EX- ANTE ECONOMIC IMPACT ASSESSMENT OF CLASSICAL BIOLOGICAL CONTROL OF DIAMONDBACK MOTH IN HIGHLAND CABBAGE PRODUCTION IN KENYA

By

Macharia Ibrahim Ndegwa
(B.Sc. (Horticulture) Jomo Kenyatta University of Agriculture and Technology)

A thesis submitted in partial fulfillment for the degree of Master of Science in Horticulture,

in the Jomo Kenyatta University of Agriculture and Technology

September 2003

DECLARATION BY CANDIDATE

This thesis is my original work and has not been presented for a degree in any other university.

Signature __________ Date 28/12/03

DECLARATION BY SUPERVISORS

This thesis has been submitted for examination with my (our) approval as university supervisor (s)

Prof. Stephen G. Agong
Department of Horticulture
JKUAT

BOX 62000, Nairobi, Kenya

Signature __________
Date 15/01/2004

Dr. Bernhard Löhr
Plant Health Division International
Center of Insect Physiology and
Ecology

BOX 30772, Nairobi, Kenya

Signature __________
Date 9/01/2004

Prof. Leonard S. Wamocho
Department of Horticulture
JKUAT

BOX 62000, Nairobi, Kenya

Signature __________
Date 19/01/04

DEDICATION

To my entire family and friends.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

List of plates

LIST OF APPENDICES

ACKNOWLEDGMENTS

I owe special thanks to a number of people who in one way or another assisted me during this study. Special thanks to Dr. Bernhard Löhr for sponsoring me towards this study. Your advice, critique and encouragement were highly appreciated.

My thanks and gratitude to Prof. Stephen Gaya Agong, Prof. Leonard Samita Wamocho and Dr. Hugo De Groote whose comments and suggestions greatly shaped this study. I am also grateful to several persons who gave several criticisms of my work. In particular, appreciation to Ibrahima Sarr who gave useful suggestions and Eric Muchungu who introduced me to the use of geographical information system (GIS) package and helped me in mapping cabbage potential areas in Kenya. I thank farmers and extension officers of the Ministry of Agriculture whose cooperation during the fieldwork made the study a success.

It would have been difficult to carry out the study smoothly and successfully without active help and cooperation of Diamondback Moth Project staff members namely Ruth Gathu, Faith Nyamu, Charles Kanyi, Geoffrey Gachanja, Caleb Momanyi and Rose Ogolla.

Lastly but not least, special word of thanks to my entire family for dedicating their time and encouragement toward my education. May the Lord be glorified.

ABSTRACT

The potential economic impact of the introduction of *Diadegma semiclausum*_(Hellen), an exotic parasitoid of the diamondback moth in Kenya was assessed. The study first assessed the crop loss caused by DBM, efficacy of the most widely used pesticide by the Kenyan farmers and farmers' cabbage crop enterprise budgets. This produced base-line data in economics of cabbage production, which were then used to project the economic impact of the introduction of parasitiod. The assessment was therefore, carried out within an *ex- ante* analytical framework, with current enterprise budgets (higher pesticides use and yield loss) being compared to hypothetical ones, where technology application is assumed.

Crop loss assessment trials were conducted in two sites, located in the highlands of Kenya: Limuru (Kiambu District) and Wundanyi (Taita Taveta District) for two seasons. Seedlings of Cultivars, Gloria and Copenhagen Market were transplanted at Limuru and Wundanyi, respectively, in the month of January and June 2002. The design used was latin square design (LSD) with four replicates. Treatments consisted of fortnightly application of: - Lambda-cyhalothrin (Karate, 3.2ml/L): (most common farmers' practice), *Bacillus thuringiensis* (Thuricide, 0.75g/L) a microbial control agent for selective DBM control, Neemroc (neem-oil based botanical pesticide standardized at 0.03% Azadirachtin and 30% neem oil, 5ml/L) and Control (no pesticide application). The information monitored included population density of different pests, crop yields and overall production costs in different treatments.

Thuricide had the lowest DBM populations and the highest yields while Karate failed to control the pest. A negative correlation was obtained in all trials between the number of 3rd and 4th instars larvae and crop yield. Crop losses were calculated between 12-22%, amounting to 2.8 ton/ha with an estimated value of KShs 28,265 per hectare. Karate also turned out to be the least effective chemical as portrayed by the low benefit cost ratio (BCA) and higher cost of production while, Thuricide was more efficient with higher BCA and low cost of production.

Potential cabbage growing regions were mapped using geographical information system (GIS). Farm field surveys were conducted in four major mapped cabbage-growing districts to find out the farmer quantitative estimate of the crop loss with their crop enterprise budget. Yield loss according to farmer's opinion was over 37% while cost of control was estimated to be KShs 2,474/ acre/season.

The economic surplus model was applied to estimate expected project benefits. Project costs amounted to net present value of KShs 81 million while benefits were estimated at 5.57 billions for 20 years. The benefit cost ratio was calculated at 68:1, clearly demonstrating that investing on this biological control was highly profitable.

It is recommended that further detailed studies be conducted per season and per cabbage growing region, with a monetary pay off matrix, damage distribution and yield loss from the DBM be determined at farmers' managed fields and an economic threshold level for DBM be established.

CHAPTER ONE

1.0. INTRODUCTION

Cabbage (*Brasssicae oleracea* var. *capitata* L.) is one of the most important and common crucifer vegetables grown in Kenya. It is eaten raw in salads or cooked and it is an important cash crop in many households. Cultivation takes place predominantly under rainfed conditions although there are few instances where irrigation is used. Cabbages are grown in all of the Kenya's eight provinces at an altitude ranging from over 750 metres. Two major growing provinces include Central and Rift Valley, which jointly make up 82 percent of total national production (Table 1.1). Central Province is the most important cabbage production province with a share of 50.6 percent.

Table 1. **Cabbage production statistics for the Provinces of Kenya (1999-2000 averages)**

Province	**Area (ha)**	**Production (t)**	**Yield (t/ha)**	**Production share (%)**
Central	10,094	132,425	13.1	50.6
Coast	288	4,598	19.4	2.2
Eastern	712	11,844	16.6	4.6
Western	1,236	11,513	9.3	4.4
Nyanza	895	17,380	19.4	6.6
Rift valley	5,686	82,108	14.4	31.5
Nairobi	45	407	9.1	0.1
Total	**18,956**	**261,275**	**13.8***	**100**

Source: Ministry of Agriculture and Rural Development, (1999, 2000)

* Average t/ha for Kenya.

The production does not generate a high income, as the average yield of 13.8 tons per hectare is very low. At an average price of KShs 10 per kilogram, this generates an average of KShs 138,000 per hectare and KShs 2.61 billions per year for the whole production.

There are various factors that influence the yield of cabbage. The most important one being insect pest damage, which can lead up to, 100% yields loss if not controlled (Talekar *et al.,* 1986). One of its major devastating pests, the Diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae), causes damage that is often sufficient to prevent the formation of marketable heads (Barroga, 1974). They also reduce marketability by contamination of the heads with larvae or frass. Synthetic insecticides have been the major component for it control (Talekar *et al.*, 1993; Verkerk and Wright, 1997). The use of chemical pesticide control often leads to serious environmental problems besides affecting the health of users and consumers, eliminating the natural enemies of DBM creating the need for more pesticides and causing considerable residue levels in the subsequent cabbage production, increase of production cost and more so development of resistance. Ironically, in order to overcome resistance, farmers have resorted to applying much higher doses of insecticide cocktails more frequently (Talekar *et al.*, 1993) making control more complicated. To address the problem, International Centre of Insect Physiology and Ecology (ICIPE) initiated a biological control programme by use of a solitary, larval endoparasitiod, *Diadegma semiclausum* (Hellen) which, is save and sustainable. This vast biological control project involved exploratory research to find out the population density of DBM, indigenous natural enemies and their influence on DBM population and introduction, research studies, monitoring, co-ordination, training, awareness creation and impact assessment of the parasitoid.

This study attempts to predict its impact in an *ex –ante* conceptual framework by first assessing the crop loss caused by DBM with the costs incurred in its control and predict how this will be changed by the introduction of the parasitoid.

1.1. Hypotheses

The study was guided by the following hypotheses that were tested either qualitatively or quantitatively.

1. DBM cause a high loss on cabbage.
2. The economic efficacy of insecticide Neemroc, Karate and Thuricide against DBM in cabbage is the same.
3. The introduced parasitoid improves the yield and quality of cabbage at reduced control costs.
4. Economic returns of *D. semiclausum* introduction surpass production costs 20-years after introduction.

1.2. General objective

The general objective of the study was to assess the economic impact of biological control of DBM on cabbage by use of the exotic parasitoid *D. semiclausum*.

1.3. Specific objectives

- To evaluate the yield loss caused by diamondback moth,
- To determine the efficacy and economic significance of pesticides: - Karate, Neemroc and Thuricide in control of diamondback moth,
- Map potential cabbage growing areas of Kenya,
- Assess the potential benefits of the biological control of DBM in quantitative terms and identify the key issues that have to be accounted for in the project design in order to fully reap these gains.

1.4. Justification of the study

It has been cited that collection of quantitative data on the production as well as the losses caused by pest before the introduction of the parasites is crucial for conducting a sound economic analysis of the classical biological control programme (Vogele, 1990). Once the parasites are released, quite often the situation before the release cannot be simulated again. As a consequence, potential benefits cannot be quantified afterward due to lack of pre-release data. These data on yield loss caused by DBM in Kenya are lacking.

On the other hand, biological control assessments, has minimum use of participatory methods (i.e. farm field comparison to the researcher's experiments) and the impact in many cases is only studied at the biological level, i.e. at the level of achievement of suppression of the target pest. However, in order to give a full estimate of the achievements of such a project, there is need for an economic assessment also to be made. Only then can the justification of the investment into the project be demonstrated.

Also farmer participatory research employed here is assumed to improve efficiency of the research by incorporating the preferences and opinions of its final clients, the farmers.

The study helped to bridge one of the major gaps in impact assessment research methodology, in that most documented impact assessment of biological control in Africa for example biological control of cassava mealy bug *Phenacoccus manihot* Matile Ferrero (Homoptera: Pseudococcidae) (Norgaard, 1988) was purely based on secondary data, later Zeddies *et al.*, (2001) did a detailed modeling, biological control of the mango mealy bug *Rastrococcus invadens* Williams (Homopter: Pseudococcidae), first descriptive (Vogele *et al.*, 1991) and later involve the beneficiaries through interviews (Bokonon-Ganta *et al.*, 2002) and biological control of water hyacinth *Eichhornia crassipes* (Martius) Solms-Laubach (Pontedriaceae) (De Groote *et al.*, 2002) which was the first time specific survey undertaken. This study is hence the first time *ex- ante*, for both crop loss assessment plus impact assessment, with farmers' interviews.

CHAPTER TWO

2.0. GENERAL LITERATURE REVIEW

2.1.0. Cabbage

2.1.1. Origin

It is assumed that cabbage and kale originated from Western Europe, where they were first domesticated. Prior to cultivation and use as food, they were used mainly for medicinal purposes (James, 1993).

2.1.2. Adaptation

Cabbage is well adapted to cool season production. The plants are quite cold resistant. Young hardened cabbage plants can withstand -10^0C for a short time; older plants are less hardy. The growth rates of cabbage stop at 0^0C and are quickest at 15^0C to 20^0C. Above 25^0C, growth stops. They require a regular water supply of 25 mm per week during the growing season. Shortage of water is detrimental for head development. The minimum temperature for seed germination is 5^0C with an optimum germination temperature of 27^0C, and a maximum germination temperature of 37^0C (James, 1993).

Crucifers require soils that can continuously provide water throughout the season. Well-drained, sandy loam soils are suited to early varieties, loamy and clay loam soils are suited to late ones. Late Cultivars are somewhat tolerant of poor drainage.

2.1.3. Nutrient Content

Crucifers are excellent source of Vitamins A and B complex. In addition, they contain vitamin C. Cabbage also supplies potassium and calcium to the diet. 250-ml (1-cup) raw cabbage contains 21 kilocalories; cooked 58 kilocalories (Tindall, 1983).

2.2.0. Diamondback Moth (DBM)

2.2.1. Origin

The Diamondback moth is assumed to have originated in Western Europe where most of crucifers originated. However, Kfir (1997) suggested an African origin for the pest on grounds of the great diversity of associated natural enemies found in South Africa.

The adaptability of this insect to different climatic conditions and its recognized status as a major pest in temperate and tropical regions makes the study of DBM important from economic as well as biological point of view (Talekar *et al.,* 1993). Diamondback moth is oligophagous and will feed on plants that contain mustard glycoside (Thorsteinson, 1953).

Important economic groups of crops with mustard glycosides are members of the family Cruciferae. In particular, the genus *Brassica* has been spread from its original home in Western Europe to almost all inhabited areas of the world. It is likely that the DBM spread along with the spread of the crucifers. These crops were probably introduced in Malaysia from China, India and European Countries (AVRDC, 1988).

2.2.2. Biology and Ecology

The Diamondback moth is a small, greyish brown moth, with diamond-shaped markings on its wings (Plate 2.1). The moths are active at night, hiding by day in leaf litter at the base of the plants. The small yellow eggs are laid in clusters or singly along the ribs and lower parts of the plants. A female DBM can lay up to 188 eggs (Harcourt, 1954).

The first larval instar mines into the spongy mesophyll leaf tissue and emerges as second instar, which feeds up to fourth instar on the lower surface of the leaf. Their behavior, when disturbed, distinguishes them from other caterpillars found on cabbage as they wriggle furiously or drop off the edge of the leaf on a silken thread. Feeding symptoms are characteristic "window feeding" where they consume all tissues except the upper epidermis. As the leaf continues to expand, the epidermis ruptures and the leaves appear skeletonized. When the fourth instar larvae has completed it's feeding; it constructs a silken cocoon on the leaf surface where it pupates and remains until the adult emerges. The duration taken by the whole life cycle depends on temperature and can be as short as 12 days (Lu, *et al.,* 1988).

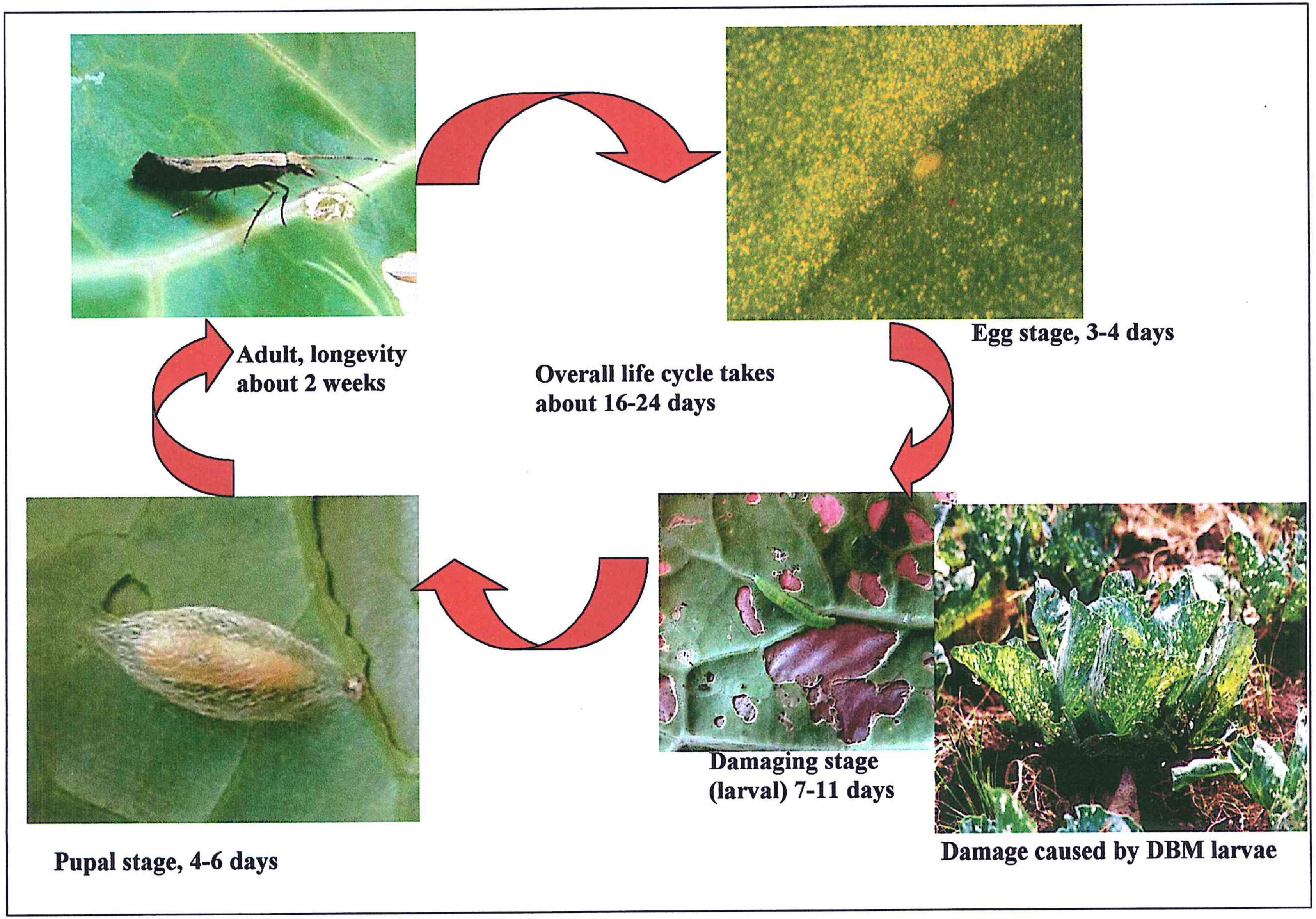


Plate 2.1 **Life cycle of DBM (at ~25°C), showing the damaging stage**

2.2.3 Hosts

Host plants on which Diamondback moth feeds on include: cabbage (*Brassica oleracea* L. var. *capitata*), cauliflower (*B. oleracea* L. var. *botrytis*), broccoli (*B. oleracea* L. var. *italica*), radish (*Raphanus sativus* L.), turnip (*B. rapa* L. *pekinesis*), kale (*B. oleracea* L. var. *alboglabra*), also feeds on a large number of cruciferous plants, most of which are considered to be weeds.

