NEEM SEED FOR THE MANAGEMENT OF THE BANANA WEEVIL, *COSMOPOLITES SORDIDUS* GERMAR (COLEOPTERA: CURCULIONIDAE) AND BANANA PARASITIC NEMATODE COMPLEX

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THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN SUBMITTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

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DEDICATION

AU FEU MON PERE NSANZURWIMO ALEXANDRE, QUI NOUS QUITTA

PRECIPITAMMENT SANS AVOIR VU LE FRUIT DE CE TRAVAIL,

A MA MERE NYIRABIGUNDA THERESE

ET A MON EPOUSE UWIZERAMARIYA VERENE

POUR LEUR AMOUR ET INLASSABLE SOUTIEN ET ENCOURAGEMENT

TOUT AU LONG DE MES ETUDES

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ABSTRACT

The study was conducted in western Kenya, a prime banana growing area during the period of May 1996 to February 1999. The objectives were to control the banana weevil and parasitic nematodes with neem materials, thereby reducing yield losses and contributing to sustainable banana production.

The repellent, antifeedant, ovipositional deterrent, and growth inhibitory effects of powdered neem seed (NSP), kernel (NKP), cake (NC) and neem oil (NO) on *Cosmopolites sordidus* and its population build-up were studied in the laboratory and outdoors tests at ICIPE's Mbita Point field station (MPFS).

In choice tests, 48 h after release, less than 30% of weevils settled under neem-treated banana corms while more than 75% settled under untreated corms. In a feeding test, weevil larvae did not feed or fed little on neem-treated corms. Larvae caused little damage to neem-treated corms, but untreated corms were heavily damaged, indicating a strong repellent and antifeedant effect of neem seed derivatives on *C. sordidus*.

Compared with the untreated control, 3-10 times fewer eggs were laid by female in neem-treated corms. Egg hatchability was less than 25% in neem-treated corms and more than 50% in the control.

Neem treatments also inhibited larval growth and development. Forty to 60% of 2nd-instar larvae died in 14 days when confined to neem-treated banana pseudostems; the survivors were small in body size and weighed 4 to 6 times less than those in the control where less than 20% larvae died and adults were recovered. The higher the concentration of neem materials, the higher was the severity of

effects.

Efficacy of neem materials against the banana weevil and parasitic nematodes was evaluated under controlled pest infestation levels at MPFS. Effective rates, methods and frequency of application of the selected neem materials were determined at MPFS and in farmers' fields, under different levels of soil fertility and pests infestation.

In a pot experiment, four weeks after planting, NSP, NKP, or NC was applied at 5g per plant to plants inoculated with 500 nematodes and 5 pairs (females and males) of the banana weevil. Compared with control, 1.5 months after the treatment, neem materials application significantly reduced the nematode population and weevil damage on a par with Furadan applied at 5 g/plant. Similar results were obtained with the application of neem materials to pared or unpared banana suckers planted in 100 or 200*l* drum's capacity and inoculated with 2000 nematodes and 5 pairs (females and males) of the banana weevil per drum.

NSP- or NC-treated unpared suckers supported much fewer nematodes than the pared treated suckers with the same neem products, obviating the need for paring of suckers. NKP and NO applications were toxic to the banana plant and were excluded from further testing.

Soil application of powdered NSP or NC against the banana pests was more effective than their application in aqueous forms. Application of NSP or NC at planting time and then at 1, 2, 3, or 4- month intervals to plants grown under controlled pest infestations in drums significantly reduced nematode density and the weevil damage.

Similarly, in farmers' fields, soil application of NSP or NC at 60, 80 or 100 g/mat at planting and then at 4 month-interval significantly reduced the weevil and nematode damage. Although the application of NSP or NC at 200 to 400 g/mat at 6 month-intervals significantly reduced the nematode population and weevil damage, they were toxic to the banana plant.

Application of NSP or NC at 60, 80 or 100 g/mat at 4-month intervals to a fertile soil with a moderate pest load, increased yields by 27-50% over the control during the 1st crop and by 30-60% during the 2nd crop. Furadan increased the fruit yield by 27 % over the control in the 1st crop but dropped down to -2 % in the 2nd crop. Under low soil fertility and high pest infestation levels, the neem treatments also controlled the pests and markedly increased the yield 7 to 10 times more than that in the control during the first crop. During the second crop, all plants in the control plots dried up before fruiting, but neem-treated plants continued to produce bunches.

Depending on the soil fertility and doses of application, net gain over the control obtained with the application of NSP or NC ranged from US $ 70 and US $ 800 per hectare. However, a loss of US $ 700/ha was observed with the Furadan application. Neem application of doses higher than 100 g/mat was also uneconomical. The beneficial effects of neem seed materials application on the banana plant growth, pest control, and implications of these findings in the banana pest management and further areas of investigation are discussed.

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1. Importance, production and utilisation of banana

Banana (*Musa* spp.) which originated in Southeast Asia (Simmonds, 1962) is now grown in many countries in the world where it plays an important role in the nutrition and economies as a staple food and as an export crop (Chandler, 1995). Banana is the world's second most traded and widely consumed tropical fruit after citrus (Hallam, 1995). It provides more than 25% of the carbohydrates and 10% of calorie intake, some vitamins and minerals for more than 400 million people in the world (INIBAP, 1987; Chandler, 1995; Lahav, 1995). In eastern Africa, banana constitutes a staple food and source of family income for more than 60% of the population (Sarah, 1989). The gross value of annual production exceeds that of maize, rice, cassava and sweet potato in Africa (IITA, 1992).

Over 76 million metric tons of bananas and plantain were produced in 1992 (FAO, 1993). Approximately, 35% of this is produced in sub-Saharan Africa (Vuylsteke *et al.*, 1993), where the per capita annual consumption ranges from 150 to 460 kg (Sarah, 1989; Ortiz and Vuylsteke, 1996). The biggest banana producer countries in this region are Uganda, Rwanda, and Tanzania (Hallam, 1995).

The fruit can be eaten as such, cooked, steamed, fried, roasted, or cooked and mashed (Stover and Simmonds, 1987; Speijer, 1993). Bananas have been recommended for the treatment of infantile diarrhea and stomach ulcers (Koszier, 1959). Ripe bananas of selected cultivars are used to make a low-alcohol content wine, especially in Rwanda, Burundi, and Uganda (Stover and Simmonds, 1987; Musabyimana, 1993; Davies, 1995).

