFS should continue to use live specimens as the major extension method for teaching farmers. The extension programme of the FFS should be expanded to include social interaction between FFS participants and non-participants to encourage the transfer of lessons learnt by participants from weekly training to non-participating farmers.

The second graduation research project, entitled 'What farmers expect from Farmer Field Schools', was prepared by Omer Abdel Maboud Abdallah. He evaluated farmers' expectations regarding cultural relations, social interactions, rural family, rural women's work (home economics and home-made food processing from vegetables and fruits) and local community development. He also assessed the FFS methods used to provide its services to farmers. The interviewed farmers said that the school did not meet all farmers' expectations; all farmers reported that they were expecting much more from these schools in various activities and areas. Farmers disagreed between themselves on their evaluation of the methods used by the FFSs. Most of the farmers preferred the teaching to be done by the trainer team, while a minority suggested that the teaching should be done by subject specialists on the subjects offered in the FFS. The student recommended that the FFSs should be sustained and that the FFS programme should, in addition to teaching IPM-related subject, include some other subjects relevant to the expectations and needs of the farmer community.

The third graduation project was prepared by Amal Elsafi Mohamed. She evaluated farmers' participation in IPM FFSs by assessing the level of participation of farmer at programme planning, execution and evaluation levels. The study was carried out at Fadasi Al halimab village north of Wad Medani, Gezira State. A survey of major results are reported in Table 6. A majority of farmers evaluated their participation in FFS planning activities, execution stage and evaluation positively. A majority of farmers (60%) commented that the FFS did not help them define and find solutions to their urgent problems during the growing season (probably other constraints than those related to pest and disease management). They tend to believe that extensionists, researchers and other officials should find proper solutions. Amal Elsafi recommended that an educational programme should be prepared to promote farmers' abilities to define their own problems and generate solutions to them. She also recommended the generalization of FFS at a larger scale to involve more farmers.

Participatory Approach in Graduate Students' Research Projects

The participatory approach in agricultural extension, including IPM programmes, is presently included in the majority of graduate

Table 4. Comparison of knowledge in identifying pests and diseases and their natural enemies, Fadasi area, 1995/1996, after Maha El Zein, 1996, unpublished

Knowledge of:	% of correct answers FFS participants	Non-participants
TOMATO		
Whitefly		
Primary knowledge (identification)	100	100
Location of insect on plant	100	100
Optimal insect management	80	
American bollworm		
Primary knowledge (identification)	100	100
Location of insect on plant	100	100
Optimal management	100	20
Aphids		
Primary knowledge (identification)	100	100
Symptoms of presence on plant	100	100
Optimal management	80	0
Bacterial leaf spot disease		
Primary knowledge	100	80
Knowledge of disease symptoms	100	80
Optimal management	100	20
Early blight disease		
Primary knowledge	100	100
Symptoms of the disease	100	100
Optimal management	100	60
ONION		
Thrips		
Primary knowledge (identification)	100	100
Fusarium wilt disease		
Primary knowledge	100	100
Symptoms of the disease	80	80
Optimal management	80	30
Farmers' Friends		
Primary knowledge	100	40
Differentiating from harmful insects	100	40

students' projects in the department. A PhD proposal of Simon Demada (a lecturer at the University of Juba and registered at the Gezira University with Dr Mohamed Bedawi Hussein as his major supervisor) is directly linked with the present work of the FAO/ARC IPM Project. The subject is the FFSs System of agricultural extension and is an investigation into FFS effectiveness with reference to IPM. Demaya's objectives are to find out the validity of the FFS as an alternative extension model that would improve farmers' adoption behaviour and to assess the suitability of FFSs for a rainfed farming system in Blue Nile State (Damazin area). Demaya is using the following criteria: increase in production levels, increase of farmer income, improvement in standards of living, diffusion (adoption rates and their distribution in the target groups), evaluation of contacts between extension services and target groups and assessment of the programme by the target groups.

An MSc degree research project, "Adoption rate of tomato IPM options in Gezira scheme and along the Blue Nile Farmer Field Schools" is being carried out by Nadir Saadabi, an IPM extensionist. He is in the final stage of writing his thesis. Dr Mohamed Bedawi Hussein is his University supervisor and Prof Z.T. Dabrowski, the IPM Project's supervisor (see Nadir Saadabi et al. in this publication).