2.2.4. Current Control Measures

During the last fifty years, synthetic insecticides have been the major component in the control of DBM (Syed, 1992; Talekar *et al.*, 1993; Verkerk and Wright, 1997). However, due to development of resistance, virtually all classes of insecticides have been used against this pest, including organochlorides, organophosphates, carbamates and pyrethroids (Rejesus, 1986).

Ironically, in order to overcome resistance, farmers have resorted to applying much higher doses of insecticide cocktails more frequently (Talekar and Shelton, 1993). As a result, DBM became the first crop pest in the world to develop resistance to DDT in 1953 (Ankersmit, 1953; Johnson, 1953) and by 1986; it had become resistant to more than 46 insecticides (Miyata *et al.*, 1986). Shelton *et al.*, (1992) tested 44 populations of DBM from 19 states within the U.S.A, Mexico, Canada and Belize. They found widespread resistance to methomyl, permethrin and methamidophos.

More recent studies have focused on DBM metabolism to try and understand the mechanisms responsible for its ability to become resistant to a particular insecticide within a very short period of time. Cheng *et al.,* (1992) conclude that its very active, efficient and inducible mixed function oxidases system is particularly responsible for the high levels of resistance to carbamates, synthetic pyrethroids and benzoylphenyl urea. On the other hand, Sun (1992) found acetyl cholinesterase insensitivity, carboxyl esterase hydrolysis and microsomal oxidation to be the major mechanisms responsible for DBM resistance to carbamates, organophosphates and pyrethroids, respectively.

Farmers within East and South Africa currently are totally dependent on insecticides for the management of this pest and consequently, most of the DBM populations have become resistant to insecticides (Kibata, 1996). In South Africa DBM was shown to be resistant to 21 formulations of 11 insecticides namely carbofuran, chlorpyrifos, cypermethrin, deltamethrin, dichlorvos, methamidifos, methomyl, mevinphos, monochrotophos, propenfos and trichlorfon, in trying to overcome resistance most of the farmers now use cocktails and these are applied at dosages and frequencies much higher than recommended levels (Dennill and Pretorius, 1995; Mingochi *et al.*, 1995).

2.3.0. Biological control

In an ecological sense, biological control is the control of one organism by another (Beirner, 1967). This control may be expressed as either a longer population of the pest (DeBach, 1964) or as a restriction or prevention of the severity or incidence of pest damage without regard to the pest population (Cook and Baker, 1983). DeBach (1964) defined biological control, as "the action of parasites, predators, or pathogens in maintaining another organism's population density at a longer average than would occur in their absence". Biological control depends on knowledge of biological interactions at the ecosystem, organism, cellular, and molecular levers and often is more complicated to manage compared with physical and chemical methods. Biological control is also likely to be less spectacular than most physical or a chemical control but is usually also more stable and longer lasting (Baker and Cook, 1974).

2.3.1. History

Biological control was discovered by trial and error and then practiced in agriculture long before the term itself came into use (Baker and Cook, 1974). One example is the ancient practice of not growing the same crop species in the same field more frequently than every second or third year or even longer. Such crop rotation allows time for the pest or pathogen population in soil to decrease below some economic threshold because of the predatory, competitive, and other antagonistic effects imposed by the associated microflora and fauna. In other words, crop rotation allows time for the natural soil microbiota to sanitize the soil, especially with regard to the more specialized plant parasites and insect pests that are highly dependent on their host crop to maintain their populations.

The era of modern biological control, involving the deliberate transfer and introduction of natural enemies of insect pests from one location to another. The principles are fairly straightforward. If a crop is established in a new area, separated from its original home, it often does not suffer from the pests from the area of origin. Similarly, natural enemies or diseases of these pests will not occur in the new areas. If a pest organism is accidentally introduced, it normally comes without its natural enemies, which keep it in check in the area of origin. Therefore, the new pests can destroy large parts of the crop. Classical biological control (as compared to the more recent use of bio pesticides and other forms of biological control) consists of identifying natural enemies in the area of origin of the pest, i.e., predators or parasitoids, to be introduced in the new zones of pest occurrence. To assure these enemies do not harm the new environment in any unexpected way, they are first studied in quarantine. When considered safe to other organisms and the environment, they are mass reared and released. Once the natural enemy is well established, it reproduces itself in a sustainable way.

Biological control in Africa has turned out to be successful for instance against cassava mealybug (Norgaard, 1988), water hyacinth (De Groote *et al.*, 2002) and mango mealybug (Bokonon-Ganta *et al.*, 2002).

Cassava was introduced to Africa four centuries ago from South America, and became a major staple food. Two pests introduced accidentally from South America in the 70s hard hit it: the cassava mealybug and the cassava green mite (Coulibaly *et al.*, 2002). In their native environment, these pests are kept in control by their natural enemies, which were absent in Africa. Hence the rapid spread of the pests and extremely high losses to the cassava crop. A natural enemy of the cassava mealybug, *Apoanagyrus (Epidinocarsis) lopezi* De Santis (Hymenoptera, Encyrtidae), a small wasp, was identified (Löhr *et al.*

1990), and mass rearing and distribution techniques were developed at the International Institute of Tropical Agriculture (Herren and Neuenschwander, 1991). By the early 1990s, the pest was basically under control (Neuenschwander, 1994)

Diamondback moth earliest parasitoid introduction was made in New Zealand where *D. semiclausum* and *Diadromus collaris* (Gravenhorst) were introduced from England (Hardy, 1938; Thomas and Ferguson, 1989). These introductions continued to suppress diamondback moth populations and the challenge today is to incorporate this natural control into a commercial IPM program (Beck, 1992).

D. semiclausum was introduced to Indonesia in the 1950s and because of overuse of insecticides the beneficial effect of this parasitoid in the control of DBM in the field was not realized until 1986 (Sastrosiswofo and Sastrodihardjo, 1986). The above was made possible due to substitution of synthetic chemical pesticides by *B. thuringiensis* in the early 1980s, where the parasitoid proliferated to desirable levels (Sastrosiswofo and Sastrodihardjo, 1986).

In Taiwan, diamondback moth has been a serious problem since mid 1960s (Chen and Su, 1986). *D. semiclausum* was imported from Indonesia and was reported to cause more than 70% parasitisation in highland areas (AVRDC, 1988). The species now occurs throughout the highland areas of central Taiwan and provides substantial savings in DBM control (Talekar *et al.,* 1990). Temperatures in the highlands (15-25°C) are suitable for establishment of *D. semiclausum* whereas temperatures in the lowlands 20-30°C are suitable for *Cotesia plutellae* Kurdjumov (Talekar and Yang, 1991).

In the highlands of northern Philippines, a single release of *D. semiclausum* in 1989 at the beginning of the season resulted in 64 % parasitism of DBM at harvest (Poelking, 1992). The biocontrol programmes in Asia introduced *D. semiclausum* with successful results (Ooi, 1990; Talekar *et al.*, 1990; Biever, 1996; Iga, 1997). It has been reported that much of the success in Asia is confined to the temperate highlands where crucifers are widely grown throughout the year and in these regions introduction of larval parasitoid *D. semiclausum* alone has resulted in dramatic drop in pesticide use.

A species of the same genus has also been recorded in Kenya, Tanzania, Uganda and South Africa (Seif and Löhr, 1998; Kfir, 1997). Data collected in recent field surveys in Kenya, Malawi, and Tanzania indicate that the parasitism rates by the local *Diadegma mollipla* (Holmgren) are about 5-11.3%, 15% and 14.5% respectively, much lower than the parasitation rates reported from *D. semiclausum* from other countries (Seif and Löhr, 1998).

2.3.2. Advantages and Disadvantages of Biological control

Bio control reduces, but does not eradicate, pest populations. Thus, the success of a bio control program will depend on level of suppression attained and the tolerable level or economic threshold of the pest. When successful, classical bio control provides self-sustaining, broad-scale control of the target pest. This is in sharp contrast to chemical control and augmentation bio control, which typically require repeated treatment and provide control only at or near the site of application. Offsetting these advantages of classical bio control are low success rates (about two-thirds of all projects fail to provide substantial or complete control) and extended periods before widespread control is attained (several-to-many years). Most natural enemies used in bio control attack a very limited number of species. Thus, instances where a specific bio control practice interferes with other, ongoing pest control practices are relatively rare. In contrast, chemical control practices often interfere with bio control because of the broad-spectrum effects of many pesticides. This makes it difficult to integrate bio control practices into pest management systems that rely heavily on pesticides.

Augmentation and some conservation bio control programs do have recurring treatment costs. Whether or not these costs are more or less favorable than chemical control costs depends on many factors, including the particular natural enemies and chemicals involved, and the relative levels of pest suppression or yield increase attained with each method.

Incorporation of bio control practices into pest management systems can result in reduced pesticide usage. This will obviously reduce exposure to the legal, environmental, and public safety hazards of pesticides. Bio control was once viewed as entirely safe technique to the environment. However, there are some fears that some introduced natural enemies pose significant threats to native species especially threatened and endangered species.

2.4.0. *Diadegma Semiclausum*

2.4.1. Biology

This species is a solitary koinobiont (host continues to develop at least for a while after parasitization) endoparasitoid of DBM. It is black in color and the adult length ranges between 5-7 mm. Distinction of the sexes within the genus is very easy due to the presence of a long ovipositor in the females. An identification key and species description by Azidah *et al.,* (2000), can be used to distinguish *D. semiclausum* from the other *Diadegma* species attacking DBM, including the African species *D. mollipla.*

The biology of *D. semiclausum* has been studied extensively, mainly in Southeast Asia. Females can live for up to 37 and 73 days when fed on 10% sugar solution and diluted honey respectively. Males survive for almost 40 days on both sugar and honey solutions (Ooi, 1980). Yang *et al.,* (1993), showed that the adults survived for up to 28 days without food, on water or on honey solution, respectively at 25^0C. Fecundity studies in Malaysia indicated that a single female could lays up to 362 eggs in its lifetime but with a mean of 117 per female (Ooi, 1980). Studies in Egypt (Abbas, 1988) and India

(Venkatraman, 1964) showed mean total fecundities of 164 and 193 respectively. The number of eggs laid was positively correlated to female longevity. Under temperate conditions the species was reported to be much more fecund than in the tropics with the females parasitizing 35-50 hosts per day and the life-span was about three weeks in the field. Under laboratory conditions a female can live for up to three months and has a parasitization capacity of more than 700 eggs (Konig, *et al.,* 1993). The egg has an average incubation period of about two days and there are five larval instars (Abbas, 1988). All host larval stages are attacked by *D. semiclausum* with a preference for the second and third instars (Velasco, 1982; Talekar and Yang, 1991; Konig, *et al.*, 1993). The species is very well adapted to its host such that no defense reactions are triggered by the presence of the parasitoid's egg or larvae in the host (Konig *et al.,* 1993). Total developmental period from egg to adult is negatively related to temperature. Yang *et al.* (1993), found mean developmental periods of 11, 12, 16, 19 and 28 days at 35°C, 30°C, 25°C, 20°C, and 15°C respectively. A temperature around 23°C is considered optimum, whereas temperatures above 30°C are considered unfavorable.

After pupation of host larvae, the parasitoid larvae eat up the prepupal contents thereby killing its host. The parasitoid then forms its own cocoon inside the DBM cocoon. The emerging adult female feeds on brassicae flower nectar (Fitton and Walker, 1992) and starts laying eggs about a day later. During the first three days it tends to lay unfertilized eggs resulting in male offspring since the genus is arrhenotokous (Ooi, 1980).

Yang *et al.*, (1993), studied the effect of host density, super parasitism and multiparasitism on the parasitisation of DBM by *D. semiclausum.* Using host densities ranging from 5-120, they found that parasitisation rate increased with an increase in host density. Super parasitism (the oviposition of an egg into a host that has already been parasitised by a member of the same species) resulted in the production of more female than male progeny. When given a choice the parasitoid discriminated between parasitised and unparasitised larvae and had a preference for the unparasitised hosts. Multiparasitism studies on *D. semiclausum* and *C. plutellae* indicated that presence of larvae of another parasitoid species within host larvae deterred multiparasitism by either species.

2.5.0. Economic analysis of biological control programmes

2.5.1. Assessment methods

Impact assessment can be generally divided into two categories:

1. *Ex- post* studies, for technologies already being used, and
2. *Ex- ante* studies, for technologies not yet adopted.

In both cases, some of the data required to measure impact can be directly observed, and other data must be estimated indirectly from existing information. *Ex ante* assessment relies on researchers' trials and extrapolations unlike *ex- post* studies where actual surveys and data are used (Masters *et al.*, 1996).

2.5.2. A general model

To study economic impact assessment, it is important to have a general framework to compare and to draw conclusions. The studies available so far use either cost benefit analysis or economic surplus. The aim of both techniques is to assess the welfare implications of two or more situations. In theory, the situation that provides more utility without making people worse off is preferred. In benefit cost analysis, this utility is approached by the value of the extra production (or abated loss), and compared to the monetary costs. In classical benefit cost analysis, the situation with intervention in terms of benefits is compared to the situation without intervention (Gittinger, 1982). The economic surplus method is a refinement of cost benefit method. Like the cost benefit method, economic surplus measures the economic efficiency associated with research themes. However, in line with the economic theory, economic surplus measures allows for price response to research induced shifts in the quantity of commodity production and the apportionment of research benefits between producers and consumers, as well as other target groups.

Technically, the impact of a new parasitoid is a shift in the production function: more cabbages can be produced with the same inputs (land, labor, and capital). The rational farmer will react by rearranging his/her inputs to reach an optimum yield reflecting this new situation. This new point will not bring the same profit/utility as the old one (or that would have been chosen before), but it is hard to assume that the lost profit equals the loss in cabbage output, at least not on the long term.

The drawback of using a supply shift is the assumption that all extra production is valued at the old price. In practice, the new equilibrium point will not only reflect the shift in the production function, but also the change in relative prices, in function of the price elasticities. As a result, producers do not receive all the benefits of the new technology, since the extra production is valued lower. Their corrected benefit is called producer surplus. These benefits accrue to the consumers i.e. they can consume more at lower prices. Consumer and producer surplus add up to economic surplus and methods have been developed to quantify them (Alston *et al.*, 1995). These methods are becoming increasingly popular for impact analysis, and special software has recently been developed for evaluation (De Groote *et al.*, 2002.).

CHAPTER THREE

3.0. CABBAGE YIELD LOSS ASSESSMENT FROM DIAMONDBACK MOTH

3.1. Introduction

Diamondback moth (DBM) is the most devastating pest of cabbage, which causes damage that is often sufficient to prevent the formation of marketable heads (Barroga, 1974). To estimate the economic value of losses due to this pest, the actual losses need to be measured. Crop loss can be defined as the difference between the actual yield and the potential yield, more precisely, the yield that would have been obtained in the absence of the pest under study. Taking into consideration the area planted to cabbage and the price of the cabbage, an economic evaluation can be made of the pest's importance.

Most farmers generally apply recommended pesticides to control DBM on the basis of schedule. They consider pesticides as an insurance against the risk of crop loss caused by pests but fail to assess whether the application is needed or if it will minimize economic loss. This study thus introduces a spraying programme of common pesticides and a control that enabled the researcher to assess the yield loss caused by DBM. The study specifically aimed at evaluating the yield loss due to DBM, determine the efficacy and economic significance of pesticides: Karate, Neemroc and Thuricide in the control of DBM.

3.2.0. Materials and methods

3.2.1. Conceptual framework of the study

Crop loss can be defined as the difference between potential yield Yp and actual yield Yr. It is convenient to express this proportionate to the potential yield, to obtain a proportional crop loss r (De Groote, 2002):

$$r = \frac{Yp - Yr}{Yp}$$

If this ratio r is known, loss can then be derived from actual yield with following formula:

$$Yp - Yr = Yr\frac{r}{1 - r}$$

The ratio r can be obtained from different sources: farmer's estimates, experts' estimates or crop loss estimates from the field trials. In this case it was determined through field trials and farmer's estimates.