Banana plant and its residues reduce soil erosion and are sources of mulch (Gold *et al.*, 1993) and also serve as animal feed when forage is scarce (Stover and Simmonds, 1987). Leaf sheaths are used for packing and wrappings (Stover and Simmonds, 1987), as roofing materials, and for making ornamental items in handicrafts (Baker, 1984 cited by Karamura and Karamura, 1995).

1. 2. Banana cultivars and morphology

The *Musa* spp. (*Musaceae*) are derived from two wild diploid species: *Musa acuminata* Colla (AA genome) and *Musa balbisiana* (BB genome). Most of edible banana types are triploid (2n = 3x =33) with different ploidy levels: AAA, AAB, ABB (Stover and Simmonds, 1987; Vuylsteke *et al.*, 1993) and occasionally diploid: AA and AB groups. Triploids are more vigorous and produce bigger bunches than diploid bananas (Gowen and Quenéhérvé, 1990).

The banana plant consists of the short underground true stem called corm, or rhizome that bears roots (Karamura and Karamura, 1995); suckers or shoots and the pseudostem with leaves. Roots and suckers originate from the corm. Most of the roots are found within a 60-cm radius of the stem (Fig 1.1). New roots are produced continuously until flowering (Beugon and Champion, 1966).

The pseudostem is composed of leaf sheaths tightly packed together and a terminal crown of leaves through which the inflorescence emerges (Stover and Simmonds, 1987). The number of suckers varies depending on cultivar and plant management.

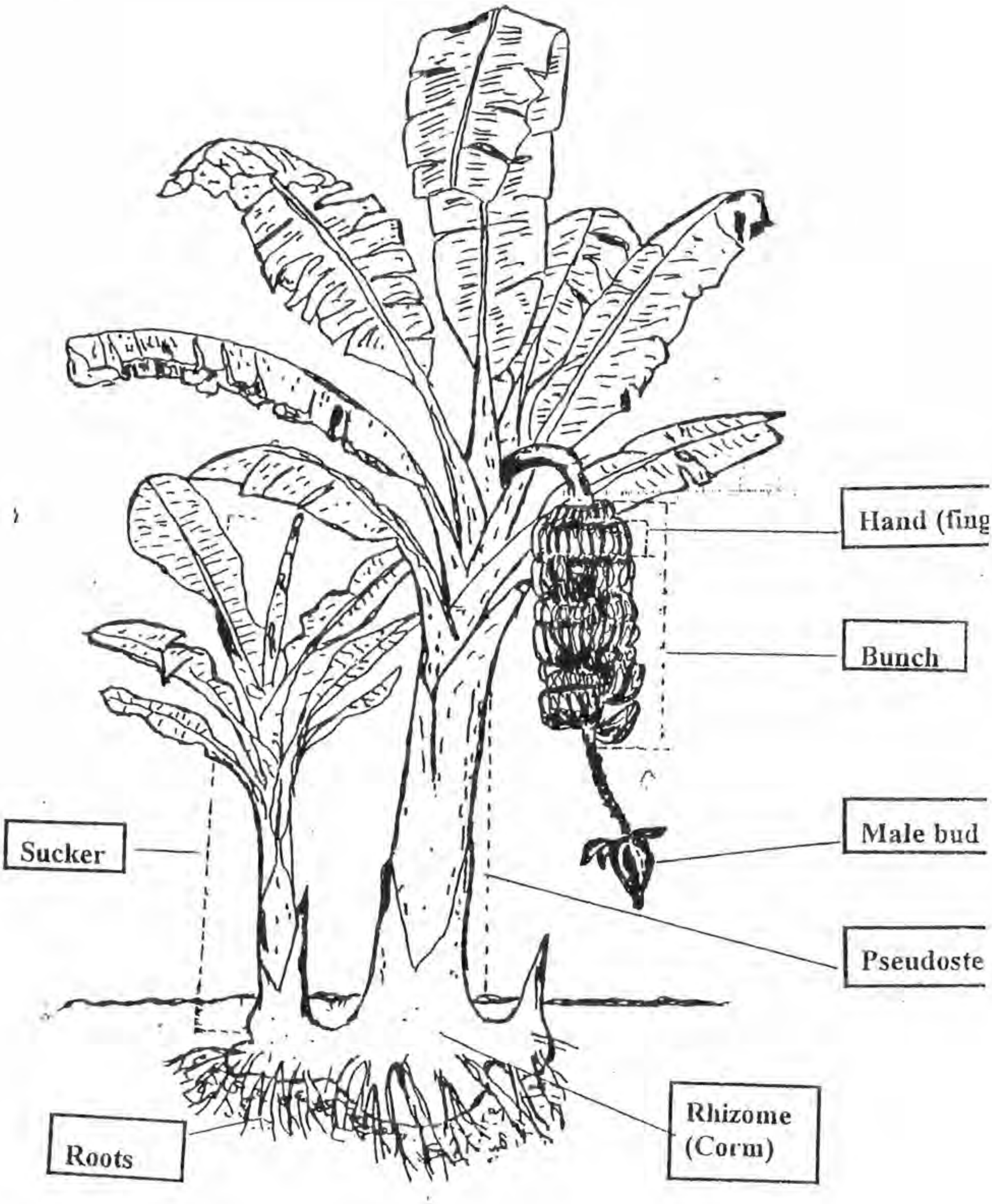


Fig. 1.1. Morphological characteristics of a banana plant at flowering stage.

A group of shoots from a single parent is referred to as a stool or mat. A sucker has different developmental stages: sword sucker, which has lanceolate leaves; maiden sucker, which is taller than 100 cm and has large leaves.

The inflorescence is composed of female and male flowers. Each ovary of the female flowers develops into a fruit or finger. A cluster of fingers constitutes a hand (Stover and Simmonds, 1987). A bunch can weigh from 1 to 70 kg depending on the cultivar and the crop management. A crop cycle is the time between planting and harvest of fruits on the same mat.