An MSc study is being done by Ahmed Mirghani, an extensionist at El Hag Abdallah area and a coordinator of the FAO/ARC IPM Project in Gezira State. His study will include evaluation of the factors influencing the process of adoption of IPM options by vegetable producers at El Hag Abdallah area.

Conclusions

The participatory approach is now very obvious in teaching and in students' research projects in the Extension Department of Gezira University; 50% of the undergraduate students (three out of six) have carried out studies directly related to FFSs.

Table 5. Comparison of yield and returns from tomato and onion crops, Fadasi area; after Maha El Zein, 1996, unpublished

Crop	FFS participants	Untrained farmers
Yield		
Tomato	10.4 t/feddan	4.3 t/feddan
Onion	138 sacks/feddan	59 sacks/feddan
Return		
Tomato	390,000 S£	204,000 S£
Onion	440,000 S£	294,000 S£

Table 6. Evaluation of farmers' participation in planning, execution and evaluation of the FFS in Fadasi Alhalimab village; after Amal El Safi Mohamed, 1996, unpublished

Participation in following activities	Positive response (%)
Planning stage of the FFS	74
Execution stage	84
Evaluation of the FFS	81
FFS response of farmers' problems	40

Ms Zein confirmed that using live specimens in the FFS was the most efficient method for teaching about pests and diseases occurring on vegetable crops. The differences between FFS participants and non-participants were mostly noticed in their knowledge on the optimal integrated methods of pest management. She recommended including a social programme in the FFS curriculum to promote interactions and dissemination of new information between farmers attending the FFS and untrained farmers.

Mr Maboud observed that farmers attending the IPM FFS in Fadasi in the 1994/1995 season expected much more information on the cultural and social interaction between agricultural production and rural family and community development than what was offered. The interviewed farmers preferred the training sessions carried out by the IPM Project's training team to teaching by subject matter specialists. Participants recommended continuation of the vegetable FFS, its sustainability and learning by working in the IPM field during another growing season.

Ms Amal Elsafi acknowledged farmers' participation in planning, execution and evaluation of the FFS organized in Fadasi area but noticed a weaker response in identifying farmers' urgent problems and generating solutions. The FFS curriculum should be strengthened to identify farmers' problems and answers to them.

In addition to student project supervision, teaching staff of the Extension Department are often involved in group training courses and workshops organized for field inspectors and extensionists by the FAO/ARC IPM Project.The Department has initiated discussion with the Gezira scheme management to organize systematic courses on agricultural extension (including organization of FFSs) for their field staff.6.

Research in Vegetable Protection at the University of Gezira

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Vegetables play an important role in the human diet. They are an essential source of vitamins and minerals and are useful in neutralizing the acid substances resulting from the consumption of animal protein and other kinds of food. In Sudan, research on vegetables has not received as much attention as field crops. Active research on vegetables is now going on in the integrated disease management at the Plant Pathology Research Centre (PPRC) in collaboration with some French institutions, in particularly the Institut National de Recherche Agronomique (INRA). The objectives are to upgrade farmers' awareness of diseases and the extent of damage they can cause and to provide vegetable farmers with technical packages composed of highly-resistant good quality and high-yielding vegetable varieties; improved, less laborious and cost/profit efficient cultural practices; and reliable, environmentally-safe and inexpensive pest control methods.

The ongoing on-station and on-farm research topics at the PPRC of the University of Gezira are as follows:

1. Tomato breeding for resistance against TYLCV;
2. Studies on *Orobanche* sp. in tomatoes and other solanaceous vegetables;
3. Studies on seed-borne tomato diseases, fungi, bacteria and viruses;
4. Studies on watermelon chlorotic stunt virus (WCSV);
5. Studies on the variability of zucchini yellow mosaic virus (ZYMV) in the Sudan;
6. Breeding for resistance against ZYMV in squash;
7. Studies on cucurbit aphid-borne yellow virus (CABYV) in melons;
8. Fusarium wilt of melons;
9. Powdery mildew (PM) of cucurbits;
10. Production of virus-free garlic.