Another method is to derive the crop loss ratio or absolute value, indirectly from occurrence, incidence, or damage indicators. Occurrence is usually expressed as a binary variable in the presence of pests. Incidence means the extent of occurrence, or the number of DBM per plant. Other indicators of incidence are damage indicators, such as the foliage damage score (De Groote, 2002). Finally to obtain an economic evaluation, losses need to be multiplied by prices.

3.2.2. Site description

Field experiments were conducted on farmer's fields at two sites. One in Limuru Division (Kiambu District) and the other one in Wundanyi Division (Taita Taveta District). Limuru is a peri- urban cabbage production area close to Nairobi city (Approximately 30 km) and is located at a latitude of 12^0 32' and longitude between 35^0 26' with an altitude of 1,600 m above sea level. Wundanyi is a small isolated elevated area in the coast region, located at latitudes $35\text{-}45^0$S and longitude $37\text{-}39^0$E at an altitude of 1,900 m above sea level. The sites have an annual rainfall of between 450- 700 mm and 750-1200 mm respectively with a bimodal distribution (MoARD, 1997). The growing season during the long rain is from March - July while short rains occurs from September to December. Soils in both areas are highly weathered. (MoARD, 1997). The high population density in these highlands has led to serious land fragmentation. Poverty in general, limited technical and material resources and small land holdings have cumulatively resulted to inadequate food production.

3.2.3. Experimental design and layout

The experiment was designed as a four replicate Latin square design (LSD), with four treatments. Plots measured 5.4 metres by 3.2 metres, consisting of 7 rows, 9 plants per row with one border row and a column in all sides. This resulted in 35 plants per plot. A path of 1 metre separated plots. Four weeks old seedlings, which had been raised in pots were transplanted to the field at a spacing of 60 cm between rows and 45 cm within rows, at each site, in the month of February (first season) and June (Second season) year 2002.

Standard growing practices of the farmers of weeding, watering and fertilizer application were followed.

Treatments consisted of fortnightly application of:

1. Lambda-cyhalothrin (Karate, 3.2ml/L): (most common farmers' practice),
2. *Bacillus thuringiensis* (Thuricide, 0.75g/L) a microbial control agent for selective DBM control,
3. Neemroc (neem-oil based botanical pesticide standardized at 0.03% Azadirachtin and 30% neem oil, 5ml/L),
4. No pesticide application (Control).

The spray programme started on the second week after transplanting when the plants were six weeks old. A hand operated Hobra knapsack sprayer was used. Care was taken to ensure a complete coverage of insecticide on each plant.

3.2.4. Data collection

All inputs used and man-hours spent on management practices were recorded to allow for an economic analysis of the results. Ten plants were scouted after every fortnight by systematic sampling procedure, i.e. every fourth plant taking the earlier one as a first plant was sampled. All pests in terms of adults, pupae, small (second instars) and big (third and fourth instars) larvae were physical counted and recorded (Appendix 1.). For damage level, a modification of classes defined by Dreyer (1987) was used, from scoring scale of 0 to 5 as detailed below:

0= No damage,

1= Few isolated small holes in the outer or lower leaves,

2= Many holes but damage limited to outer or lower leaves,

3= Considerable damage of the outer or lower leaves, slight damage on the cabbage head, head marketable with minor leaf removal,

4= Outer or lower leaves completely destroyed, moderate attack of inner leaves, head marketable after considerable removal of outer head leaves,

5= Severe attack on the head, head unmarketable.

Damage Index (D.I) was calculated using the formula: -

$$D.I = \frac{\sum[\text{Damage score} \times \text{Number of cabbage in that class}]}{\text{Total number of cabbage sampled}}$$

At maturity, which coincided with the end of twelfth week after transplanting, fields were harvested and the outer damaged leaves were removed to remain with a marketable head from which, weight was taken to the nearest 0.01 kilogram (Kg).

Selling prices in terms of highest, normal, average and lowest for different treatments were determined at farm gate, nearest market, middlepersons and brokers.

3.2.5. Data analysis

Data collected were processed and analyzed using SAS for windows software (V6.12) and Excel software. All returns were standardized on per hectare basis by scaling up yields and inputs from the research plots. Where required, particularly for larval counts, data were log transformed (Log_{10} (x+1)) prior to statistical analysis to lower the coefficient of variance (C.V.) where it was above 30. SNK multiple range test was used to separate means at $P < 0.05$.

Regression and correlation analyses were conducted to study the relationship between larval density and marketable yield.

Complete and partial budget analysis, cost benefit analysis, net benefit curves were used to assess the economic significance of the pesticides and to determine the most profitable treatment. Sensitivity analysis was used to determine the profitability of spraying in case of price fluctuations.

3.3.0. Results

3.3.1. DBM infestation

The effects of the different treatments on DBM larval infestation in Limuru Division (Gloria Cultivars) for the two seasons are shown in figure 3.1. In the first season (Figure 3.1A), treatments had no influence on the level of infestation within the first two weeks. Infestation for all the treatments increased over the 4th and 6th week, peaking on 6th week. The highest DBM numbers were recorded in the control plots and the lowest where Thuricide was applied. In the following weeks, there was a gradual decline of infestation for all treatments, except Karate treated plots that had a rapid increase of infestation, declining only on the 12th week. The highest level of infestation of the Karate treatment was 7.2 larvae per plant recorded during the 10th week. Neemroc seemed to have no effect on DBM on the 8th week. Thuricide maintained a lower population density all through the growing season.

In the second season (Figure 3.2B), treatments had no influence on the level of infestation within the first two weeks, just like in the first season. Infestation in all treatments increased over the 4th, 6th and 10th weeks, having a peak on week 10 for Karate, just like in the first season. In the 8th week, there was a gradual decline of infestation for all the treatment except Karate. The highest level of infestation of the Karate treatment was 2.1 larvae per plant, recorded during the 10th week. Thuricide maintained a lower population density throughout the growing season. In general, effect of time of infestation was the same for the two seasons apart from a generally lower population density observed in the second season.

Concurrently to the two trials at Limuru Division, similar trials were set up at Wundanyi with the variety Copenhagen Market. In the first season, the DBM population was very low throughout the growing period (Figure 3.2A). Treatments had no influence on the level of infestation within the first two weeks. Infestation in the Karate and Neemroc treatments increased gradually up to week 8 and then declined. Control exhibited the same trend. Thuricide maintained a very low level of infestation throughout. The highest level of infestation was observed on Karate and Neemroc applications at 1.8 and 1.5 larvae per plant respectively, recorded during the 8th week. Again, Neemroc seemed to have no effect on DBM on this week (earlier observed on Gloria Cultivar).

In the second season (Figure 3.2B), treatments had little influence on the level of infestation within the first six weeks. Infestation for all treatments increased significantly in week 8 and all except Neemroc peaked on 10th week, control recording the highest (5.6 larvae per plant) and Thuricide lowest (1.9 larvae per plant). Infestations for all treatments except Neemroc declined in week 12.

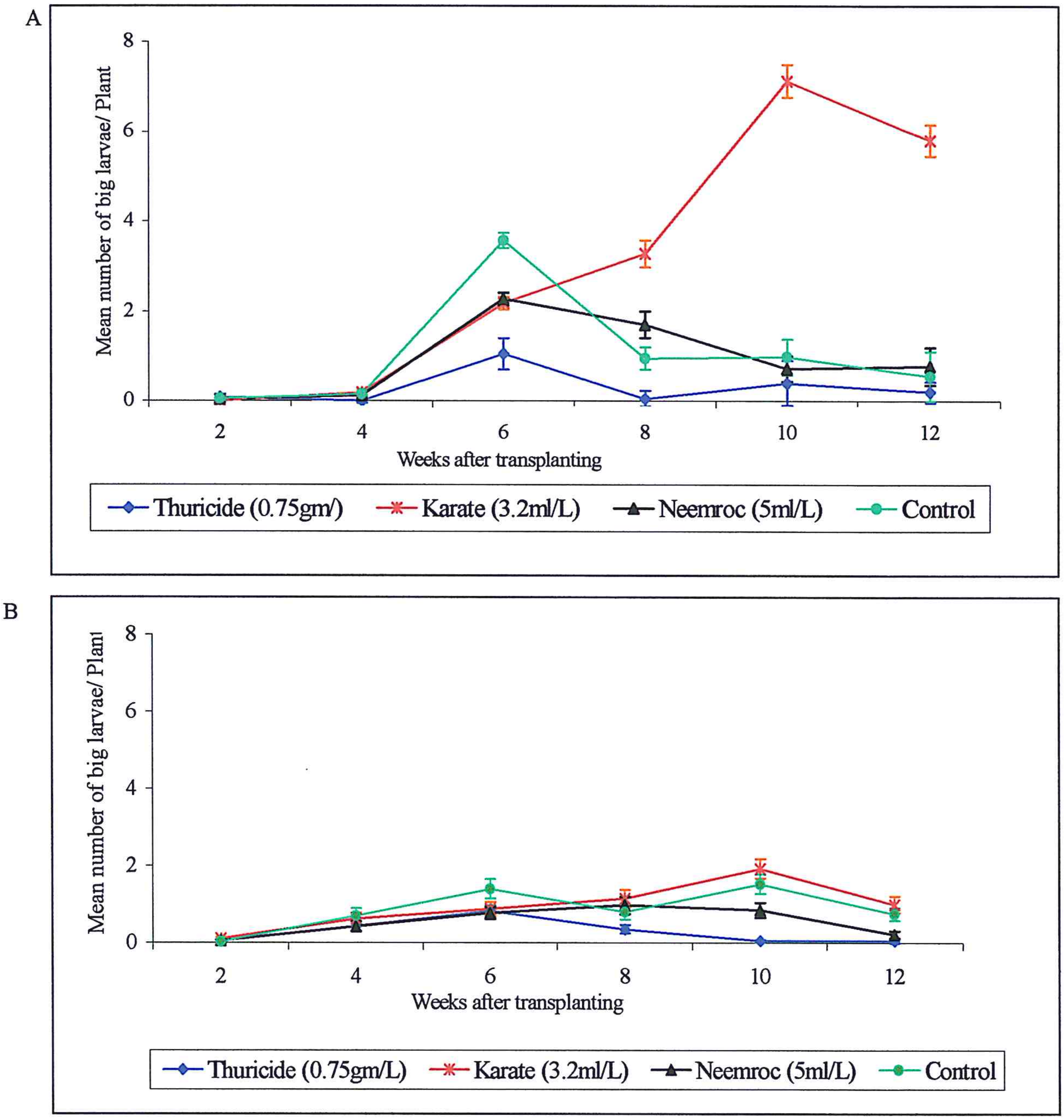


Figure 3.1: **Effect of three insecticide treatments on Diamondback moth numbers during two seasons (A-First season, B-Second season) at Limuru Division, Central Kenya, 2002.**

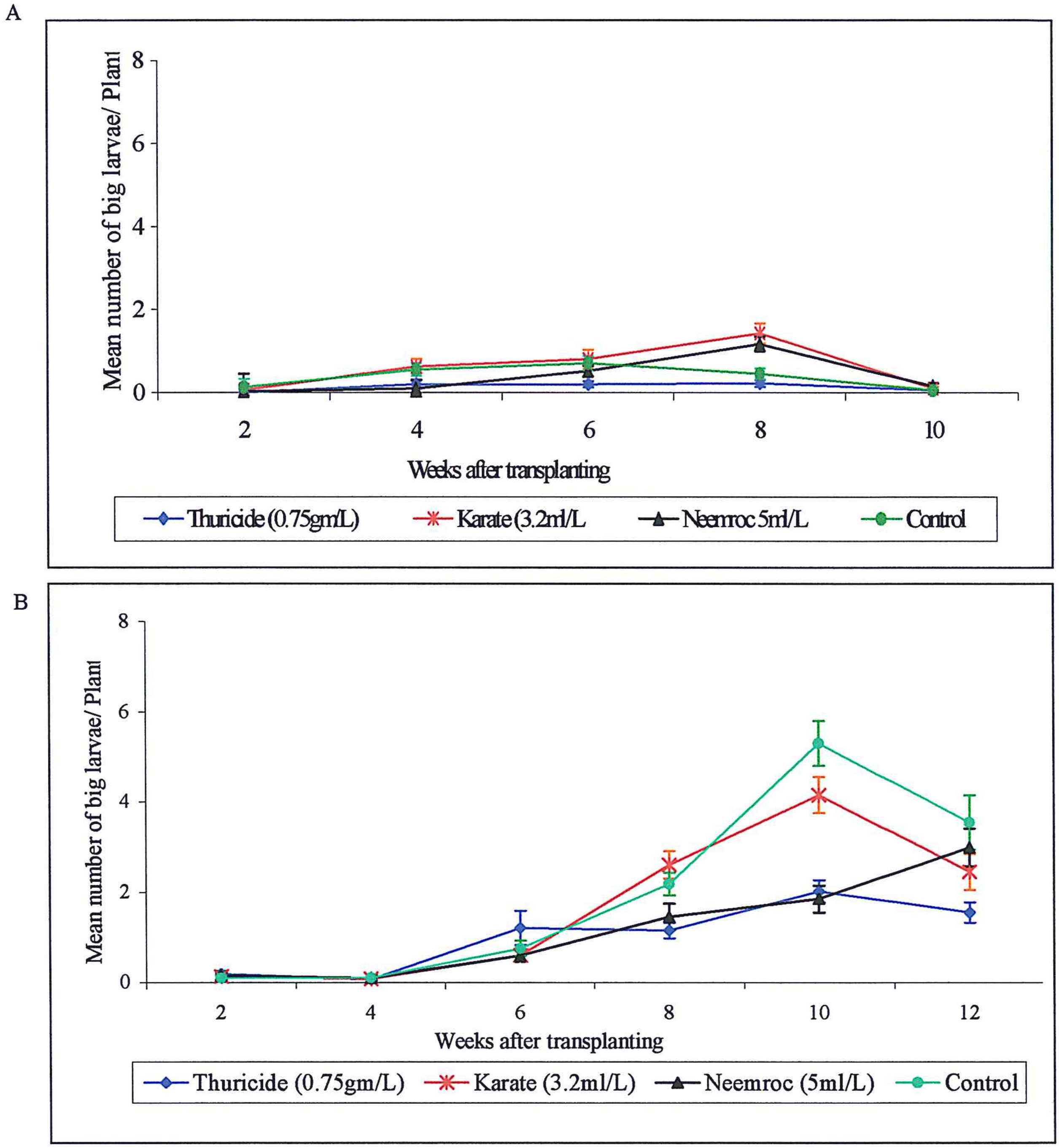


Figure 3.2: **Effect of three insecticide treatments on Diamondback moth numbers during two seasons (A-First season, B-Second season) at Wundanyi Division, Coast Region of Kenya, 2002.**

Table 3.1, shows the average numbers of big larvae (3rd and 4th instar) and total DBM numbers with damage index on Gloria Cultivar (Limuru Division) as affected by the three insecticidal treatments. In the first season trial, there was a highly significant difference in density of big larvae, total DBM and damage index between the treatments ($p< 0.001$).

Control had an average of 1 DBM larva/plant. Thuricide achieved the best control, down to 0.3 larvae/plant (70% decrease) while Karate was the least effective with an increase of 68% of larvae/plant. Total DBM population per plant followed the same trend, Karate with highest and Thuricide lowest. Damage indexes for the treatments were also similar. The Karate treatment produced cabbage with significantly higher damage index (2.51) than Thuricide (1.73), which produced the least damaged cabbage (Plate 3.1). Damage rates of Karate, Neemroc and Control were not statistically different from each other.

In the second season, highly significant treatment effects on big larval density and total DBM count was observed ($p< 0.001$). However, no significant difference was found between Karate and Control. Highest average number of big larvae per plant (0.9) was recorded from Karate and Control while Thuricide had the lowest (0.3) down by 70%, conforming to the findings obtained in the first season. Total DBM count per plant and damage index followed a similar trend. However, damage rating of Neemroc was significantly different from that of Karate and control.

For both seasons, Thuricide maintained a lower population density and damage index while the highest was recorded in the Karate plots.

In Table 3.2, means of the total larval count, number of big larvae and damage index are presented for Cophen Hagen Market Cultivar. In the first season, significant differences were observed between the treatments ($p < 0.001$) for all parameters. The comparison of the means between treatments showed that differences between Neemroc and Control were not statistically different for larval counts. However, Neemroc reduced larval population by 25%, while Karate increased it by 33%. The damage index levels for both Thuricide and Neemroc treatments were lower than in the control plot and Karate applied plots.

In the second season, a highly significant effect of the treatments on big and total larval numbers and damage index was observed ($p < 0.001$). However, comparing the means, no significant differences were found between Karate and Control and between Neemroc and Thuricide treatments. Control had the highest number of big larvae per plant (1.9), followed by Karate (1.7 larvae/plant), while Thuricide had the lowest (1.0 larvae/plant). Total number of larvae/plant and damage index followed the same trend, with Control having the highest and Thuricide lowest.

For both seasons treatment Thuricide maintained a lower population density and damage index while Karate (season one) and control (season two) had the highest.