Conventionally, bananas are propagated vegetatively; suckers or bits of a large rhizome (Gowen and Queněhěrvě, 1990; Speijer, 1993). Also, biotechnology has permitted the production of pest and disease free planting materials (Israeli *et al.*, 1995)

1. 3. Constraints to banana production

Worldwide, banana yields are adversely affected by a number of abiotic and biotic stresses (Stover and Simmonds, 1987; Gowen, 1995). A complex of pests, diseases, parasitic nematodes, and poor crop husbandry practices limit the banana production. The banana weevil, *Cosmopolites sordidus* Germar, and the nematode complex, especially *Radopholus similis* (Cobb) Thorne, *Pratylenchus goodeyi* Sher & Allen, *Helicotylenchus multicinctus* Cobb, and *Meloidogyne* spp. are the major destructive pests of banana, (Gowen and Quénéhervé, 1990; Peña *et al.*, 1993; Pinochet, 1996) causing severe yield losses (Nsemwa, 1991; Gowen, 1993; Davide, 1994).

The same pests limit banana and plantain production throughout Africa (Traoré *et al.*, 1993; Musabyimana, 1993; Ogenga-Latigo and Bakyalire, 1993).

1. 4. Weevil and nematode damage and yield losses

The banana weevil, *C. sordidus* (Coleoptera: Curculionidae) is specific to *Musa* spp. (Moznette, 1920; Cendaña, 1922; Gowen, 1995). According to Viswanath (1979), banana weevils feed and breed only on *Musa* spp. Although the weevil originated in Southeast Asia (Neuenschwander, 1988), it is now distributed in all banana-producing areas worldwide (Ostmark, 1974; Cuillé, 1950; Mestre, 1997). The distribution from place to place is facilitated by infested planting material (Gowen, 1995; Rukazambuga, 1996); eggs and larvae are easily transported through infested corms (Wallace, 1938; Harris, 1947; Treverrow *et al.*, 1992).

Banana parasitic nematodes live mostly in roots of banana plants, but are also found in the soil. They require at least a film of water to enable locomotion, and die in dry soil or roots. *R. similis* and *P. goodeyi*, belonging to Pratylenchidae family, are migratory endo-parasitic nematodes of major concern in the banana and plantain production throughout the world (Luc *et al.*, 1990). *R. similis* is predominant in the hot, humid tropics, whereas the root-lesion nematode, *P. goodeyi* dominates in the highlands of eastern Africa (Bridge, 1988; Sarah, 1990; Speijer *et al.*, 1994). In some places, the root-knot nematodes, *Meloidogyne* spp. (Heteroderidae),which are sedentary endoparasites are found together with *P. goodeyi* and may cause severe yield losses. *R. similis* and *P. goodeyi* cause deeper lesions, which extend up to the stele of large primary roots (Gowen and Quénéhervé, 1990).

Nematode penetration occurs near the root apex, but *R. similis* can invade any portion of the root length (Sarah and Fallas, 1996). The endoparasitic nematodes feed and reproduce in cortical cells of roots and in the rhizome where their life cycle is completed in 20 to 25 days at 24-32 °C (Luc *et al.*, 1990). Females lay an average of 4 to 5 eggs per day within infected tissue. Eggs hatch after 8 to 10 days and juvenile stages are completed in 10 to 13 days. All four juvenile stages are invasive and moulting terminates each stage. Eggs of *Meloidogyne* are stuck together in a gelatinous matrix and retained within the swollen female body (Luc *et al.*, 1990).

Heavy nematode burden damages the root system of banana plants and affects plant vigour, resulting in toppling or in smaller bunches with shorter fingers (Sarah, 1989; Gowen, 1995). Infected plants have less secondary and tertiary roots and root hairs. Razak (1994) reported an annual banana yield loss of US$ ~ 178 million worldwide due to nematodes attack.

Nematodes survive in infected corms and roots of previous banana crop or other host plant, especially weeds, associated with banana plantations (Gowen and Quénéhervé, 1990). They are also dispersed by farm tools and animals, but to a large extent by infested planting materials (Mbwana, 1992). Therefore, nematode control involves the use of cultural practices, such as leaving the field fallow, selecting an appropriate crop in inter-cropping system, use of clean planting materials and crop hygiene (Gowen and Quénéhervé, 1990) or soil amendment (Mbwana, 1992). In addition, yield losses can be prevented by repeated use of nematicides (Fogain, 1996). However, the use of nematicides is generally economically unjustified.

The banana weevil and nematodes normally occur in the same plant (Bridge, 1988). They are associated with similar damage symptoms, such as poor plant growth, destruction of the corm and root system, reduced anchorage and nutrient uptake, reduced fruit-filling, toppling as well as providing entry points for various pathogens (Vilardebó, 1984; Bridge and Gowen, 1993; Ortiz and Vuylsteke, 1996). The banana weevil larvae bore tunnels in the corm and occasionally in the pseudostem, while nematodes damage the roots and corm of plant, resulting in toppling (Vilardebó, 1973; Uronu, 1992; Vuylsteke *et al.*, 1993).

Although yield losses due to the weevil-nematode complex may be quite excessive (Gowen, 1995), the combined effect of the two pests has not yet been well quantified. In contrast, yield loss due to nematodes solely has been estimated at 30 to 75% in Africa (Sarah, 1989), 30 to 50% in Costa Rica and Panama, 10 to 20% in Honduras and Guatemala (Davide, 1996) and 30 to 41% in India (Reddy, 1994). Yield losses due to *C. sordidus* were estimated at 50% in Bukoba, Tanzania (Walker *et al.*, 1984) and 35 to 40% Africa-wide (Sery, 1988). In Ghana, yield loss due to the banana weevil is up to 25% for the first crop and 50 to 90% in subsequent crops (Afreh-Nuamah, 1993). In Kenya, yield loss can be as high as 100% (Koppenhöfer, 1993). In the Caribbean region and Central America, the yield losses range from 30 to 90% (Peña *et al.*, 1993). Recent declines in banana productivity in eastern Africa have also been attributed to weevil and nematode damage and further accentuated by declining soil fertility and poor crop husbandry (Sebasigari and Stover, 1988, Vuylsteke *et al.*, 1993).

Damage caused by nematodes and borers are difficult to separate, as the two pests occur together in the same plant (Gowen, 1995). Therefore, the best control methods should have a coupled action against the weevil and nematodes. Certain chemical and cultural techniques used for nematode management can also control the banana weevil (Gowen and Quénéhervé, 1990).