Future programmes include the biological, ecological and economic importance of leaf miner in central Sudan; screening PM species and races against the currently used fungicides in the Sudan; and investigating PM in tomato and other solanaceous crops.

Tomato Breeding Against TYLCV

Tomato yellow leaf curl virus (TYLCV) is the most important disease of this vegetable crop in Sudan. Chemical control of the vector as well as other cultural practices have not yet proved satisfactory in reducing its damage. Resistant varieties were long thought of as the ultimate weapon against this disease. The line EC-UG-104 90-1, recently recommended by the National Release Committee under the commercial name *Giha*, is highly tolerant to TYLCV. Other promising lines which were tested include TY52 (processing tomato) and FC-94-14 Chipertylc; both proved promising against TYLCV in the Gezira. The performance of these lines was tested under field conditions and compared with the locally grown cultivars. Seeds were sown in mid-October in 1995, and transplanting was done during the third week of November. The experimental site was selected near Fadasi village (20 km north Wad Medani) in relatively light soil with good percentage of silt and the farm was irrigated by pump. The experimental area (a total of 90 wide ridges, each 10 metres long) was situated in the middle of the field which was surrounded by farmers of tomato crop (Peto 86, UC 82) which were estimated to have 10% infection with TYLCV at the time of transplanting the experimental lines. The FAO/ARC IPM Project GCP/SUD/025/NET provided necessary funds for on-farm validation experiments.

Results showed that one month after transplanting, the disease incidence attained 100% in an area of 3 feddans, and the farmer was compelled to destroy his crop. With regards to the experimental lines cv. Giha, Fiona and TY52, no disease incidence was reported up to fruiting time. At the end of the season, mild infections of about 2% in Giha, 3% in TY52 and 12% in Fiona were reported, while Peto 86, UC 82 and Gadambalia (local collection) were 100% infected with TYLCV.

As for fruit yield, the farmer was able to harvest only about 2 tonnes of marketable fruits from an area of 3 feddans. The average production was less than one tonne/feddan of Peto 86 and 1.2 t/feddan for UC 82 compared to

8.2 t/feddan for cv. Giha. Seed production from some selected lines was done particularly from cv. Giha which yielded average seeds of 6.9 g/kg of fruits and a total of 4.1 kg of seeds was obtained. Seed yield from other lines and control did not exceed 3 g/kg of fruit. Therefore, the objective of this programme is to develop resistant varieties well adapted to local Sudanese conditions (e.g., heat tolerance) with good fruit quality. This breeding work is now actively going on in collaboration with INRA, with the following objectives:

- Search for resistant sources in wild tomato types, *Lycopersicon pimpinellifolium*, *L. chilense*, *L. chesmanii* and *L. hirsutum*;
- Creation of resistant population through crosses with commonly grown tomato varieties (e.g., Strain B);
- Introduction of tomato varieties and breeding lines and crosses directed towards TYLCV control;
- Screening of F_1 hybrids developed by commercial seed companies.

Studies on *Orobanche* sp. in Tomato and Other Solanaceous Vegetables

Orobanche sp. is becoming increasingly important in tomato crops especially in silty soils along the Blue Nile bank. During recent years, rapid southward spread of this parasite has been noticed. Many farmers have already stopped growing tomato as a result of heavy infestation. As a result of this problem, a programme was setup to identify the different species and strains of *Orobanche* in Sudan. Further objectives were to study the geographical distribution of *Orobanche*, its biology—parasitism, ecology and host specificity— and control methods (cultural, chemical, resistant varieties).

Experiments were carried out in farmers' fields near Fadasi village (20 km north of Wad Medani). The whole farm area was known to be highly infested with *Orobanche*. The experimental area was situated in the most heavily infested parts of the farms during the 1995/1996 season.