Table 3.1: **Number of diamondback moth and damage index on head cabbage treated with three insecticides, Gloria *cultivar*, (Limuru Division, 2002).**

Treatment	**Season one***			**Season two****		
	Number of big larvae/plant	Total number of larvae/plant	Damage Index	Number of big larvae/plant	Total number of larvae/plant	Damage Index
Thuricide	0.3±0.08 C	1.3±0.13 C	1.73±0.03B	0.3± 0.04 C	1.0±0.09 C	1.4± 0.04 B
Neemroc	0.9±0.10 B	3.2±0.24 B	2.15±0.2 A	0.6± 0.07 B	2.1±0.19 B	1.6± 0.17 AB
Karate	3.1±0.24 A	9.5±0.75 A	2.51±0.12A	0.9±0.08 A	2.7±0.19 A	1.9± 0.14 A
Control	1.0±0.11 B	3.9±0.27 B	2.19±0.03A	0.9±0.09 A	2.8±0.22 A	2.0± 0.1 A
Pr. > F Ratio	< 0.001	< 0.001	0.03	< 0.001	< 0.001	0.017
C.v.	5.9	9.7	28	3.9	23	13.9

Means followed by the same letter are not significantly different at $p< 0.05$ Student-Newman-Keuls test for comparison of means

*February-April

**June- August

Table 3.2: **Number of diamondback moth and damage index on head cabbage treated with three insecticides, Copenhagen Market *cultivar,* (Wundanyi Division, 2002)**

Treatment	**Season one***			**Season two****		
	Number of big larvae/plant	Total number of larvae/plant	Damage Index	Number of big larvae/plant	Total number of larvae/plant	Damage Index
Thuricide	0.1±0.03 C	1.2±0.11 C	2.09±0.1 B	1.0±0.09 B	4.7±0.34 B	2.0 ±0.09 B
Neemroc	0.3±0.05 B	1.9±0.16 B	2.15±0.24 B	1.2±0.12 B	5.8±0.49 B	2.1± 0.18 B
Karate	0.6±0.08 A	2.7±0.22 A	2.44 ±0.08 A	1.7±0.14 A	7.0±0.53 A	2.7± 0.07 A
Control	0.4±0.06 B	2.2±0.18 B	2.40±0.06 A	1.9±0.18 A	7.8±0.63 A	2.6± 0.06 A
Pro. > F Ratio	< 0.001	< 0.001	0.001	< 0.001	< 0.001	0.001
C.v.	2.9	6.6	10.7	5.6	9.7	7.2

Means followed by the same letter are not significantly different at $p< 0.05$ Student-Newman-Keuls test for comparison of means

*February-April

**June- August

Karate treated cabbage

Control

Neemroc treated cabbage

Thuricide treated cabbage

Plate 3.1: **Degree of DBM damage on Gloria cultivar in Limuru Division in plots receiving different treatments**

3.3.2. Yields

Yield data for both trials in Limuru Division (Gloria Cultivar) are presented in table 3.3. In the first season, yield differences between the treatments were highly significant ($p=0.002$). Lowest yields, both in terms of average head weight and total yield per unit area were recorded in the control plot (1.5 kg/head and 55.8 t/ha, respectively) while Neemroc treatment yielded highest (1.9 kg/head and 71.9 t/ha). There was no statistical difference in yields between Neemroc and Thuricide treated plots. The percentage yield increase compared to the control was 29% for Neemroc, 26% for Thuricide and 13% for Karate.

In the second season, there was a highly significant difference between treatments in yield ($p<0.001$). However, there was no statistical difference between the yield of Thuricide, Neemroc and Control treatments. Karate treated yielded significantly lower yields; this was reflected by both individual head weight and total yield per hectare. Relative to the control, Thuricide and Neemroc treatments resulted in an increase of 3% and 11%, respectively, while Karate resulted in a drop of 22%. Generally, season one had higher yields than season two.

Table 3.4 shows the effect of treatments on yield of Copenhagen Market Cultivar in Wundanyi Division. In the first season, treatments effect on yield was low and only significant for Thuricide, which produced an increase of 4% above the control. Both Neemroc and Karate resulted in a yield drop of 5% and 12%, respectively. However, head weights and yield per hectare of Neemroc, Karate and Control were not significantly different from each other.

In the second season, Thuricide performed best in terms of head weight and yield per unit area, recording an increase of 31% as compared to the control. Neemroc had an increase of 7%. Though Neemroc had this increase relative to Control, they were not statistically different from each other. Karate again recorded a drop of 9%.

Table 3.3: **Yield response of cabbage treated with three insecticides for the control of Diamondback moth, Gloria Cultivar, (Limuru Division, 2002).**

Treatment	**Season one***		**Season two****	
	Head weight (kg)	Yield/hectare (tons) [1]	Head weight (kg)	Yield/hectare (tons) [1]
Thuricide	1.8±0.05 A	70.2±2.3 A	1.3±0.05 A	46.0±1.8 A
Neemroc	1.9±0.06 A	71.9±2.4 A	1.3±0.06 A	49.7±2.1 A
Karate	1.7±0.04 B	62.9±2.1 B	0.9±0.05 B	35.1±2.0 B
Control	1.5±0.05 C	55.8±1.8 C	1.2±0.05 A	44.8±1.8 A
Pro. > F Ratio	0.002	0.002	<0.001	0.001
C.v.	6.07	7.3	6.12	5.4

[1] The estimated yield/ha is 37,037 marketable heads, in a spacing of 0.45*0.6m. Assuming all the heads are marketable. Means followed by a common letter within columns are not significantly different at $p< 0.05$ Student-Newman-Keuls test for comparison of means

*February-April

**June- August

Table 3.4: **Yield response of cabbage treated with three insecticides for the control of Diamondback moth, Copenhagen Market Cultivar, (Wundanyi Division, 2002).**

Treatment	**Season one***		**Season two****	
	Head weight (kg)	Yield/hectare (tons) [1]	Head weight (kg)	Yield/hectare (tons) [1]
Thuricide	1.6±0.06 A	58.5±2.4 A	1.5±0.07 A	55.3±2.46 A
Neemroc	1.4±0.07 AB	53.1±2.7 AB	1.2±0.05 B	45.3±1.95 B
Karate	1.3±0.07 B	49.1±2.6 B	1.0±0.04 C	38.4±1.61 C
Control	1.5±0.06 AB	56.1±2.4 AB	1.1±0.05 CB	42.2±1.69 B
Pro. > F Ratio	0.02	0.02	<0.001	<0.001
C.v.	4.05	7	5.7	4.7

[1] The estimated yield/ha is 37,037 marketable heads, in a spacing of 0.45*0.6m. Assuming all the heads are marketable. Means followed by a common letter within columns are not significantly different at $p< 0.05$ Student-Newman-Keuls test for comparison of means

*February-April

**June- August

3.3.3. Yield loss

Since Thuricide did not offer full protection, potential yield was calculated through extrapolating the linear regression of marketable mean yield per hectare on pest incidence, and calculating the yield at zero incidence (intercept). The regression of the first season for both sites was significant with a linear relationship $Y=-4.6L+71$, $R^2=0.49$, $p=0.03$ (Limuru Division) and $Y=-19L+63$, $R^2=0.40$, $p=0.02$ (Wundanyi Division) respectively (fig 3.3). Regressions were not significant in the second season in both sites with ($p=0.06$, $R^2=0.2$ for Limuru and $p=0.12$, $R^2=0.01$ for Wundanyi). When all the data were pooled together with location, season and variety as dummy variables, the result was not significant ($p=0.15$, $R^2=0.14$).

Based on the results that were significant and with an assumption that DBM was the sole major pest, the yield loss was estimated to range between 12- 22% (lower value was calculated from control while the upper value was calculated from Karate treated plots using the formula for calculating crop loss as described earlier. This amounted to 2.8 ton/ha with an estimated value of KShs 28,265 per hectare. Due to lack of agreement between the first and second season data, farmer's subjective estimate of yield loss was necessitated.

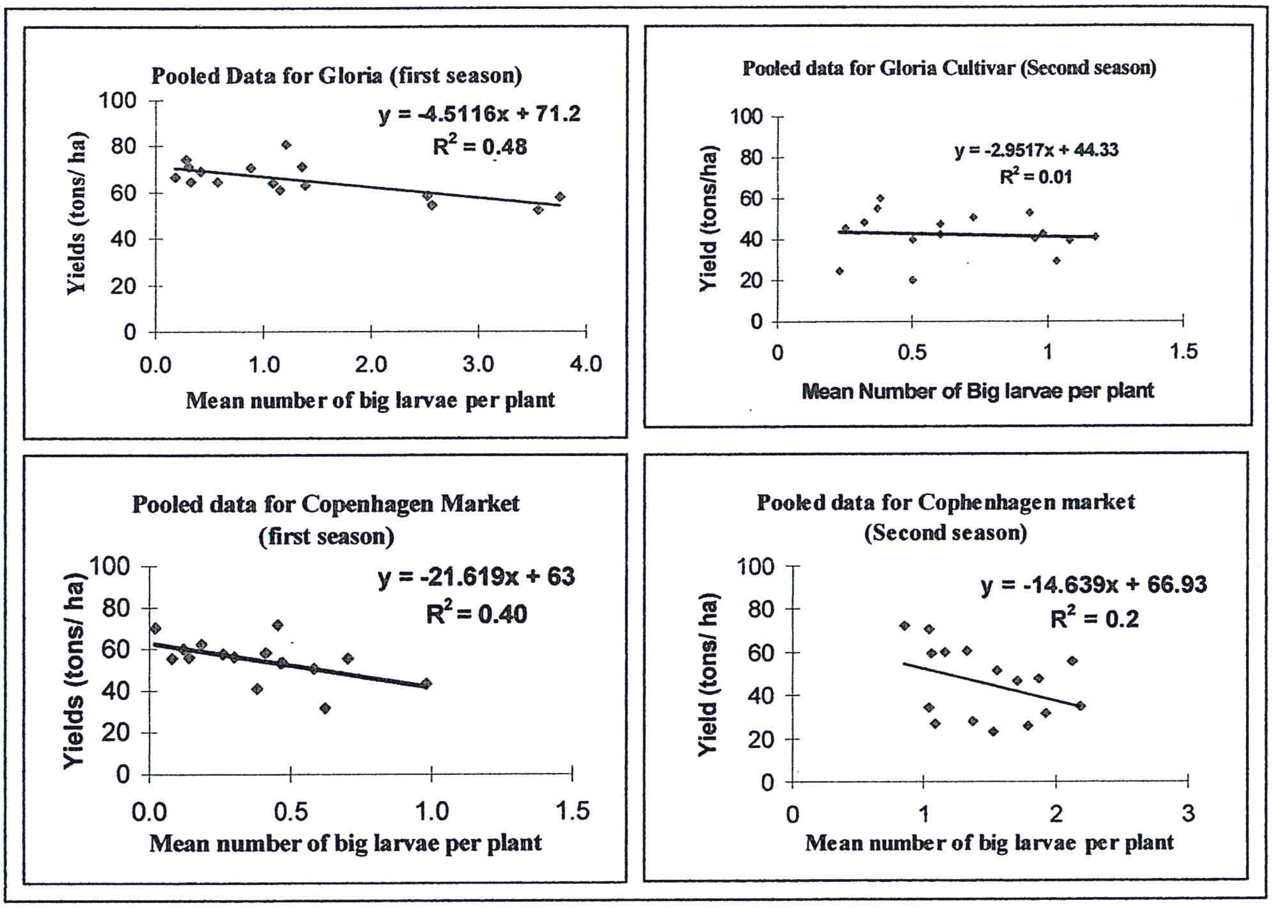


Figure 3.3: **Linear regression results of the relationship between average larvae density per head and average yields per hectare for Gloria and Copenhagen Market variety for two seasons, 2002**

3.3.4. Partial budget analysis

Partial budget computed for the three treatments against that of the control with respect to profit and benefit cost analysis (BCA) for Gloria Cultivar in the two seasons is summarised in Table 3.5. Additional cost for sprayer, chemical and labour were incurred for these treatments.

In the first season, the use of Karate provided a net benefit of 33,794 KShs/ha with a production cost of 4.97 KShs/kg and a benefit cost ratio of 0.96. The economic returns of Neemroc and Thuricide ranged from nearly twice to approximately three times higher than control, with benefit cost ratio of 5.34 and 5.37 respectively. Notably, the benefit cost analysis, revealed that Thuricide had superior performance over Neemroc. This was not possible in the Net benefit analysis.

In the second season, Karate resulted with a loss of -139,184 KShs/ha with a production cost of 4.47 KShs/kg as an absolute value. Thuricide had a loss of 14,033 KShs/ha. Only Neemroc had a benefit of 18,217 KShs/ha. For cost benefit analysis for every shilling invested it, result in a loss of KShs -3.18 for Karate, and KShs -0.55 for Thuricide was registered. Only Neemroc resulted in a return of KShs 0.61 for every shilling invested.

Table 3.6 shows the effect of the three insecticide treatments on profit and benefit cost ratio, for Cultivar Copenhagen Market (Wundanyi) for the two seasons. In the first season, all treatments except Thuricide (benefit 4,631 KShs/ha, production cost of 7.14

KShs/kg and benefit cost ratio of 0.26), accounted for a loss, showing that for every shilling invested on Karate there was a loss of KSh 3.21 and KSh 2.33 for Neemroc.

The low yield observed in the Karate treatment in the second season is reflected here, with a loss of 67,966 KShs/ha and a loss of KShs 2.03 for every shilling invested. Thuricide was the best with net benefit of 96,698 KShs/ha, productions cost (KShs) per unit Kg of 1.55 and benefit cost ratio of 4.8. Neemroc had a benefit cost ratio of 0.19.

Revenue realised from the treatment is linearly related to the cost of production unlike yield as observed on the partial budget analysis. Going by benefit cost ratio, treatments showed a significantly different rank order: Thuricide>Neemroc>Control>Karate.

Table 3.5: **Partial Budget analysis of three insecticides applied for Diamondback moth control in head cabbage versus an unsprayed control[1] (Gloria Cultivar, Limuru Division, 2002)**

	First season*			**Second season****		
	Thuricide	Karate	Neemroc	Thuricide	Karate	Neemroc
Yield increase (Kg/ha)	14,370	7,065	16,113	1,224	-9,788	4,921
Gross field benefits	140,108	68,884	157,102	11,934	-95,433	47,980
Cost of chemical	10,226	22,927	12,899	13,774	31,040	17,460
Cost of spraying labour	11,022	11,022	11,022	11,317	11,317	11,317
Depreciation cost of the sprayer	123	123	123	123	123	123
Interest cost on chemicals	307	688	387	413	931	524
Interest cost on spraying labour	331	331	331	340	340	340
Total cost that change	22,008	35,090	24,762	25,967	43,751	29,763
Net benefits	118,100	33,794	132,340	-14,033	-139,184	18,217
Productivity indicator (B/C)	5.37	0.96	5.34	-0.54	-3.18	0.61
Production cost/ Kg	1.53	4.97	1.54	21.21	(4.47)	6.05

[1] All costs and benefits in KShs/ha,

The selling field price of the cabbage was taken as an average during that growing seasons of 2002 which was 9.75 KShs/Kg,

Interest expense was assumed to be 1% per month. One cropping season is 3 months.