1. 5. Banana weevil and nematode control

Since early decades of the 20th century, studies on effective weevil and nematode control methods were initiated. Good results were obtained; especially when chemicals, cultural practices and the use of clean planting materials were combined (Sarah *et al.*, 1988). Control techniques based on crop rotation were inappropriate (Gowen, 1995).

1. 5. 1. Chemical control

Despite problems of toxicity, high cost, build-up of pest resistance, and adverse effects on the soil micro-fauna, the banana pest control has relied on the use of synthetic pesticides (Mitchell, 1980; Sarah, 1989; Gowen, 1993). Although the most effective pesticides, such as Dieldrin, Aldicarb and Carbofuran are being banned by many countries due to environmental considerations (Sarah, 1994), they continue to be used. Since the use of nematicides or insecticides is becoming economically unsustainable for the banana pest management in less intensive production systems (Gowen, 1995), the search for alternatives continues with varied results.

1. 5. 2. Cultural methods

Cultural methods comprise the use of resistant cultivars, the use of clean planting material, trapping of adult weevils, deep planting and crop hygiene. Unfortunately, so far, few cultivars resistant to both the banana weevil and parasitic nematodes have been identified (Sarah, 1994). The east African highland bananas (AAA-EA) are susceptible to the two pests (Sarah, 1990; ICIPE, 1995). Trapping is the oldest method, but it is labour-intensive and traps less than 15% of the pest population (Mitchell, 1980). According to Seshu Reddy *et al.*, (1995), trapping reduced the weevil density by 47% but led to high build-up of parasitic nematodes. The use of pared and hot water-treated suckers to reduce the initial pest population in planting materials has also been recommended (Feakin, 1971; Mitchell, 1980), but nematodes located deep within the cortex may escape removal. The paring and hot water practice may give plantations a good start (Sarah, 1990), but has little effect on the banana weevils and nematodes immigrating from neighboring fields (Rukazambuga, 1996).

1. 5. 3. Biological control

So far biological control of both the banana weevil and nematodes has not been successful. Although the predatory beetle, *Plaesius javanus*, the fungal pathogens, *Beauveria bassiana* and *Metarrhizium* spp., and the entomopathogenic nematode *Steinernema* spp have been tried against *C. sordidus* worldwide (Delattre and Jean-Bart, 1978; Kaaya *et al.*, 1993), their practical use has not been feasible in the banana fields.

1. 5. 4. Botanical control

In recent years, interest has grown in the use of natural plant products for pest management. Indeed, plants are virtually the richest source of bioactive organic chemicals on earth (Saxena, 1989). Synthetic pesticides are now considered a serious threat to human health and to the integrity of the environment (Alkofahi *et al.*, 1989). In contrast, natural chemicals pose little environmental risk and are generally cost- effective (Russell Mason and Matthew, 1996). The selective and biodegradable natural compounds could possibly replace synthetic pesticides.

Although more than 2400 plant species are known to possess pest-control properties (Grainge and Ahmed, 1988), little is known about their value in the banana pest management. In addition, some plant products have been tested against only one group of banana pests. For instance, Walungululu *et al*., (1993) tested the repellence of leaf powder of *Tephrosia spp*. (Leguminosae) against the banana weevil and found that fewer weevils were attracted to the treated bait. In the Philippines, root extracts from 11 plant species were reported to have nematicidal effect on *M. incognita* (Hoan and Davide, 1979). Also, leaf extracts of *Anthocephalus chinensis*, *Eichornia crassipes*, *Allium sativum* and *Allium cepa* effectively controlled *R. similis* and *M. incognita* (Guzman and Davide, 1985). However, the findings had little practical applications in the banana field.

1. 5. 4. 1. The neem tree: pest control potential

Over the past two decades, neem tree *Azadirachta indica* A. Juss. (Meliaceae), a botanical cousin of mahogany, has come under close scientific scrutiny as a source of environmentally "soft," novel pest control agents (Saxena, 1989). Neem is an evergreen tree that thrives in many different types of soil under hot and dry conditions. It has an attractive crown of deep-green foliage, which can spread 10 m across (Plate 1.1). Fruiting begins in 3 to 5 years. The ripe fruit has a yellow fleshy pericarp, a white hard shell, and a brown, oil-rich seed kernel. Depending on rainfall, type of soil and neem ecotype or genotype, fruit yields range from 30 to 100 kg per tree. Fifty kilograms of fresh fruit yield 30 kg of seed, which gives about 6 kg of oil and 24 kg of seed cake. Neem derivatives have been evaluated against more than 400 species of insect pests, 72 of which are coleopterans (Schmutterer and Singh, 1995), and against 16 species of plant parasitic nematodes (Singh and Kataria,

Plate 1.1. Four-year-old neem tree at Mbita Point Field Station, western Kenya, along the shores of Lake Victoria

1991; Alam, 1993; Mojumder, 1995). However, little information exists on the efficacy of neem materials against the banana weevil and banana parasitic nematodes. Alam (1993), Singh (1993), Schmutterer and Singh (1995) reviewed the bioactivity of neem materials against insect pests and phytonematodes, but their reviews did not cover the banana weevil and the banana parasitic nematodes, especially *P. goodeyi, R. similis* and *H. multicinctus*.

1. 5. 4. 2. Neem derivatives: active ingredients and their mode of action

Neem products commonly used in agriculture include the oil, cake, seed powder, kernel powder and the leaf powder. Neem oil is effective against many sucking insects, such as leafhoppers and planthoppers (Saxena, 1989), aphids (Lowery, 1992) and white flies, and also against some species of locusts and grasshoppers (Schmutterer, 1995). It is also effective against beetles in stored grain (Saxena, 1995). On the other hand, neem cake, incorporated into the soil reduces the plant damage caused by nematodes and suppresses certain fungi in the rhizosphere of the plant (GTZ, 1996).