The results showed that in the 17 farmers' fields surveyed in Fadasi area, the incidence of the parasite weed was high (ranging between 40 and 100%), and most of the farmers had already abandoned growing tomato. Strain B, the most popular variety, was found to be very susceptible to infestation by *Orobanche*. Early planted tomato (October–November) was more affected than the late planted (December–January). The following vegetable crops were found to be hosts for the parasite viz: carrot (5%), eggplant (2%), sweet pepper (1%), hot pepper (1% of infestation); a total of 96 tomato lines and varieties covering a wide genetic background (cultivated and wild type) were tested for resistance. Only two lines showed a very high level of resistance, another eight lines showed good tolerance level and the rest were susceptible. The judgement was based on the number of *Orobanche* shoots attached to the plant and the time of shoot appearance above the ground. It was found that on the most resistant line, the shoots appeared very late. This experiment was partly financed by the FAO/ARC IPM Project GCP/SUD/025/NET.

Studies on Seed-borne Tomato Diseases

Tomato is the most important vegetable crop in the Sudan. More than 90% of the tomato seeds used annually are imported from various parts of the world. In addition to requiring substantial amounts of hard currency expenditures, some imported seeds were shown to harbour many pathogens such as fungi, bacteria and viruses. The research programme intended to isolate and identify seed-borne pathogens from both local and introduced tomato seeds.

The results obtained proved the presence of a seed-borne virus bacteria and fungi. Using differential media and the study of morphological traits, biochemical reactions and some confirmatory tests, five different bacteria were isolated and identified: *Pseudomonas viridiflava* (Burkholder, 1930), *Pseudomonas syringae* pv. tomato, *Xanthomonas campestris* pv. *vesicatoria* (Doidge), *Clavibacter michiganensis* subsp. *michiganensis* (Spiecherman and Kothof) and *Erwinia herbicola* (Lohnis, 1991). This was the first recording of *P. syringae* pv.tomato in the Sudan. *X. campestris* pv. *vesicatoria*, *C. michiganensis* subsp. *michiganensis* and *P. syringae* pv. tomato are pathogenic and cause bacterial black spot, bacterial canker and bacterial speck leaf spots on tomato, respectively.

Fungi were detected by using two incubation methods (Blotter and Agar plate methods). Identification was done under both stero-binocular and compound microscopes. The following fungi were noted: *Alternaria tenuis*, *Aspergillus* sp., *Chaetomium* sp., *Cladosporium* sp., *Fusarium* sp., *Penicillium* sp., *Phoma* sp. and *Rhizophus* sp. Many of these fungi are pathogenic to tomato.

By using the growing-on test and DAS-Elisa, tobacco mosaic virus(TMV) was detected on tomato seed samples. The commercial variety, Strain B, showed high incidence of the disease, which indicates that, the imported varieties are playing an important role in introducing and distributing this disease in the Sudan.

The study has shown that tomato seed is an efficient means for the spread of many seed-borne pathogens; possibly the majority of these diseases, particularly viruses, were introduced into the Sudan through unorganized and uncontrolled seed importation. Therefore, tomato seed-borne pathogens must be taken into consideration during the importation of seeds, and routine seed-health testing must be strictly enforced. The climate in the Sudan is very suitable for vegetable seed production, including tomato; hence, it is appropriate to produce seeds locally to avoid introduction of many pathogens since it is known that:

- Seed-borne inoculum of many diseases is difficult to detect under a binocular microscope;
- Routine seed-health testing methods are developing very slowly;
- Laboratory seed health testing is not available for many seed-borne diseases;
- Seed-borne pathogens may be present at low incidence that may pass undetected in a seed sample.

Studies on Watermelon Chlorotic Stunt Virus

Field surveys have shown that WCSV is the most important and most widely spread disease in watermelon throughout the country. It is the most important single factor responsible for the high yield losses in Gash Delta, Gezira, Shuwak and Um Shoka area near Singa. The disease was only recently reported in the country (Lecoq et al., 1994) ,and some of its genetic characteristics have been studied. Further research work has focused on the molecular characteristics of the virus, epidemiology of the disease, collection and evaluation of the local germplasm for resistance against the virus, the nature of resistance and inheritance studies.

Studies on the Variability of Zucchini Yellow Mosaic Virus

ZYMV is the major disease limiting the production of squash in the country. It was also observed to cause considerable yield losses in melon, watermelon, pumpkin, and *tibish* in various localities in Sudan. Previous studies (Hanan, 1993) confirmed the identity of the virus and indicated its spread in the country. ZYMV is an aphid-borne polyvirus.