*February -April

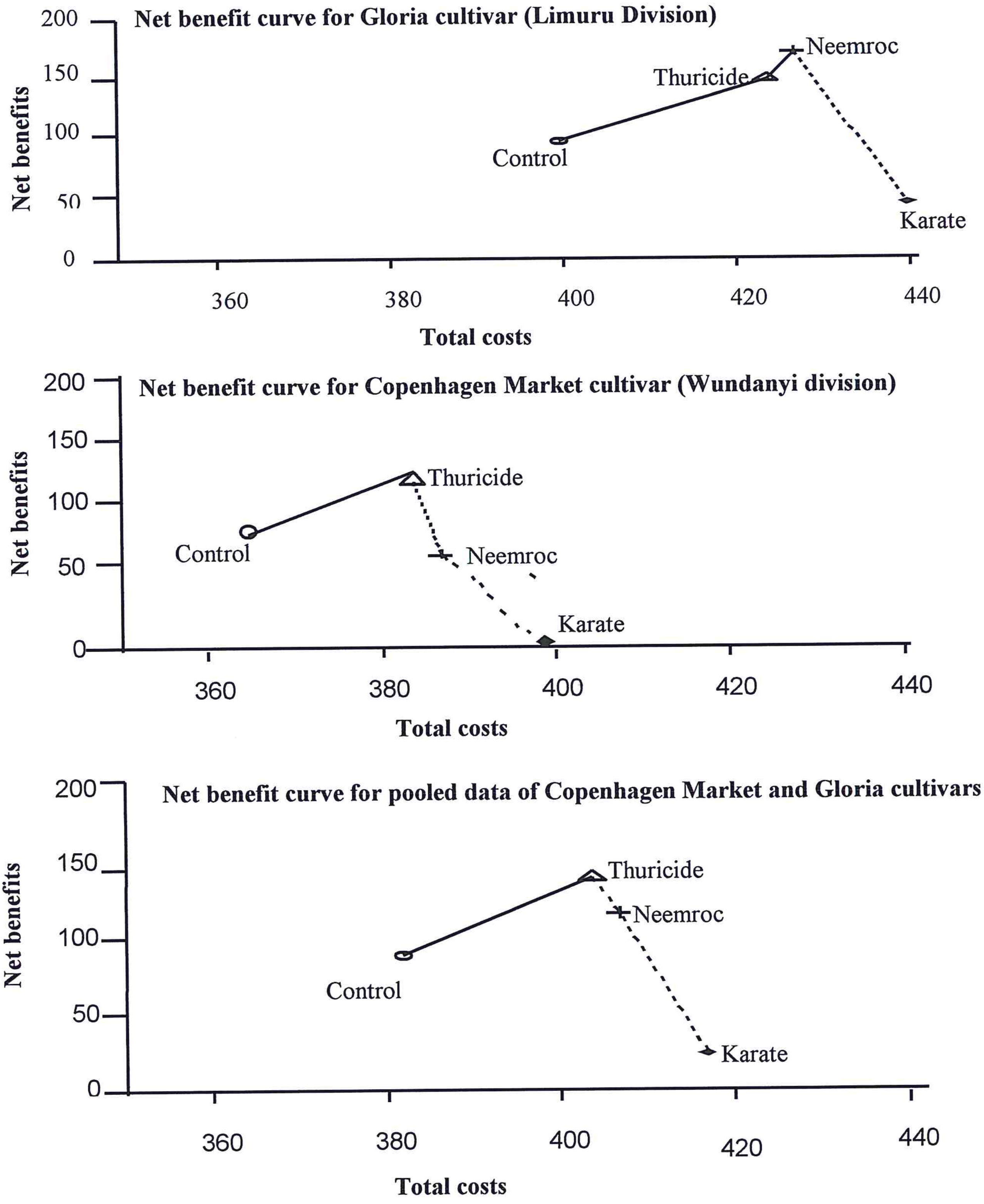
**June - August

Table 3.6: **Partial Budget analysis of three insecticides applied for Diamondback moth control in head cabbage versus an unsprayed control[1] (Copenhagen Market Cultivar, Wundanyi Division, 2002).**

	First season*			Second season**		
	Thuricide	Karate	Neemroc	Thuricide	Karate	Neemroc
Yield increase (Kg/ha)	2,486	-6,993	-2,967	12,981	-3,833	3,041
Gross field benefits	22,374	-62,937	-26,703	116,829	-34,497	27,369
Cost of chemical	8,306	18,694	10,555	10,331	23,280	13,095
Cost of spraying labour	8,818	8,818	8,818	9,112	9,112	9,112
Depreciation cost of the sprayer	105	105	105	105	105	105
Interest cost on chemicals	249	561	317	310	698	393
Interest cost on spraying labour	265	265	265	273	273	273
Total cost that vary	17,743	28,442	20,059	20,131	33,469	22,978
Net benefits	4,631	-91,379	-46,762	96,698	-67,966	4,391
Productivity indicator B/C	0.26	-3.21	-2.33	4.80	-2.03	0.19
Production cost/Kg	7.14	(4.07)	(6.76)	1.55	(8.73)	7.56

[1] All costs and benefits in KShs/ha,
The selling field price of the cabbage was taken as an average during that growing seasons of 2002 which was 9.75 KShs/Kg,
Interest expense was assumed to be 1% per month. One cropping season is 3 months.
*February -April
**June - August

Net benefit curves for the treatments based on complete budgets were plotted as shown in figure 3.4. In these net benefit curves, each treatment is plotted according to its net benefits and total costs of production. The treatments that were not dominated were connected with a line. The dominated were graphed as well with a dotted line. To show that they fall under the net benefit curves this was carried out by listing the treatments in order of increasing costs that vary. Any treatment that had net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated. Karate and Neemroc were dominated for Copenhagen Market (Wundanyi) while only Karate was dominated on Gloria Cultivar (Limuru). Overall, comparison indicates Thuricide to be superior chemical while Neemroc and Karate are dominated. This analysis shows that values of increase in yields are not enough to compensate for the increase in costs as potrayed by Neemroc and Thuricide.



Continuous line= Non-dominated. Dotted lines= dominated

Figure 3.4: **Net benefit curves for three insecticide treatments to control Diamondback moth on cabbage based on complete budgets (Thousand Ksh/ha), 2002**

3.3.5. Sensitivity analysis

Sensitivity analysis was conducted to predict risks regarding the profitability of treatments in case the farm gate prices of the cabbage increased or decreased (Table 3.7 and 3.8). For this purpose, the lowest and highest farm gates prices experienced by the farmers during the year of the study were used.

For the first season in Limuru Division (table 3.7A), a lower farm gate price resulted in a benefit for Thuricide and Neemroc treatments, while Karate had a loss of 17,428 KShs/ha. In the second season (table 3.7B) all resulted into benefits. At higher prices (first season), Neemroc had the highest benefit 233,046 KShs/ha followed by Thuricide 207,912 KShs/ha and Karate 77,950 KShs/ha. In the second season, Karate resulted in a loss of 200,359 KShs/ha, while Neemroc treatment had a marginal benefit.

When the low price scenario was applied in Wundanyi Division, all treatments resulted in a loss in the first season (table 3.8A). In the second season (table 3.8B), loss was reflected on Neemroc and Karate treatment, while Thuricide recorded a benefit of 25,302 KShs/ha. With higher prices, only Thuricide treatment resulted in a benefit of 18,304 KShs/ha (first season). In the second season the highest earning treatment was Thuricide (KShs 168,093), while a loss of 129,841 KShs/ ha was incurred for Karate.

Table 3.7 **Sensitivity analysis for the application of three treatments against Diamondback moth for Gloria in Limuru Division, based on partial budget, 2002.**

(A) First season

Case A (lower field price of 2.5 Ksh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	14,370	7,065	16,113
Gross field benefits (Ksh/ ha)	35,925	17,663	40,283
Total costs that vary (Ksh/ ha)	22,008	35,090	24,762
Net benefits Ksh/ ha)	13,917	-17,428	15,521

Case B (Higher field price of 16 KSh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	14,370	7,065	16,113
Gross field benefits (Ksh/ ha)	229,920	113,040	257,808
Total costs that vary (Ksh/ ha)	22,008	35,090	24,762
Net benefits Ksh/ ha)	207,912	77,950	233,046

(B) Second season

Case A (lower field price of 2.5 Ksh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	1,224	-9,788	4,921
Gross field benefits (Ksh/ ha)	3,060	-24,470	12,303
Total costs that vary (Ksh/ha)	25,967	43,751	29,763
Net benefits (Ksh/ ha)	-22,907	-68,221	-17,461

Case B (Higher field price of 16 Ksh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	1224	-9788	4921
Gross field benefits (Ksh/ ha)	19584	-156608	78736
Total costs that vary (Ksh/ha)	25,967	43,751	29,763
Net benefits Ksh/ ha)	-6,383	-200,359	48,973

Table 3.8 **Sensitivity analysis for the application of three treatments against Diamondback moth for Copenhagen Market in Wundanyi Division, based on partial budget, 2002.**

(A) First season

Case A (lower field price of 3.5 Ksh/ kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	2,486	-6,993	-2,967
Gross field benefits (Ksh/ ha)	8,701	-24,476	-10,385
Total costs that vary (Ksh/ ha)	17,743	28,442	20,059
Net benefits Ksh/ ha)	-9,042	-52,918	-30,444

Case B (Higher field price of 14.5 Ksh/ kg)			
	Thuricide	Karate	Neemroc
Yield increase Kg/ ha)	2,486	-6,993	-2,967
Gross field benefits (Ksh/ ha)	36,047	-101,399	-43,022
Total costs that vary (Ksh/ ha)	17,743	28,442	20,059
Net benefits Ksh/ ha)	18,304	-129,841	-63,081

(B) Second season

Case A (lower field price of 3.5 Ksh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	12,981	-3,833	3,041
Gross field benefits (Ksh/ ha)	45,434	-13,416	10,644
Total costs that vary (Ksh/ ha)	20,132	33,469	22,978
Net benefits Ksh/ ha)	25,302	-46,885	-12,335

Case B (Higher field price of 14.5 Ksh/kg)			
	Thuricide	Karate	Neemroc
Yield increase (Kg/ ha)	12,981	-3,833	3,041
Gross field benefits (Ksh/ ha)	188,225	-55,579	44,095
Total costs that vary (Ksh/ ha)	20,132	33,469	22,978
Net benefits Ksh/ ha)	168,093	-89,048	21,116

3.4.0. Discussions and recommendations

Generally, the study showed that DBM population during the two seasons at both sites was relatively low not exceeding two larvae/plant as observed in the Control plots. The apparent effectiveness of Thuricide in control of DBM was associated with its having the lowest population densities through out the season in the two varieties at the two sites. These results are in agreement with report by Greene *et al.*, (1969) and Ho *et al.*, (1970), that Thuricide is an effective insecticide for controlling Diamondback moth. It is especially effective on lepidopterous larvae and does not affect beneficial insects, thus compatible with biological control. In addition, it is relatively host- specific and does not upset other biotic systems or cause upsurge of secondary pests. It is especially useful since the crops can be treated shortly before harvest, with no medical or legal dangers.

Higher infestation on the Karate treated plots than control, could have been due to elimination of indigenous DBM natural enemies making the Control to have relatively low DBM than Karate. Another reason could have been due to DBM resistance to the active ingredient because of its use over many years. Evidence of DBM resistance to Karate and other pyrethroids in Kenya had also been observed by Kibata (1996). Conclusive evidence of resistance in other parts of the world (Liu *et al.*, 1994) indicates sole reliance on chemical insecticide control is not sustainable, necessitating biological control, which is sustainable.

The fluctuation of population densities over the weeks, seasons and sites shows that DBM densities are diversified with regard to time and locality. The findings on lower infestation toward maturity support that of Lumban and Raros (1975) that infestation during late stages does not relatively affect production. The study also showed that more larvae are found in the younger leaves than the older ones.

With respect to yield, Karate had the lowest yield in three out of four trials. No significant differences were found between Neemroc and Thuricide on Cultivar Gloria. Probably, the slight high DBM on Neemroc did not account for any loss.

Non-significance of regression analysis conducted in the second season for both Cultivars was probably due to low infestations. It is also important to state that these regressions were conducted on pooled data, which did not reflect full range observed in farmers' fields, more so the analysis is based on low DBM pressure. Low R^2 suggests that the parameters affecting yields could not only be explained by DBM pressure. R^2 is the proportion of yield variation explained by the model and its value of 0.4 and 0.49 for the pooled data may indicate that there are other factors 60% and 51%, explaining the variability in yield. One would expect, a priori, that increasing larval density (L) would reduce yield, thus forming an inverse relationship, the negative coefficients on the regression equations support it.

Values for marketable yield did not coincide with damage rating, this lack of agreement could be due to the fact that both are expressed as means and damage-rating criteria was subjective with low damage pressure due to low DBM count.

From the farmers viewpoint the money spent on any kind of pest control has to be rewarded with an increase in return large enough to at least cover this investment. Below this break-even point, pest control is not economical. Most of the treatments in these trials provided economically viable returns for the cost invested, apart from few instances, in particular that of cultivar, Copenhagen Market in the first season and Karate treatment in Gloria cultivar (second season). Despite the higher yields of Neemroc in the first season of Gloria cultivar, the cost benefit analysis and net benefit curves showed clearly that Thuricide is more profitable due to its lower cost of production per unit Kg. This is why; potential yield differs from the economist and plant protectionist point of view. For a plant protectionist or agronomist, potential yield is the attainable yield. This ignores the economic consideration. From the Economist perspective potential yield is the maximum yield where methods to limit yield losses are economically justifiable i.e. the yield where the cost of control do not exceed the prevented yield in monetary terms.

Cabbage yield loss trials like the ones described is quite good but it would be ill advised, however, to extrapolate the results to estimate crop losses over large geographical areas. For example crops in high altitude areas suffer less than those in low altitude, similarly DBM is affected significantly by rainfall. Hence therefore, only systematic surveys under farm fields can produce more reliable crop loss estimates for a given area. Krish *et al.,*

(1988) estimated a loss in marketable yield of 52% due to DBM damage on cabbage, much higher than the one estimated in the trials conducted. The study hence could be improved by undertaking the suggested recommendations below.

1. The experiment be tested per season and per cabbage growing region, with a monetary pay off matrix because results in one area and from two seasons cannot give a true picture of what happens at all the recommendation domains,
2. It might be best to determine DBM damage, distribution and loss in farm fields, due to the fact that researcher are often precise and some times more timely than farmers in operations such as plant spacing, fertilizer application, or weed control. Also yield estimated from small plots often overestimate the yield of an entire field because of errors in the measurement of the harvested area and because the small plots tend to be more uniform than large fields,
3. An economic threshold level for DBM be established,
4. A more detailed study be conducted on a monitoring system particularly on the 6th week after transplanting with bi weekly spraying as treatments.

CHAPTER FOUR

4.0. PREDICTED POTENTIAL TECHNOLOGICAL EFFECTS AT FARM LEVEL WITH ESTABLISHMENT OF THE PARASITIOD *Diadegma Semiclausum* (HELLEN)

4.1. Introduction

Biological control of insect pests has received increasing attention in many African countries in the past few years, particularly classical biological control approach (Vogele *et. al*, 1991). The history of four classical biological control case studies of cassava mealybug, cassava green mite, mango mealybug and water hyacinth, showed a high returns to investment, with benefit cost ratios ranging from 149 and above (De Groote *et al.* 2002), indicating high suitability of biological control for the African environment.

Economic benefits of biological control programmes usually consist of the monetary value of the prevented yield losses and reduced cost of control due to the beneficial organisms (Vogele, *et al.,* 1991), hence the successful bio control of DBM would certainly result in increase in yield and reduced pesticides cost, therefore careful collection of data on cost of control of DBM from the farmers is necessary for any sound assessment.

Predicted potential effects of this bio control of DBM is thus analysed by juxtaposing, the current observed situation (high pesticides use and crop loss) and the projected one after the introduction and release of the parasitoid.

This chapter hence presents results of an *ex- ante* assessment, which was achieved by analysing the cabbage enterprise budget and the economic changes projected due to the parasitiod.

4.2.0. Materials and methods

4.2.1. Conceptual framework

At this stage, no concrete information is available about the yield effect and production situation of this bio control at farm level. The assessment is therefore carried out within an *ex -ante* analytical framework. It is build upon the yield loss trials, experts' projections and farm level data resulting out of interviews conducted in four cabbage-growing districts of Kenya. For this analysis, potential effects at the farm level are analyzed by comparing current yield loss from DBM with hypothetical ones, where low yield loss and pesticides reduction is assumed. The analysis was conducted based on input - output relationship of cabbage production at farmers level. For the quantification of benefits economic surplus model was applied.

4.2.2. Farmers' interviews

Farmers' interviews were conducted in four purposely-selected districts. Criteria for selection were cabbage growing potential as mapped via the use of geographical information system (GIS) and national cabbage production statistics. The parameters used for the mapping were: rainfall (500-1200 mm), soil acidity level (pH 5.5-7.5) and altitude (over 800), these are the basic requirement for cabbage growth (MoARD, 2000). Because a complete list of the cabbage growers who had just harvested or were harvesting cabbage on their farm at the time of survey was unavailable, a sample frame of the farmers was acquired by estimates from the Ministry of Agriculture officers in each survey area. Farmers were then randomly selected from the list.

Given that there were time and financial constraints, only 36 growers were interviewed. The farms surveyed fell under the category of mixed farming system. A combination of Interviews and direct observations survey techniques were used to collect basic data on cabbage production systems. The main instruments applied were farm walk and discussions with the farmer using a semi-structured schedule or open keyword guideline (Appendix 2). Main respondents were mostly heads of the households, their wives and adult members living in the compound. Where the farmer sampled was unavailable, the adjacent farmer on the list was visited. During the farm visits, the researcher and the extension officers introduced themselves, the purpose of the visit and the planned activities. The first step was to ask the farmer about the main farm activities and the location of his cabbage field. After the initial discussions, the researcher asked the farmer to show the farm, especially the areas for further cabbage production.

During the walk to the plot, there were discussions on farming activities and familiarisation with the farm, the farmer, the actual situation and the existing problems in cabbage production. On reaching the cabbage plot the farmer explained the area, the situation of the crop, incidences of insect pest (particularly DBM), estimated yield with and without DBM, both on high and low infestation and during different seasons, the inputs used such as fertiliser, manure, pesticide etc, previous and expected harvests as well as the selling prices.

Interviews were also conducted to essential informants composed of agricultural officers in the districts and scientist related to biological control. The agricultural extension officers interviewed provided information on agricultural production practices in their respective areas. They also provided qualitative data on cabbage production systems in their respective districts and provided general information such as rainfall, temperature, soils and agricultural production.