All parts of the neem tree are bitter. The bitterness is due to the presence of an array of complex compounds called "limonoids," or more specifically "triterpenoids." Unlike synthetic pesticides based on single active ingredient, neem derivatives comprise of more than 100 compounds: the main active ingredient for pest control is called azadirachtin (Saxena, 1989; Kraus, 1995). Some other Meliaceae also contain azadirachtin, but the East African tree, *Melia volkensii* (Gurke) which is widespread in Kenya, Tanzania, Ethiopia and Somalia, is reported to have terpenoid compounds but not azadirachtin. However, the potential of its fruit extract in the control of locusts has been demonstrated (Mwangi *et al.*, 1997). Likewise, the seeds of chinaberry tree, *Melia azaderach* L. which is frequently mistaken for the neem tree, contain limonoids common to neem seeds except azadirachtin. Although derivatives from chinaberry have insecticidal properties, the tree does not have a future as a potential source of pesticides due to its extreme toxicity to warm-blooded animals (Jacobson, 1989). The limonoids in neem belong to nine basic structure groups, such as azadirone (from oil), amoorastatin (from fresh leaves), vepinin (from seed oil), and vilasinin (from green leaves), the seco-systems related to gedunin (from seed oil and bark), nimbin (from leaves and seed), nimbolinin (from kernel), and salannin (from fresh leaves and seed), and the azadirachtin group (from seed; basically nimbolinin type compound (Kraus, 1995). Azadirachtin that is high in seeds (Jacobson, 1989) and its analogs have fascinated researchers for the past 30 years. This formidable array of highly bioactive compounds makes neem a unique plant with potential applications in agriculture (Saxena, 1996).

Neem derivatives possess a broad spectrum of biological activity on insects and nematodes: repellence, feeding and oviposition deterrence, inhibiting growth and development mating disruption, chemo-sterilization etc. (Jacobson, 1989; National Research Council (NRC, 1992).

1. 5. 5. Integrated pest management

None of the above control methods, singly is completely effective in reducing pests pressure. Therefore, integrated pests management (IPM) approaches, involving genetic control, cultural methods, crop hygiene, biological control and chemical control, where applicable are needed. In spite of that, it is generally believed that the use of pesticides can effectively reduce the pest population. Once banana plantations are infested with weevil or nematodes, their elimination is quite impossible. Therefore, the continued control practices have to be applied regularly. Therefore, keeping the nematode or weevil populations below economic threshold level (ETL) in banana plantations requires a sustainable and integrated pest management strategy.

1. 6. Rationale and objectives of the study

From the above review, it is obvious that although at present banana growers, especially for export, rely on the use of nematicides/insecticides, suitable alternatives are needed. Also, small-scale farmers need low-cost technologies to control pests in order to improve banana production.

The overall aim of the study was to contribute to higher and sustainable production of banana by using neem derivatives for integrated management of the banana weevil and parasitic nematodes, thereby alleviating yield losses.

The specific objectives were to:

- establish the effects of neem derivatives on the behaviour and physiology of the banana weevil and on the build-up of its population
- determine the efficacy of neem seed derivatives against banana weevil and parasitic nematodes under controlled and natural conditions
- determine the most effective methods, rates, and frequency of application of selected neem seed derivatives for the control of banana weevil and parasitic nematodes in farmers' fields and outdoor trials

- determine the increased banana fruit yield and economic benefit of neem application in pest management

CHAPTER TWO

GENERAL MATERIALS AND METHODS

2. 1. Location and site description

The study was conducted during the period of May 1996 to February 1999 in western Kenya, Nyanza province, a prime banana growing area (Fig. 2.1) where *C. sordidus* and *P. goodeyi* constitute the major banana pests. The effects of neem seed derivatives on the behaviour and physiology of banana weevil and its population build-up under laboratory and outdoors conditions were studied at ICIPE's Mbita Point Field Station (MPFS). The efficacy of neem seed derivatives for the control of the banana weevil and parasitic nematodes was also studied in the screen-house and outdoors in 100- and 200-*l* capacity drums at MPFS. Effective methods, and frequency of application of selected neem materials under controlled conditions were determined outdoors at MPFS. MPFS is located at an altitude of 1240 m, at the shores of Lake Victoria with annual rainfall averaging 1200 mm, temperature ranges between 18 and 33 °C. The area is characterised by two cropping seasons: the long-rainy season (mid-March to early June) and the short rainy season (September to late November). The soil at MPFS is black cotton, cracking-loam-clay that is poorly drained. The Station has irrigation facilities.

Effective rates and frequency of application of selected neem materials were also determined in farmers' fields at Oyugis area. The area is located at an altitude of 1500 m with rainfall exceeding 1600 mm annually. The long- and short rainy seasons extend from February to July and from September to December-January, respectively.