The present study aims to further characterize ZYMV isolates collected from various parts of the country in comparison with other strains from other parts of the Sudan in attempts to use cross protection techniques and to investigate varietal susceptibility. This work was carried out through a joint scientific cooperation between the PPRC and INRA.

Squash germplasm was obtained from UK, Cornell University (USA) and the Genebank (USA). Some of the promising plants which were crossed with the commonly grown cv. Eskanderany F_1 plants showed some promise. Other selections were also made within Eskanderany which showed high variability of this character. Some promising lines were obtained. The subsequent selection will be directed towards release of resistant varieties. This research programme is now actively advancing.

Studies on Cucurbit Aphid-Borne Yellow Virus

CABYV, a newly identified virus in cucurbits in the Sudan (Lecoq et al., 1994), is the most commonly observed disease in melons, snake cucumber, *tibish* and watermelon in the country. It constitutes the major factor of premature senescence of these cucurbit species, thus affecting both quality and quantity of production. Some wild cucurbits were found to be naturally infected with CABYV, indicating that they may play a role in its survival under natural conditions. The virus is readily transmitted from naturally diseased melon plants to healthy seedlings of the same species by *Aphis gossypii*. The objectives of this programme were to investigate various epidemiological aspects of the disease, such as transmission, host range, factors affecting disease incidence, severity and varietal response and to screening for resistance using both introduced melon varieties and breeding lines as well as local germplasm collected from the White Nile area. Plant pathologists and breeders are fully involved in this programme and an MSc thesis has been completed in the PPRC laboratory on this project (Kamal, 1995).

Fusarium Wilt of Melons

Fusarium wilt is the most devastating fungal disease of melons in the country. Wide areas grown with Galia type melons for export purposes were reported to be completely wiped out by the disease. Two races of *Fusarium oxysporum* f.sp. melonis, race 0 and race 1, were reported to be present in Sudan (Mohamed et al., 1994). It was observed that other organisms, such as root-knot nematode (*Meloidogyne incognita*), red melon beetle (*Aulacophora africana*) and termite (*Microtermis thoracalis*) were associated with wilted plants, and it is thought that these organisms may play an important role in aggravating wilt disease of muskmelon in the Sudan (Fadlelseed, 1995). The objectives of the programme are to investigate the geographical distribution of the various races in the country, to study the various factors affecting disease incidence and severity, to develop reliable inoculation methods for screening purposes and to search for resistance in local and introduced melon germplasm.

Currently, a PhD candidate is working on resistance breeding and screening for this disease.

Powdery Mildews of Cucurbits

Powdery mildew is one of the most important diseases of cucurbits in Sudan. It causes particularly severe damage to melon (*Cucumis melo* L.), an economically important crop, but also to snake cucumber (*C. melo* var *flexous* Naudin), squash (*Cucurbita pepo* L.) and pumpkin (*Cucurbita moschata* Duchesne and *Cucurbita maxima* [Duchesne]). Among the fungi known to cause powdery mildew on cucurbits are *Erysiphe cichoracearum* DC. and *Sphaerotheca fuliginea*. *Leveillula taurica* has been reported occasionally on cucurbits.

The present study was intended to identify the causal agents of powdery mildew fungi on cucurbits in the Sudan and to determine which physiological races may be prevalent, since it is known that these causal agents differ in their virulence to varieties of cucurbits and in their sensitivity to a number of fungicides. In a survey of cucurbit crops in the Sudan, 234 samples of melon, cucumber and squash showing symptoms of powdery mildew were identified as infected with *S. fuliginea*, while *E. cichoracearum* was observed in only two samples of watermelon showing mild symptoms. *L. taurica* was not observed on any sample. Field trials with differential lines of melon revealed the presence of race 1 and race 2 of *S. fuliginea* in Gezira and race 0 in the Gash Delta (Mohamed et al., 1995).

Production of Virus-Free Garlic

Garlic production is limited to the northern, cooler parts of the Sudan. Efforts are directed towards its adaptation and introduction in the Gezira area. A virus-free variety, Ramses, was kindly sent by Dr H. Lot (INRA-France) for evaluation. The programme started with experimental sites at the University of Gezira farm, Fadasi, Abu Haraz and Massaad. The programme involved a virologist and breeder and is backed by INRA scientists.

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