Table 4.1: **Characterisation and selection criteria of the study areas**

Districts	Agro-ecological	Production potential	Parasitoid release site	Distance to a major city	Ethnic origin
Kiambu	UH2 &3	Very high	Yes	40 km	Kikuyu
Meru Central	UH2 ,3 &4	High	No	200 Km	Meru
Nyamira	UH3 & UM3/4	Moderate	Yes	150 Km	Gusii
Taita Taveta	UM3/4 M4/5	Low	Yes	200 Km	Taita

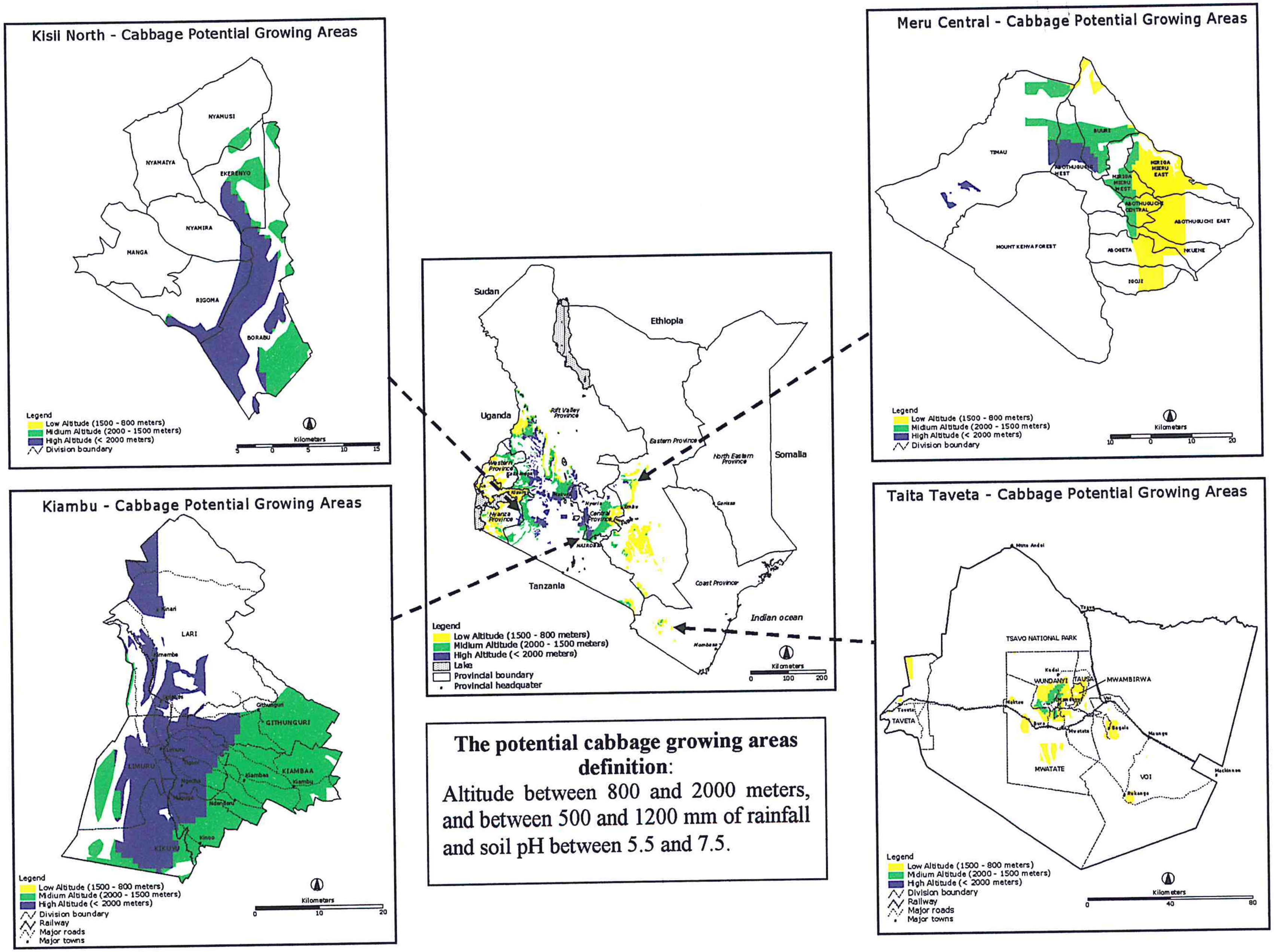
4.2.3. Model of analysis

The economic evaluation framework used in this study was gross margin (G. M) analysis. Gross margin analysis is the difference between gross incomes (G. I) earned and the total variable costs (TVC)

$$G.M = G.\ I - TVC\ (KShs)$$

For farm production, the costs included cost of seeds, fertilizers, extra labour, pesticides and herbicides, marketing costs involving direct costs of transport and selling.

Yield loss was estimated using the earlier formula, taking potential yield as the farmer estimate of the yield without DBM.



The potential cabbage growing areas definition:

Altitude between 800 and 2000 meters, and between 500 and 1200 mm of rainfall and soil pH between 5.5 and 7.5.

Figure 4.1: **Map of Kenya showing the study sites**

4.3.0. Results

4.3.1. Production aspects

Regional cabbage production aspects are shown in table 4.2. On average, typical cabbage holding is 0.5 acres, which constitutes 13% of the total farm area. Kisii North District had a higher average total acreage than the other districts except Meru Central. Obviously it is important to note that cabbage in Kisii North District are grown in settlement schemes, where farmer have relatively bigger farms as compared to other areas of the district. Overall, there was no significant difference in the area under cabbage production between districts (F=1.43, d.f =3, 35; p=0.25).

Nearly all of the cabbage grown in the study districts consists of hybrid varieties of green cabbage, these included Gloria, Cophen Hagen Market, Sugarloaf and Drumhead. Seeds are first raised in nursery bed and later transplanted at a distance of 50 to 70 cm between rows and 30 to 50 cm between plants, giving a plant population of approximately 11,701-27,196 per acre. Ploughing is mostly done by hand except for few instances in Kisii North District where ox-ploughs were used.

In 56% of all cases, cabbage received no regular manure. In Kisii North District, farmers do not use manure at all. Instead, almost every farmer uses fertiliser, although not at recommended rate. Irrigation is done by only a small portion of farmers in Meru Central, Kiambu and Taita Taveta Districts, while none were found using irrigation in Kisii North District.

For insect pest control, most farmers used a wide range of chemicals like Karate, Diazinon, Dithane, Ambush, Brigade, Poltrin, Ripcord, etc. None of the farmers was found using pesticide for control of diseases, however black rot was prevalent in most areas. In contrast to manufacturers' recommendations, farmers used their own mixing rate. These were in most instances below the recommended rates. This is a clear reflection of misuse of farm chemicals. Scheduled spraying is done by 73% of the farmers with an application approximately every two weeks, while only 28 percent monitor the pest before spraying.

Based on farmers' qualitative (subjective) estimates of crop losses, average yield loss of 37% was obtained. Higher estimates were mentioned in Kisii North (medium potential area) while lower one was obtained in Taita Taveta District (low potential area).

Harvesting was by hand, usually, about three or six of the green wrapper leaves are left on each head at harvest unless they are damaged. Most often, the product is put into bags and then packet in the lorry for transport.

Table 4.2: **Aspects of cabbage production in selected districts of Kenya, 2002.**

Aspect	Kiambu	Meru Central	Kisii North	Taita Taveta	Average
Total farm size (acres)	3.12± 0.69	3.9± 0.88	3.6± 0.70	1.8± 0.30	3.2± 0.38
Cabbage holding (acres)	0.6± 0.17	0.4± 0.11	0.7± 0.18	0.2± 0.03	0.5± 0.08
Percent of farmer using manure	77	61	0	45	44
Percent of farmer using pesticides	100	100	87	80	92
Percent using irrigation	26	15	0	65	27
Percentage who do schedule spraying	63	57	86	80	73
Percentage who do monitoring	38	43	14	20	28
Farmer estimate of DBM yield loss	32	44	48	24	37

1 acre =0.405 Hectares. Acre was used for the analysis because it is the standard measure used by most farmers.

n= 36

4.3.2. Enterprise budgets

Per acre costs that farmers incur for cabbage production in the surveyed districts is shown in table 4.3. Although most of the farms surveyed were less than one acre, they were extrapolated to a full acre for comparative purposes. The amounts of inputs used were calculated as per the information given by farmers. Non-purchased inputs and labour were approximated by respective market value i.e. opportunity costs. Therefore, it is important to note that not all the costs indicated here are associated with farmer paying them in monetary terms.

On average total production cost was calculated at KShs 18,950 per acre. Of that total, KShs 2,508 and 2,508 represented manure and fertiliser costs, while labour cost for ploughing, planting and weeding was 1,771, 2,674 and 2,674 KShs/acre respectively. Average insecticide costs were KShs 1,797 per acre, and their application cost totalled KShs 677 per acre.

Comparing the districts, highest production cost was found in Taita Taveta District, which is a good reflection of higher cost of seeds and labour found in our earlier analyses. Kisii North District had the lowest.

Table 4.3: **Cabbage production cost (in KShs/Acre) at farm level in selected districts of Kenya (in 2002)**

District	Kiambu	Meru Central	Kisii North	Taita Taveta	Mean
Labour for land preparation	2,333	950	2,652	1,980	1,992± 445
Cost of seeds	2,395	3,806	696	4,167	2,648± 365
Labour for planting	2,050	1,288	1,643	2,180	1,771± 261
Labour for weeding	2,425	1,728	3,314	3,500	2,674± 431
Labour for irrigation	850	1,371	0	2,483	1,067± 515
Manure	4,689	1,298	0	4,224	2,508± 662
Fertiliser	3,143	3,993	1,542	3,136	2,947± 391
Labour for top dressing	42	451	1,085	2,460	866± 275
Insecticides	1,815	1,969	1,469	1,984	1,797± 290
Labour for insecticide application	426	711	634	1,092	677± 143
Total	**20,170**	**17,570**	**13,039**	**27,208**	**18,950± 1861**

78 KShs = 1 US dollar according to 2002 exchange rate
n=36

The yields, Gross margins and per unit costs are given in table 4.4. The average yield is 11.6 tons per acre, while the overall average gross margin is KShs. 26,070 per acre with KShs 1,633 per unit cost. Lowest yield (4.6 tons) was reported in Kisii North District. Correspondingly, gross margin for Kisii North District was 34 percent lower, when compared to the average. Highest yields and gross margins were obtained in Meru Central District with 16.9 tons and KShs 53,638 respectively. The average yield

11.6tons/acre (28tons/ha) were twice what is reported by the MoARD (13.8 tons/ha, average of 1999 and 2000).

Table 4.4: **Mean cabbage production costs and related income (per acre) in four districts of Kenya, 2002.**

District	Kiambu	Meru Central	Kisii North	Taita Taveta	Mean
Total cost per season (KShs)	20,170	17,570	13,039	27,208	18,950± 1861
Average yields (t)	9.9	16.9	4.6	12.3	11.6±1.64
G. M per season (KShs)	23,215	53,638	6,494	19,453	26,070±6,420
Per unit cost (KShs/ t)	2,037	1,040	2,834	2,212	1,633

78 KShs = 1 US dollar according to 2002 exchange rate
n=36

4.3.3. Effect of the establishment of parasitoid on cost of production of cabbage

Based on the above farmers' interviews, it was clear that most farmers used pesticides that cost them much more than it would be necessary after successful establishment of the parasitoid. Nevertheless, it has to be stressed that the potential technology advantages indicated earlier can only be realised with the adoption of bio control-compatible pesticides. Or more pessimistically, farmers could suffer remarkable losses without adjusting the input mix accordingly, due to the fact that eliminating DBM does not mean that other pests are not there and need control. This hence brings up the importance of transferring the technology to the farmer in combination with the extension of awareness of how to use it successfully. Otherwise, farmer might experience losses that would affect adoption. Because the effect of other pest in lowering yields cannot be overlooked, monitoring and spot spraying of Neemroc at a rate of 5ml per litre was suggested to control aphids, which are second important pest in cabbage production in Kenya and occurs in spots. Accounting for this alternative, potential per unit cost reduction on chemical pesticide through this bio control project was estimated to be 36.3% in pesticides, which, translate to 4.7% cost reduction for the whole production.

4.3.4 Effect of the establishment of parasitoid on cabbage yield and incomes

As projected, benefits are obvious, since there will be a reduction in the costs of chemicals, spray labour and an increase of yield as discussed earlier. To date, no accurate data are available as to how far yields are reduced by DBM and at what rate the losses will be mitigated by the parasitoid. The trials conducted earlier and spot surveys, however, indicate that infestation under the current control methods cause yield loss of between 12%-22% (average 17%), much less than farmers calculated estimate of 37%. Taking the yield loss as an average of that obtained from the yield loss trials and farmers estimates (27%) a farmer looses 4.29 tons/acre/season using the data from farm interviews and 5.1 tons/ha by the data from the Ministry of Agriculture.

Predicting that due to introduction of the parasitoid, yield losses in individuals farms will be reduced by 30% (predicted by biological experts), the benefits will amount to approximately 1.28 tons per acre per season, which translate into KShs 12,871/acre/season without reduction in cost of production and 13,769 KShs/acre/season with reduction of cost of production. Total benefits will amount to KShs 332 million/ year for the whole economy in completely elastic demand and supply situation. Extrapolated for twenty year and taking other factors constant result into KShs 6.7

billions. Farmers are not expected to have any additional cost related to this bio control including harvesting because the buyer does the harvesting.

Although the benefits are likely to increase, since the full effect is not taken care off, we have no reliable means of calculating exactly how this would be. Therefore, it is convenient to see these figures as a conservative estimate, to be updated when more evidence becomes available.

4.4.0. Discussions and recommendations

In general the high gross margins from cabbage production showed that it was an economical enterprise, which, if done with optimum management practices, can contribute to reduction of poverty. The figures of average yield observed are very different from what is reported by the ministry of Agriculture. These contrasting sets of data are valuable to researchers as they leave a gap, which require to be researched on. Probably this may be attributed by lack of clear data from some front line extension officers. In addition these data are just estimates without any crop census.

Farmers' level of pesticides use was high, account for 13% of the total cost of production this support finding by Kibata, (1996) that farmers increase spraying frequencies in order to control DBM. Important to note that pesticide use also have hidden cost, for example in the Philippines damage to farmers healthy by pesticide use in rice production are about equal to the amount farmer spend for pesticides (Rola *et al.*, 1993). Cost related to healthy include, cost of medication, doctors fees and opportunity cost of time lost when the farmer is sick.

Farmer estimate of the crop loss due to DBM was almost twice what was calculated from on farm loss assessment studies in the two locations. Suggesting higher loss from farmer point of view, probably this is due to high DBM population resulting from increased use of Karate by most farmers. Another factor could be as a result of bigger scope of information from different farmers as opposed to the limited locality of the trials.

Bio control normally is expected to raise farm yields, lower pesticides use and thereby, raise farm profits (Waibel, 1994), all the three are testable hypothesis, which in this case were calculated through projection of what is expected to happen. The findings indicate that there could be substantial reduction in cost of production due to reduced use of insecticide and increase of yields if the establishment of the parasitoid is successful.

It is recommended that research be conducted in every cabbage production region in Kenya so as to have a good baseline statistic of cabbage growing. Intensive awareness creation on compatible pesticide should also be advocated.

CHAPTER FIVE

5.0. PREDICTED MARKET EFFECTS OF BIOLOGICAL CONTROL OF DIAMONDBACK MOTH PROGRESS IN KENYA

5.1. Introduction

Potential yield and income effects of establishment of the parasitoids was investigated and analysed in the previous chapter. However, many major assumptions were made from the economic point of view. First, the income calculation assumed that farmers are using the technology without any constraint of adoption. Secondly, potential benefits to other groups like consumers caused by lower prices were neglected and thirdly, supply and demand responses due to low prices were neglected. Hence, this chapter attempts to show possible market changes with the new situation in Kenya cabbage production sector.