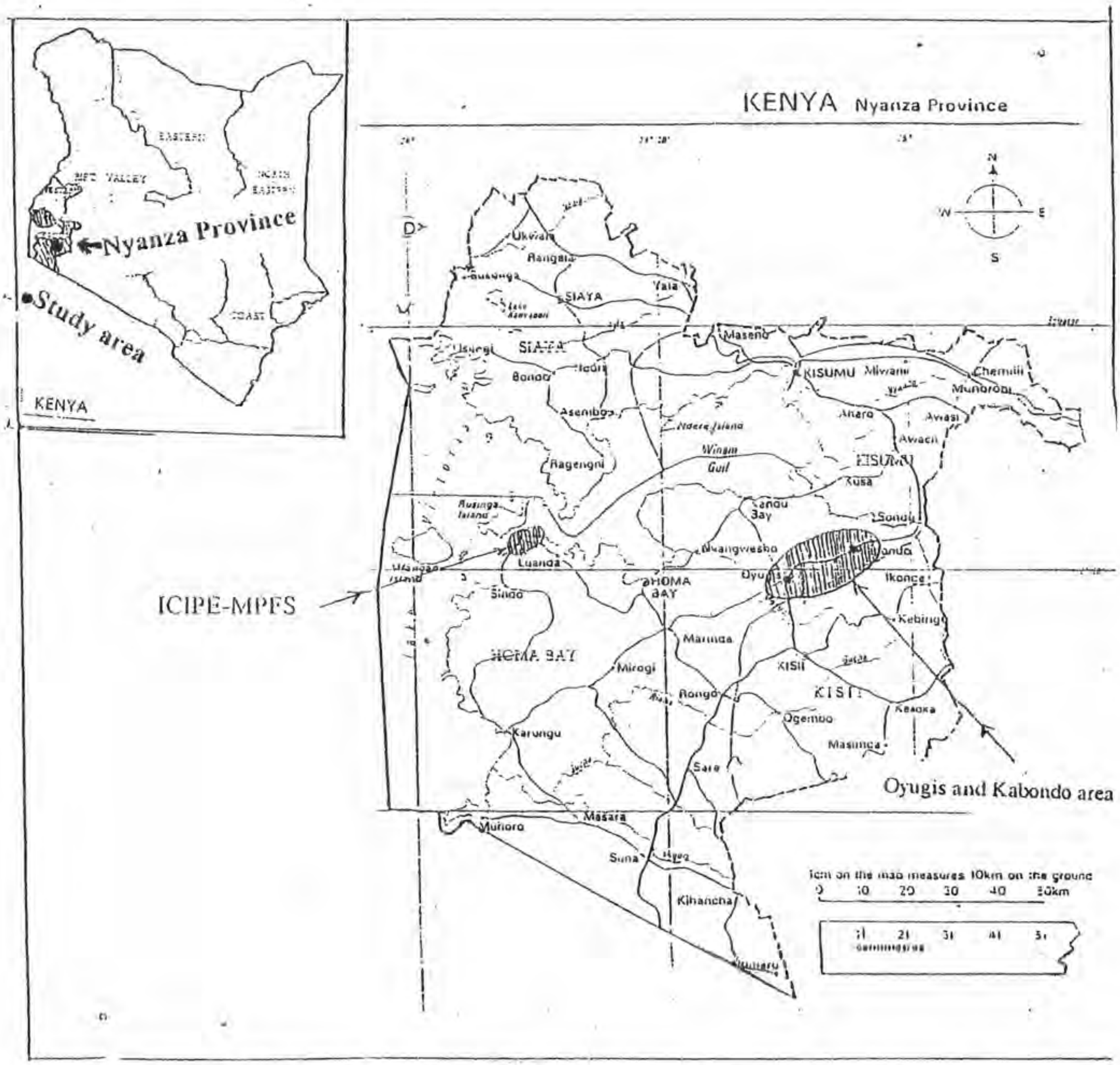


Fig. 2.1. Location of the study area in western Kenya, Nyanza Province

(Singh Malkiat 1995, GHC, Workbook, Standard 6: Kenya and Her Neighbours), Nitosol, well-drained, dark-red, friable clay with humic topsoil is the major soil type in Oyugis area (Jactzold and Schmidt, 1982).

The efficacy of powdered neem seed or cake against the weevil and nematodes and the consequent increase in fruit yield was tested in two farmers' fields at Oyugis and Kabondo, with varying levels of soil fertility and pest infestation and at MPFS (Tables 2.1 & 2.2).

The field at MPFS had been planted to a mixture of banana cultivars for the past 6 years. Assessment of pest infestation in the field, prior to land preparation, revealed that it was uniformly infested. On an average, 16000 nematodes/100g roots and 4 weevils/trap were recorded. A farmer's field at Oyugis had been planted to 'Nakyetengu,' a highly susceptible banana cultivar to weevils and nematodes (Seshu Reddy and Lubega, 1992) for the past 15 years. Nakyetengu is an eastern african genotype (AAA-EA) which is a popular cooking type. The field had an initial pest infestation of 6 weevils per trap and ~120000 nematodes/100g of roots. *P. goodeyi* was the predominant nematode species. The soil was laterite with low fertility. In contrast, the field at Kabondo (~25 km away from Oyugis) had never been planted to banana before, but it had a 15- to 20-year-old plantation of mixed banana cultivars along its northern boundary. This field had~12000 nematodes/100g of roots and 2 to 3 weevils/trap. The Kabondo field was thus vulnerable to pest infestation from the use of unpared planting material and possibly through water runoff and migrating weevils. The plot had deep, reddish-brown, friable sandy loam, with humic topsoil.

Table 2.1. Physical soil characteristics of field sites in western Kenya[1]

Site	Sand (%)	Silt (%)	Clay (%)	Texture
MPFS	44	12	44	Clay
Oyugis	72	6	22	Sandy clay loam
Kabondo	74	8	18	Sandy loam

Table 2.2. Chemical soil characteristics of field sites in western Kenya[1]

Site	pH	Na (me%)	K (me%)	Ca (me%)	Mg (me%)	Mn (me%)	P (ppm)	N (%)	C (%)
MPFS	8.1	1.60	0.44	**18.4***	5.75	0.30	1.19	0.22	**0.30****
Oyugis	5.2	0.28	0.46	**1.60****	2.05	1.77	**8****	0.40	1.51
Kabondo	6.0	0.68	1.17	5.60	1.55	1.34	25	0.31	1.46

[1]Analysis by National Agricultural Research Laboratories, Kenya Agricultural Research Institute, Nairobi)

*= Toxicity; ** = Deficiency

2 2. Planting material and methods of planting

Since banana vitroplants were not available, the planting material used in the study, comprised suckers of 'Nakyetengu' collected from the infested fields. The fields at MPFS and Oyugis were prepared for the experiment by uprooting and removing banana stems from the fields, but the corms were left to serve as sources of prospective nematode and weevil infestations. The fields were ploughed and leveled using a hoe. Holes for planting were 60 cm in diameter and 60 cm in depth. Subsequent to planting, ~10 kg of well-decomposed cow dung was applied per hole at the MPFS field. No soil amendment was provided in the farmer's fields at Kabondo and Oyugis. Due to limited size of land at farmer's level, experimental unit plot size was 36 m^2. The blocks were completely randomized in 3 to 4 replicates. Each replicate comprised of 4 rows of 4 plants, spaced at 3 by 3 m between plants and within rows. In all fields, maiden suckers collected from neighboring banana fields, regardless of the pest infestation, were planted. In general, suckers were not pared, nor treated with hot water before planting unless specified in the experiment.