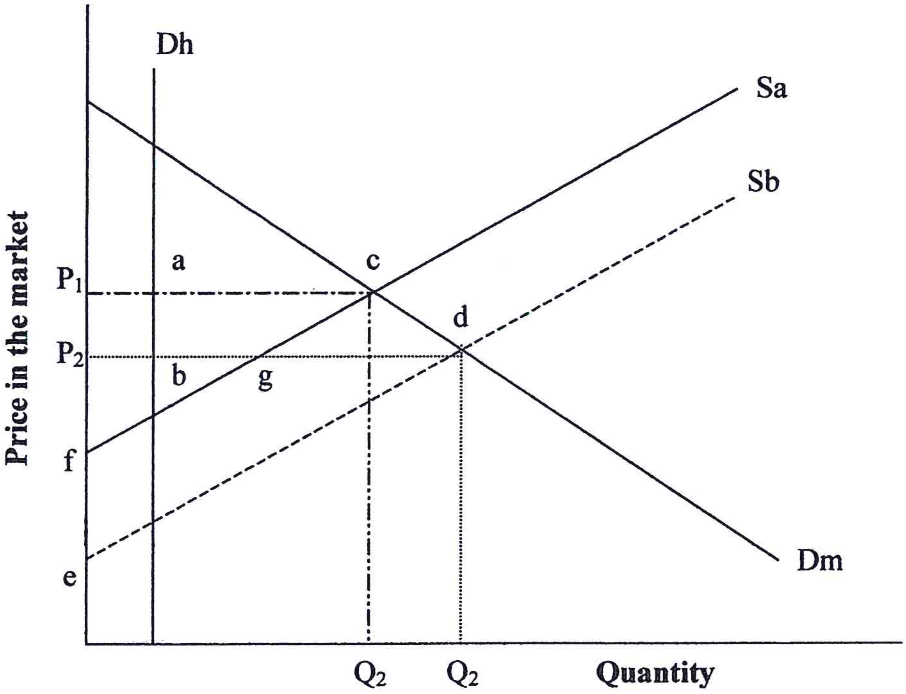
5.2.0. Materials and methods

5.2.1. Conceptual framework

The linear economic surplus model is the most common approach for the evaluation of commodity related research activities and technologies in agriculture (Alston *et al*, 1995). It uses a partial equilibrium approach to estimate the net benefit due to technologies and the distribution of such gains to producers and consumers expressed as changes in producer and consumer surplus. The technologies here were the release of *D. semiclausum*, which would result in a reduction of pest populations and hence abatement of loss caused by DBM and a reduction in frequency of pesticide application and hence production cost. However, this method only captures the direct and immediate benefits of the technology for producers and consumers. Spill over to other markets as well as indirect and dynamic effects are not included in the quantitative model. These effects includes, long-term benefit through environmental and health effects and agricultural growth linkages through economic growth due to increased purchasing power and generation of employment.

A simple model of biological control progress in the Kenyan market, taking account of home consumption, is shown in Figure 5.1. It should be noted that home consumption of own produced crops is less price responsive than the market demand for the same produce. The supplies curve without the use of the technology is Sa (Fig 5.1). Demand curves in the market and home consumption are denoted Dm and Dh, respectively. The equilibrium price, supply and demand is given at point E. Lowering the cost per unit of output will cause initial supply curve to shift to a lower level marked Sb. This shift in supply moves the equilibrium to a lower level of price (P_2) and higher level of quantity (Q_2). For producers, as indicated earlier, the impact of this technology is a reduction of production cost and an increase of produce. In terms of economic surplus, this is represented by an increase of the area cdef (the area between the lines Sa and Sb). But it also reduces the price received by the producer surplus area abgc. Thus the net change in producer surplus is the gain of area cdef minus the loss of area abgc. This is only true when the demand curve is elastic and the markets are spatially integrated. For consumers, the effect will always be a gain; they receive whatever is lost by the producers due to lower prices (area abcg), plus the economic surplus on the increased quantity (area cdg).

If cabbage production were a completely commercialized enterprise, consumers would additionally capture area P_1abP_2, part of which the producers retain due to home consumption.



Source: adapted from Qaim (2000)

Figure 5.1: **Predicted market effects of the establishment of *D. Semiclausum* in Kenya**

To move from the graphical approach presented to practical application, production increase (J), adoption cost (C), supply shift (K) and equilibrium quantity change (Q) need to be estimated.

The J parameter can be defined as the total increase in production that would be caused by adopting the new technology, in the absence of any change in the costs or prices.

$J = Y*t*A$.

Where Y= yield increase caused by the technology. t= adoption rate expressed as the rate of adoption of package. A= total area under the crop. For many applications, it is more practical to compute the J parameter in proportional term, as the increasing quantity produced as the share of the total quantity $j =(Y*t)/Y$.

The I parameter may be defined as the increase in per unit input costs required to obtain the given production increase (J). It can be calculated based on the following parameter. Adoption cost C. Adoption rate t and overall average yield (Y). The complete formula is $I= C*t/Y$.

The K parameter may be defined as the net reduction in production cost induced by the new technology $K= (J*b)-I$. Using proportional terms we can have $k = K/P$. Then using supply elasticity (E) we get $k=(j/E)- c$.

The change in quantities actually caused by technology Q depends on the shift in supply and responsiveness of the supply and demand. The equilibrium would be that price and quantity, which satisfy both, demand and supply. Based on this the analysis is conducted from 2000 to 2020. Assuming spatial market integration a single national demand curve was observed.

5.2.2. Sources of data.

Production figure, prices and other relevant information were got from the Ministry of agriculture and rural development. Details on expenses at ICIPE- DBM biological control project on research and extension were obtained from ICIPE finance office.

5.2.3. Model of analysis

The economic evaluation framework used in this study was net present value, cost benefit ratio and the internal rate of return. If the net present value is positive, the impact was considered to be economically beneficial.

The net present value model used was: - NPV= PVB- PVC

Where: - NPV= Net Present Value, PVB= Present value of benefits, PVC= Present Value of Costs

$$PVB = B_0 + \frac{B_1}{(1+r)} + \frac{B_2}{(1+r)^2} + \frac{B_n}{(1+r)^n}$$

$$PVC = C_0 + \frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \frac{C_n}{(1+r)^n}$$

Where: - B_0 = Benefit at year 0

B_1 = Benefit at year 1

B_2 = Benefit at year 2

B_n = Benefit at year n

C_0 = Cost at year 0

C_1 = Cost at year 1

C_2= Cost at year 2

C_n= Cost at year n

Dynamic Research Analysis for Management (DREAM) package was used to conduct the economic analysis. Because international trade on cabbage is negligible, we build a closed economy model. Benefits were simulated for 20 years.

5.3.0. Results

5.3.1. Supply shifts parameters

An average yield of 13.8 tons/ha and total production of 261,275 tonnes (average of 1999 and 2000 MoARD) were used as the basis. It was assumed that most of the production is from the highlands because these are the areas that the parasitoid is expected to work. An average price of 10 KShs/kg was considered.

Estimates of supply and demand elasticity could not be found in the literature. For the semi-subsistence farming system and in the absence of better information, supply response parameters for agricultural crops in developing countries like Kenya are often approximated with a value close to one (Alston *et al.*, 1995). We assume a supply elasticity of 0.9, as it tends to be very low in short run and high in the long run.

Given that the price responsiveness of demand is usually higher in the developing countries, a demand elasticity coefficient of -1.4 was assumed (Qaim, 1999). Because of high population growth in Kenya and expectation of higher demand in future an annual growth rate of 2.6% on average (World Bank, 1999) was used to refine the demand situation expected.

5.3.2. Financial returns from the bio control

Table 5.1 shows projections of benefits obtained by cabbage producers and consumers over the 20 years investigated. Yearly benefits up to 2019, a reasonable period for the full impact are presented in appendix 3. There is strong evidence of positive economic impact of this biological control project. The net present benefits for both producers and consumers were calculated at KShs 5.57 billions. Consumers were estimated to get 39% of the benefit and producers 61%. Although the benefits are likely to increase, once again this figure should be treated as a conservative estimate to be updated when more evidence become available.

Table 5.1: **Distribution impact and social gains from the biological control of Diamondback moth.**

	Billions KShs	Percentage
Producer net present benefit value	3.39	61
Consumer net present benefit value	2.18	39
Total net present value benefit	5.57	100

5.3.3. Cost of the project implementations

The costs of DBM biological control programme from the start 2000 to 2003 were estimated at KShs 48.56 millions (table 5.1), which was 49% of the total budget allocated for whole project covering East and South Africa. The costs comprise those of exploration to obtain and screen the parasitoids and the cost of rearing and release of the parasitoids. Important to note that another phase of the project was required after the first three-year phase of donor support for the extension and monitoring. This cost was estimated to be around KShs 65.52 million. Total cost compounded/ discounted at a rate of 10% relative to the base year of 2000, account for a total of KShs 81.23 millions.

Total cost divided by cabbage hectarage (18,956 ha) result in a cost of KShs 6,017 per Ha. Divide over the 20 years of the analysis, amount to KShs 301per ha per year.

Table 5.2: **Costs of development and implementation of DBM bio- control strategy in Kenya (Thousand, KShs)**

Budget topic	**Year 1**	**Year 2**	**Year 3**	**Total**
Personnel costs	7,747.9	7,747.9	7,981.9	23,477.7
Travels and Vehicle running costs	257.4	721.5	2,203.5	3,182.4
Training workshops and professional services	3,159.0	585.0	351.0	4,095.0
Introduction, release and monitoring	0.0	1,131.0	273.1	1404.0
Student training	3,510.0	1,950.0	1,950.0	7,410.0
Additional personnel	546.2	624.0	702.1	1,872.3
Institutional services to ICIPE 18%	2,739.7	2,296.7	2,063.1	7,099.5
Grand total	17,960.2	15,055.1	15,524.7	48,540.9

5.3.4. Cost benefit analysis

Comparing the present value of benefit (KShs 5.57 billions) to the cost (KShs 81.23 Million), benefit cost ratio was estimated at 68:1. Clearly demonstrating that investing on this bio control was profitable.

5.3.5. Sensitivity analysis

Sensitivity analyses were carried out to strength credibility of results by varying some parameters based on uncertainties. With a conservative minimum loss abatement of 15% and a maximum of 75%, the benefit in scenario 1 amount to KShs 4.86 billions and the benefit cost ratio becomes 59:1. With maximum abatement (75%) the benefit becomes KShs 7.78 billions and a benefit cost ratio of 96:1. More over, the sensitivity with respect to the price elasticity of demand and supply was tested. A reduction of demand elasticity (-0.7) result into benefit of KShs 5.69 billions, shifts more benefits from the producers to consumers by almost half and slightly increases the benefit cost ratio (70:1). For higher value the opposite hold true. For various discounting rates, the total benefit changes from KShs 5.57 billions with 10% p.a. to KShs 1.91 billions with 20% p.a. and the benefit cost ratio from 68:1 to about 31:1. Even in worst situation where the discount rate is highest no reduction in cost of control and recovery of yield is 15%, there are still some benefits (benefit cost ratio 3.4:1). These results indicate that even with pessimistic assumptions this bio control will still be profitable.

5.4. Discussions and recommendations

In the present analysis the programme was found to be beneficial for Kenya, although not as higher as others conducted e.g. cassava mealybug in Africa, benefit cost ratio of 149:1 (Norgaard, 1988), water hyacinth in Southern Benin, benefit cost ratio of 124:1 (De Groote *et al.*, 2002) and mango mealybug in Benin, benefit cost ratio of 145:1 (Bokonon-Ganta *et al.*, 2002).

Important to note that the analysis considered the least favorable case of yield recovery and pesticide reduction and did not include other benefits like: reduction of loss and pesticide use in other crucifers crop in Kenya and neighboring countries, possibility of increase in market value for the pesticide free cabbage and their export, reduced healthy hazard of food stuff, reduced healthy hazard to pesticide applicators and consumers, reduced pollution of ground and surface water and reduced danger of biodiversity loss and other intangible benefits like increase of self confidence and knowledge of the farmers after being trained on compatible pesticide use. Hence, the figure should be treated as a conservative estimate as portrayed by sensitivity analysis confirms this to be updated when more evidence become available.

Current efforts at expressing benefits to the environment in monetary terms have generally been confronted with difficulties and the need for a more strategic approach to ecological impact assessment has been identified (Treweek, 1996).

CHAPTER SIX

6.0. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

In the yield loss assessment experiments, Thuricide was more effective than both Neemroc and Karate in checking DBM. Economically, Thuricide is recommended, as the best performing DBM control product. Karate had the highest DBM populations than the non-sprayed plots in all trials. Probably this is due to insecticide resistance and elimination of natural enemies by Karate, hence it's use for DBM control should be discouraged. Future research should address the determination of resistance of DBM to Karate. Diamondback moth was found to be more prevalent during weeks 6 and 8 after transplanting; possibilities of investigation should be conducted to find out which is the critical time to spray pesticides to control DBM.

Yield loss due to DBM was estimated to be around 12- 22% under the current control practices. This is approximately half of farmer's subjective estimate (37%), accuracy of the estimates should be tested. There is also need for future research to determine yield loss per season and per cabbage growing region, with monetary pay off matrix. It is also recommended that an economic threshold level for DBM in Kenya be established.

Yields under farmers' fields (28 tons/ha) were twice what is reported by the Ministry of Agriculture (13.8 tons/ha). Economic benefit for this bio control was estimated to be KShs 5.57 billions for the simulated time lapse of 20 years with a benefit cost ratio of 68:1. This is a rather conservative figure, which should be updated when more evidence becomes available. It should also be noted that the chosen parameters did not take into account the possibility of intensification of cabbage production, which would mean higher yields, but also higher potential losses, and hence higher savings due to this project. Due to large standard errors of individual parameters investigated for most of the farmers' data (Table 4.1-4.4), it would be recommended that for future surveys, a larger sample size should be pursued. Creating awareness and improving the information flow among the small-scale farmers should be taken as a priority.

REFERENCES

Abbas, M.S.T. (1988). Biological and ecological studies on *Diadegma semiclausum* Hellen (Hym. Ichneumonidae), a larval parasite of the Diamondback Moth, *Plutella Xylostella* (L.) (Lep. Plutellidae) in Egypt. Anz. Schadlingskde., Pflanzenschutz, and Umweltschutz 61:1-2.

Alston, J.M., G.W. Norton and P.G. Pardey (1995). Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press, Ithaca, NY, USA.

Ankersmit, G.W. (1953). DDT resistance in *Plutella maculipennis* (Curt.) (Lepidoptera) in Java. *Bulletin of Entomological Research* 44: 421-25.

AVRDC. (1988). Progress Report. Shanhua, Taiwan: Asian Vegetable Research and Development Center. 540 pp

Azidah, A. A., M.G. Fitton and D. L. J. Quicke. (2000). Identification of the *Diadegma* species (Hymenoptera: Ichneumonidae, Campopleginae) attacking the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Bulletin of Entomological Research* 90: 375-389.

Baker, K. F., and R. J. Cook. (1974). Biological Control of Plant Pathogens, W. H. Freeman and Co, San Francisco, California. 433 pp. (Book, reprinted in 1982, Amer. Phytopathol. Soc., St. Paul, Minnesota).

Barroga, S. F. 1974. A survey of diamondback moth population for resistance to the insecticides in the Philippines. M.S. thesis. Univ. of the Philippines at Los Banos. 117 pp.

Beck, N. G. (1992). Lepidopterous pests on vegetable brassicas in Pukekohe, New Zealand: their seasonally, parasitism, and management. Ph.D. thesis .University of Auckland , New Zealand.

Beirner, B. P. (1967). Biological control and its potential. World Rev. Pest Control 6(1):7-20.

Biever, K.D. (1996). Development and use of a biological control -IPM system for insect Pests of crucifers. In Sivapragasam, A., Kole, W.H., Hassan, A.K. and G.S. Lim (eds.). *The management of diamondback moth and other crucifer pests.* Proceedings of the third International worKShsop, Kuala Lumpur, Malaysia.

Bokonon-Ganta A., H. De Groote and P. Neuenschwander. (2002). Socio-economic impact of biological control of mango mealybug in Benin. Agriculture, Ecosystems and Environment Journal 93, 367-378.

CIMMYT. (1993). The adoption of agricultural technology: A guide for survey design . Economics Programme, International Maize and Wheat Improvement Center, Mexico city.

Coulibaly, O, V. Manyong, S. Yaninek, R. Hanna, P. Sanginga, D. Endamana, A. Adesina and P. Neuenschwander. (2002). Economic impact of classical biological contro of cassava green mite in West Africa. Submitted to agriculture, ecosystems and environment.

Chen, C. N., W. Y. Su (1986). Ecology and control thresholds of Diamondback moth on crucifers in Taiwan. See Ref. 40, pp. 415-21.

Cheng, E.Y., C.H. Kao & C.S. Chiu (1992). The resistance, cross resistance, and chemical control of diamondback moth in Taiwan: Recent Developments. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the Second International Workshop Tainan, Taiwan, 10-14 December 1990. Asian Vegetable Research & Development Centre. AVDRC Publication No. 92-368.

DeBach, P. (1964). Biological Control of Insect Pests and Weeds. Reinhold, New York, New York. Pp 844.

De Groote H., O. Ajuonu, S Attignon, R. Djessou, P. Neuenschwander. (2002). Economic impact of biological control of water hyacinth in southern Benin. IITA, Benin, submitted to Ecological Economics.

Dennill, G.B. and W.L. Pretorius. (1995). The status of diamondback moth, *Plutella xylostella* (Linnaeus) (Lepidoptera: Plutellidae), and its parasitoids on cabbages in South Africa. *African Entomology* 3 (1): 65-71.

Dreyer, M. (1987). Field and laboratory trials with neem products as protetants against pests of vegetable and field crops in Togo, pp. 431-447. In; Natural pesticides from the neem Tree(Azadirachta indica A. Juss). 9Eds. H. Schmutterer, K.R.S. Ascher) Proceedings of the third international Neem Conference, 10-15 July, 1986, Nairobi, Kenya. GTZ, Escborn, FRG.

Fitton, M. and A. Walker. (1992). Hymenopterous parasitoids associated with diamondback moth: the taxonomic dilemma. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the Second

International Workshop Tainan, Taiwan, 10-14 December 1990. Asian Vegetable Research and Development Centre. AVDRC Publication No. 92-368.

Gittinger, J.P. (1982). Economic Analysis of Agricultural Projects. Washington DC, The World Bank.

Greene, G. L., Genung, W. G., Workman, R. B and E.G. Kelsheimer. (1969). Cabbage looper control in Florida A co-operative program. J. Econ. Entomol. 62: 798-800.

Harcourt, D. G. (1954). Population dynamics of the Diamondback Moth in Southern Ontario. In Talekar, N.S. and T.D. Griggs (eds.). Diamondback Moth Management. Proceedings of the First International Workshop, AVDRC Shanhua Taiwan.

Hardy, J. E. (1938). *Plutella maculipennis* Curt, its natural and biological control in England. Bulletin of Entomological Research 29: 342-372.

Herren, H. and P. Neuenschwander. (1991). Biological control of cassava pests in Africa. Annual Review of Entomology. 36, 257-283.

Ho T. and K. Y. Nag. (1970). *Bacillus thuringiensis* (Berliner) for the control of diamondback moth in Weastern Malaysia Agric. Jonur. 47: 313-322.

Iga, M. (1997). Effect of release of the introduced ichneumonid parasitoid, *Diadegma semiclausum* (Hellen), on the diamondback moth, *Plutella xylostella* (L.) in an experimental cabbage field. Japanese Journal of Applied Entomology and Zoology, 44(4) 195-199.

James, K. (1993). Integrated Pest Management for Cole Crops and Lettuce.. Un. of California Publication No. 3307. Davis, C. A.

Johnson, D. R. (1953). *Plutella maculipennis* resistance to DDT in Java. Journal of Economic Entomology 46:176.

Kfir, R. (1997). Parasitoids of Plutella *xylostella* (lep. plutellidae) in South Africa: An Annotated List. Entomophaga 42 (4): 517-523.

Kibata, G.N. (1996). The diamondback moth: a problem pest of Brassica crops in Kenya. In Sivapragasam, A., Kole, W.H., Hassan, A.K. and G.S. Lim (eds.). The management of diamondback moth and other crucifer pests. Proceedings of the third International workshop, Kuala Lumpur, Malaysia, pp 47-53.

Kirsh, K., H. Schmutterer. (1988). Low efficacy of *Bacillus thuringiensis* (Berl.) formulations in controlling the diamondback moth, Plutella xylostella (L.) in the Philippines. J. Appl. Entomol. 105: 249-55.

Konig, K., L. Deogracias and J. Amend. (1993). Mass rearing and utilization of *Diadegma semiclausum.* Philippine-German Biological Plant Protection Project, Department of Agriculture, Manila, Philippines.

Löhr, B., Varela, A. M., B. Santos. (1990). Exploration for natural enemies of the cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae), in South America for the biological control of this introduced pest in Africa. Bull. Ent. Res. 80, 1-17.

Lumaban, M. D. and R. S. Raros. (1975). Yield responses of cabbage and mungo to injury by important insect pests in relation to insecticidal control efficiency. Phil. Entomol. 2:445-452.

Masters W., B Coulibaly, O. Sanogo, M. Sidibe and A, Williams. (1996). The economic Impact o Agricultural Research: Practical Guide. Purdue University, West Lafayette.

Mingochi, D. S., S. W. Luchen and J. Kembo. (1995). Biological control of vegetable pests in Zambia. Integrating biological control and host plant resistance. In Proceedings of a CTA/IAR/IIBC seminar, Addis Ababa, Ethiopia, 9-14 October 1995, pp 107-112.

MoARD. (1997). Ministry of Agriculture and rural Development. National annual report 2000, Kenya

MoARD. (1999, 2000). Ministry of Agriculture and rural Development. Horticultural annual report 2000, Kenya.

MoARD. (2000). Local and export vegetable manual. Ministry of Agriculture and rural Development in conjunction with Japan International cooperation agency. AIRC.

Miyata, T., T. Saito and V. Noppun. (1986). Studies on the mechanisms of diamondback moth resistance to insecticides. In Talekar, N. S. and T. D. Griggs (eds.). Diamondback Moth Management. Proceedings of the First International Workshop, AVDRC Shanhua Taiwan, PP 159-171.

Neunschwander, P. (1994). Control of the cassava mealybug in Africa; lesson from a biological control project. Afri. Crop Sci. J. 2,369-383.

Norgaard, R.B. (1988). The biological control of the cassava mealy bug in Africa. Amer. J of Agricultural Economics, 70: 366-371.

Ooi, P. (1990). Role of parasitoids in managing diamondback moth in the Cameron Highlands, Malaysia. Diamondback moth and other crucifer pests. Proceedings of the second International workshop, Tainan, Taiwan, 10-14 December 1990. AVRDC publication No. 92-368, pp 255-262 Talekar, N. S. (ed.) 1992.

Poelking, A. (1992). Diamondback moth in the Philippines and its control with *Diadegma semiclausum*. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the Second International Workshop Tainan, Taiwan, 10-14 December.

Qaim, M., and J. Von Braun. (1999). Crop Biotechnology in developing Countries: A Conceptual Framework for ex ante Economic Analysis. ZEF Discussion Papeers on Development Policy No. 3, Center for Development Research Bonn.

Rejesus-Morallo B. (1986). Botanical insecticides against the diamondback moth. Proc. 1st Int. diamondback Moth management workshop.(Tainan,Taiwan, 1985). Pp 241.

Rola, A., and P. Pingali. (1993). Pesticides, rice productivity and farmes health. An economic assessment.International rice research insitiute (IRRI), Manilla, Phillipines.

Sastrosiswojo, S. and S. Sastrodihardjo. (1986). Status of biological control of diamondback moth by introduction of parasitoid *Diadegma eucerophaga* in Indonesia. See Ref. 40. Pp. 185-94.

Seif, A. A. and B. Löhr (1998). Brassica planning meeting for East and Southern Africa Region, ICIPE Duduville, Kasarani Nairobi-Kenya, 12-22 May 1998. GTZ-IPM.

Shelton, A.M., J.L. Robertson, J.D. Tang, C. Perez, S.D. Eigenbrode, H.K. Presler, W.T. Wilsey and R.J. Cooley (1992). Resistance of diamondback moth (Lepidoptera: Plutellidae) to *Bacillus thuringiensis* subspecies in the field. Journal of Economic Entomology 86: 697-705.

Sun, C.N. (1992). Insecticide resistance in diamondback moth. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the Second International Workshop Tainan, Taiwan, 10-14 December 1990. Asian Vegetable Research and Development Centre. AVDRC Publication No. 92-368.

Syed, A.R. (1992). Insecticide resistance in the diamondback moth in Malaysia. In N.S. Talekar (ed.). Diamondback Moth and other Crucifer Pests. Proceedings of the Second International WorKShsop Tainan, Taiwan, 10-14 December 1990. Asian Vegetable Research and Development Centre. AVDRC Publication No. 92-368.

Talekar, N.S. and A.M. Shelton. (1993). Biology, ecology and management of the diamondback moth. Annual Review of Entomology 38: 275-301.

Talekar, N.S. and J.C. Yang. (1991). Characteristic of Parasitism of Diamondback Moth by Two Larval Parasites. Entomophaga 36 (1): 95-104.

Talekar, N. S., S. T. Lee and S. W. Huang (1986). Intercropping and modification of irrigation method for the control of the diamondback moth. In Talekar, N.S. and T.D. Griggs (eds.) Diamondback Moth Management. Proceedings of the First International Workshop, AVDRC Shanhua Taiwan.

Talekar, N. S.; Yang, J. C. and S. T. Lee. (1990). Introduction of *Diadegma semiclausum* to control diamondback moth in Taiwan. Diamondback moth and other crucifer pests. Proceedings of the second International workshop, Tainan, Taiwan, 10-14 December 1990. AVRDC publication No. 92-368, pp 263-270. Talekar, N. S. (ed.) 1992.

Tindall, H.D. (1983). Vegetables in the tropics. Macmillan Press Ltd., London. 533pp.

Thomas, W. P., A. M. Ferguson. (1989). *Plutella xylostella* (L.*),* diamondback moth (Lepidoptera: Yponomeutidae). Tech Commun Commonw. Inst. Biol. Control.

Thorsteinson, A. J. (1953). The chemotactic responses that determine host specificity in an oligophagus insect (*Plutella maculipennis* (Curt.): Lepidoptera). *Can. J. Zool.* 31:52-72.

Treweek, J. (1996). Ecology and environmental impact assessment. J. appl. Ecol., 33, 191- 199.

Velasco, L.R.I. (1982). The life history of *Apanteles plutellae* Kurdj. (Braconidae), a parasitoid of the diamondback moth. Philippines Entomologist 5(4): 385-399.

Venkatraman, T.V. (1964). Experimental studies on superparasitism and multiparasitism in *Horogenes cerophaga* (Grav.) and *Hymenobosmina rapi* (Cam.), the larval parasites of *Plutella maculipennis* (Curt.). *Indian Journal of Entomology* 26: 1-32.

Verkerk, R. H. J. and D. J. Wright. (1997). Field-based studies with diamondback moth tritrophic system in Cameron Highlands of Malaysia: Implications for pest management. International Journal of Pest Management, 43(1), 27-33.

Vogele, J.M, D. Agouke and D. Moore. (1991). Biological control of fruit tree mealybug Williams in Togo: A preliminary sociological and economic evaluation. Journal of tropical Pest Management. 37 (4), 379-382.

Vogele, J. (1990). The economics of biological and conventional pest and disease control strategies in major crops in Western Samoa. Dissertation Zur Erlangung Des Grades eines Doktors der Agrarwissenchaften. Hohenheim University, Stuttgart Hohenheim Wallingford, Oxon, Uk: Commonwealth Agricultural Bureaux.

Waibel. H. (1994). Toward and economic framework of pesticide policy. Proceedings of the Gottingen wokshop on pesticides policy, Ed. By S. Agne, G.Fleischer and H. Waibel,Gottinger Schriften Zur Agrarokonomie, Vol.66 institute of agricultural economics, University of Gottingen, 1994.

World Bank. (1999). World Development Report 1998/1999; Knowledge for Development. Oxford University Press, New York.

Yang, J.C., Chu, Y.I. & N.S. Talekar (1993). Biological Studies of *Diadegma semiclausum*. (hym., ichneumonidae), a Parasite of Diamondback Moth. Entomophaga 38 (4): 579-586.

Zeddies, J., R. P. Neuenschwander, H.R. Herren. (2001). Economics of biological control of cassava mealybug in Africa. Agricultural Economics 24, 209 - 219.

Appendices

Appendix 1: Assessment form

Crop---------- Variety-------------Site----------------Treatment---------------Date------------------------

	DBM					Aphids								
plant	s	big	pupa	adult	Dam.	BB	LE	MP	%par	thrips	W .flies	L miner	Helico	others
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	DBM					Aphids								
plant	s	big	pupa	adult	Dam.	BB	LE	MP	% par	thrips	W. flies	L miner	Helico	others
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	DBM					Aphids								
plant	s	big	pupa	adult	Dam.	BB	LE	MP	% par	thrips	W. flies	L miner	Helico	others
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

	DBM					Aphids								
plant	s	big	pupa	adult	Dam.	BB	LE	MP	% par	thrips	W. flies	L miner	Helico	others
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														

S=small larvae, big=big larvae, dam= damage score, BB=*Brevicorynr brassicae,* LE=*Lipaphis erysimi* MP= *Myzus persica*, %par=% parasitism, W.flies=white flies, L.mine= leave miner, Helico=Helicoverpa.emirgira

Appendix 2: **Keyword guideline for data collection in farmers interview**

001. Date _________________________002 sheet No. _________________________

003. Name of the farmer____

004. Age of the farmer__________________ 005. Education level_______________

006. District/ Division/ Loc/Sublo____

007. Farm size in acres___________________________

008. Ownership of land. Private ☐, Inherited ☐, Leased ☐, Any agreement ☐.

009. Any farm records___, if yes, which types ________________________________

____

010. Size of land covered by Frenchbeans.

At the time	Ist season (	2ndseason (	Third season (

011. Varieties Grown. ____

012. Preferred varieties and reasons (Rank)___________________________________

____

013. Quantities and cost of seeds____

INPUTS

014. Fertilizers

Kind	Time of application	No. Applications	Quantity	Cost/ Kg	Total cost

015. Manure.

Kind	Time of application	No. Applications	Quantity	Cost/ Kg	Total cost

016. Pesticides and Fungicides.

Kind	Where purchased	No. Applications	Quantity	Cost/ Kg	Total cost	Target pest names	Good or bad

017. Irrigation.

Technic	Manhour/irrigation	No. per week	Cost/irrigation	Total cost

018. Labour.

	No. People	Manhour or days	How often	Local wage	Total cost
Ploughing					
Planting/seeding					
Weeding					
Top dressing					
Pesticide application					
Harvesting					

019. Harvesting.

Time of harvest	Quantity harvested	Amount sold	Amount home consumption	Amount wasted	Market price	Total production

020. Where are the Markets ______________________________

021. Transport costs____________________

022. Selling prices in the market. (Month)

	1st season (	2nd season (	3rd season (
Selling units			
Highest			
Lowest			

023. Any brookers involved ______

024. If yes, Names____

____

025. Buying prices. (Months)

	1st season (	2nd season (	3rd season (
Selling units			
Highest			
Lowest			

026. Any contract with buyers _____

027. If yes, Names and their regulations.

____

____

____

028. Do the contractors give any assistance__

029. If yes, what kind____

____

030. Is it difficult for the farmer to sell his produce.

031. If yes, the most important reasons___________________________

____

032. What happen to the product the farmer cannot sell_______________

____

033. Does the farmer know the pests and diseases affecting his or her cabbage?

Insect Pests		Diseases	
English name	Local name	English name	Local name

034. How many years the farmer had insect attack

Insect name					
NO. Of years					

035. Which of the following the farmer believe cause the most yield loss.

Season	Rainy	Long	Dry
Excess rain			
Not enough rain			
Weeds			
Insects			
Diseases			

036. How the farmer apply pesticides and equipment used. (Singly, Mixture,)

____

____

____

____

037. Which pesticides were used in the past 5 years.__________________________

____

038. Reasons for selecting certain pesticides_________________________________

____

____

____

039. Does the farmer Know health harzards of pesticides____. If yes, state.

____

____

____

040. Any experience. _____. If yes, state____________________________________

____

____

042. How does the farmer decide when to spray next? Monitoring.__Routine schedules__

043. Other Methods of pest control the farmer applies.

Method	Real method applied	Target pests
Cultural		
Biological		
Bio chemical		
Others		

044. Farmer suggested solutions for insect pest control

Solution	Enter priority 1- 6	Reasons
Chemical		
Cultural		
Biological		
Varietal		
No control		
Others		

045. General problems farmer faces in cabbage production.

Reasons	Ranks	Why
Pests		
Input cost		
Seeds inpurity		
Pesticide inpurity		
Marketing		
Water shortage		
Poor soil fertility		
Natural disaster		
Others		

046. Farmer estimation of loss if there is no control of (The crop in the farm to be used for this).

	Insects	Diseases	Weeds	Combination
Severe attack				
Light attack				

047. Typical year-to-year variance or general uncertainty associated with variable pests crop prices, effectiveness of control etc (Discussion required)

Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prices												
Pests incidence												
Pesticide efficacy												

____

____

Field observations

048. Farm slope. ____________

049. Damage rating of the crop____________________

050. General questions asked by farmer.______________________________

____

____

____

---

051. Comment/ observations

Factor	Comment
Cropping systems	
Cropping pattern	
Fertiliser use	
Environmental factors	
Weeding	

St No.

052. Farm sketch map.

St No.

Appendix 3: **Costs and Benefits Summary for the biological control of Diamondback moth (Thousand KShs)**

Year	Producer	Consumer	Total (B)	Costs (C)	B-C
2001	0.0	0.0	0.0	17960.2	-17960.2
2002	0.0	0.0	0.0	15055.0	-15055.0
2003	0.0	0.0	0.0	15524.7	-15524.7
2004	0.0	0.0	0.0	21840.0	-21840.0
2005	32190.8	20694.1	52884.9	21840.0	31044.9
2006	187335.5	120429.9	307765.5	21840.0	285925.5
2007	592087.6	380627.7	972715.4	0.0	972715.4
2008	857527.1	551267.4	1408794.5	0.0	1408794.5
2009	922506.4	593039.8	1515546.2	0.0	1515546.2
2010	930797.0	598369.5	1529166.6	0.0	1529166.6
2011	939173.3	603754.2	1542927.5	0.0	1542927.5
2012	947635.9	609194.5	1556830.5	0.0	1556830.5
2013	956185.9	614690.9	1570876.9	0.0	1570876.9
2014	964824.1	620244.1	1585068.3	0.0	1585068.3
2015	973551.4	625854.5	1599406.0	0.0	1599406.0
2016	982368.8	631522.8	1613891.6	0.0	1613891.6
2017	991277.0	637249.5	1628526.5	0.0	1628526.5
2018	1000277.1	643035.2	1643312.4	0.0	1643312.4
2019	1009369.9	648880.7	1658250.6	0.0	1658250.6