2. 3. Management of field trials

The banana crop was managed according to standard practices. Through the entire duration of the experiment, plots were kept weed-free by using a hoe. Plants were de-suckered at flowering in such a way that each stool had a mother plant, a daughter and a grand daughter whose bunches could be harvested at 4-month intervals. The suckers were cut at their base and the apical meristem killed using a machete. Old, dried leaves were regularly removed and used as mulch in the same field. The male flower bud was removed when differences between male and female flower clusters became visible. Plants were propped to prevent them from toppling. Banana bunches were harvested when the fruits became fully rounded or reached the bursting stage

2. 4. Neem materials

Neem seeds are a plentiful source of limonoids, particularly azadirachtin. Because of high cost, purified azadirachtin is used primarily for studies on mode of action in the laboratory (Schmutterer and Hellpap, 1989). Neem leaves can also be a source of certain limonoids, but vast quantities are needed for obtaining satisfactory results in the field. Because of these considerations, neem seed materials, such as powdered seed, kernel, or cake were used as such or as emulsions or suspensions in water in the present study. Certain experiments used neem oil emulsified in water.

Neem seeds, freshly collected from the coastal Kenya, were dried in the shade to ~13% moisture content. Neem seed powder (NSP) and neem kernel powder (NKP) were prepared by pounding whole seeds and dehulled seeds, respectively. Neem cake (NC) and neem oil (NO) were prepared by crushing neem seeds in a single-screw vegetable oil expeller with a three-phase motor (IBG Monforts, GmbH & Co., Germany) installed at MPFS. The azadirachtin content in NSP, NKP, NC, and NO was determined by reverse-phase gradient, high performance liquid chromatography (HPLC) at ICIPE, Nairobi, using a standard reference material. NSP, NKP, NC, and NO had 4000, 5500, 5800, and 850 ppm of azadirachtin-A, respectively. Neem oil emulsions of varying concentrations were prepared in distilled water (vol/vol) by adding 1% 'Teepol' liquid detergent. To prepare NSP, NKP or NC extracts, known quantities of test materials were soaked in water and stirred overnight using a magnetic stirrer. The homogeneous suspensions were then filtered using a fine muslin cloth.

2. 5. Trapping, mass-rearing and sex differentiation of banana weevil

Weevils for laboratory and outdoors experiments were trapped in banana fields in western Kenya. Traps, made of longitudinally split pieces of 'Nakyetengu' pseudostems, were placed on the ground near the base of plants. Traps were checked at 3-days intervals for collection of banana weevils for 2 weeks. The technique traps only adults (Mitchell, 1980; Stover and Simmonds, 1987).

The banana weevil was mass-reared in a laboratory at 24-28 °C and 55-65% relative humidity at MPFS. Unsexed weevil adults were released in plastic bucket (10 *l* capacity) containing a ~2 kg fresh corm of 'Nakytengu.' The bucket was then covered with a mosquito net to stop the weevils from escaping. The corms in the buckets were kept moist by watering them as and when needed.

The weevils were sexed by the method described by Longoria (1968). Males and females were confirmed by observing the angle of inclination of the 9^{th} abdominal segment (Mestre, 1995). In males, the distal end of the abdomen truncates sharply, while in females the distal end of the abdomen (ovipositor) truncates gently. In addition, punctuation on the rostrum of males extends 2/3 downward from the head, while in females the punctuation's on the rostrum extends 1/3 downward from the head (Fig. 2.2).

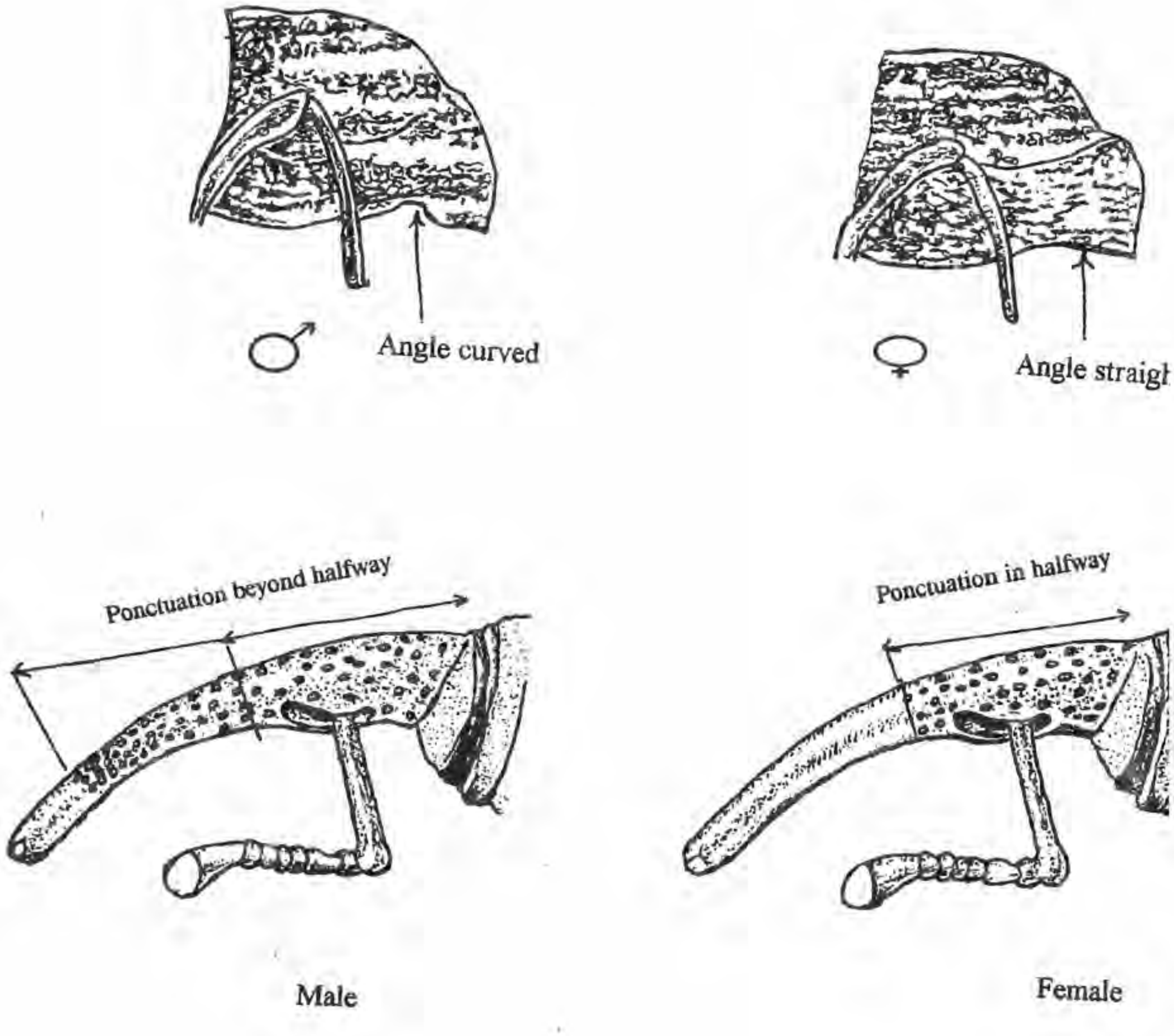


Fig. 2.2. Sex differentiation in *C. sordidus* using pits on rostrum and angle of 9th abdominal segment

2. 6. Assessment of the weevil damage

The banana plants to be assessed for weevil damage were uprooted and the corms pared slightly (1 cm) to expose the peripheral corm tissue consumed by weevil larvae.

The presence or absence of weevil galleries was scored on the damage scale or percentage coefficient of infestation (PCI), as described by Vilardebo (1973) (where 0 = no galleries, 20 = galleries on one-fourth area of the corm, 100 = galleries on the entire corm).

To assess the depth of larval tunneling through the corm, the corm was cut across at 5 cm below the base of the pseudostem and PCI of the inner (PCI inner) section of the corm scored.

2. 7. Damage evaluation and extraction of nematodes

For each treatment, roots for evaluating the nematode damage and nematode extraction were excavated at 20-30 cm away from the mother plant (Mbwana, 1992). From each plant, a sample of ~100g roots was collected in a plastic bag and brought to the laboratory for examination. For each treatment, roots from several banana plants were bulked. To determine the weight and assess the root damage, 15-cm-long, randomly selected pieces of roots were weighed. Root damage was assessed by splitting the pieces to expose the stele and scored on a 0-4 scale: 0 = no damage; 1 = slight damage or<25% of total root cortex necrotic; 2 = moderate damage or 25-50% of total cortex necrotic; 3 = severe damage or 51-75% of the total cortex necrotic; 4 = very severe damage or >75% of the total cortex necrotic (Brigde and Gowen, 1993). Nematodes were extracted within 48 h after sampling. Heavily attacked roots were discarded for nematode extraction as nematodes leave the old and heavily damaged roots to invade the young ones (Price and McLaren, 1996). Since endo-parasitic nematodes, such as *R. similis,* occur in low numbers in the soil (Sarah, 1993; Gowen, 1996), they were only extracted from roots by the maceration-sieving technique (Pinochet, 1988; Luc *et al.*, 1990). Roots were washed-free of soil particles and cut into 1-cm-long pieces and were further cleaned in a pan of water. Roots in samples of 25g each were macerated for 45 seconds in a blender containing 100 ml of water (15 seconds blending intervals with a pause of 10 seconds in between). The root suspension was passed through a set of 75, 200, 300 and 400μ mesh sieves. Holdings from the two last screens were washed gently with a jet of water back to back with a rubber tube connected to a water tap and collected into a beaker (Plate 2.1).

Water was added to make the suspension volume to 300 ml. The suspension was kept overnight with a Pasteur-pipette dipped in the beaker to provide oxygen to nematodes. An aliquot of 1 ml was drawn from the suspension and pipetted into a Sedgewick Rafler S-50 counting slide to count the nematodes using a compound microscope. Five aliquots were taken for each treatment and the number of nematodes/100g roots determined. Nematode species were identified and confirmed by Dr. V. Mojumder, Nematologist at the Indian Agriculture Research Institute, New Delhi, India.

Plate 2.1. Nematode extraction from banana roots by maceration-sieving technique: Nematodes are collected in jars through funnels.

2. 8. Data collection and analysis

Growth parameters, such as plant height, girth at 100 cm above the ground level, nematode population, suckers produced at flowering time, days to flowering were recorded. Girth was measured in cm using a tape while height was measured from the ground level up to where the last two leaves meet the cigar leaf using a 4-m graduated ruler. Flowering period was recorded when 60% of the plants had flowered in the test plots. Necrosis index and the absence or presence of galls was recorded at regular intervals. Bunches were harvested at 'bursting stage' when one or two fingers on the proximal hand of the bunch had burst (Stover and Simmonds, 1987) or when the fruits became more rounded (Thompson and Burden, 1995).

The yield parameters were the bunch weight, number of hands, fingers per hand, and the total number of fingers per bunch. The crop cycle, i.e., the planting to harvest period as well as the period between flowering to maturity, was also determined. Biomass of the pruned suckers was taken as an indicator of plant health. Weevil damage was assessed and expressed as PCI (cf p..24; 2.6) Data were collected both from the mother plant and the first daughter plant.

Data were analysed using ANOVA or general linear model procedures of SAS/STAT (1987). The treatment means were separated using Student-Neuman-Keuls (SNK) test, Tukey or T-test. Before statistical analysis was carried out diagnostic check was performed on all the data. Transformation of data that stabilizes the variance specifically squared root, and logarithm transformation was performed. Association among parameters was examined using Pearson correlation method. Other statistical tests used for specific experiments are stated under appropriate sections.

CHAPTER THREE

EFFECTS OF NEEM SEED DERIVATIVES ON BEHAVIOUR AND PHYSIOLOGY OF THE BANANA WEEVIL AND ITS POPULATION BUILD-UP

3. 1. Introduction

Insects have intimate and subtle relationships with their host plants (Khan and Saxena 1986). Therefore, even minor changes in the chemical or physical attributes of plants can affect their suitability as hosts. Bioactive chemicals, such as repellents, antifeedants, growth inhibitors, etc., which affect insect behaviour and physiology, may have some scope in management of insect pests. An insect repellent is a chemical stimulus that causes the insect to make oriented movement away from the source of stimulus (Saxena, 1989), while an antifeedant is a substance which when tasted by insect, reduces or prevents the insect feeding (Klocke *et al.*, 1989). On the other hand, a growth inhibitor is a chemical, which selectively and specifically affects the growth and development of an insect (Saxena, 1983). Its effectiveness depends on synchrony with certain events in the insect's life.

The insect repellent and antifeedant properties of neem are well known (Saxena, 1986). For centuries, farmers in some countries of Asia and Africa successfully protected crops using derivatives from neem leaves and fruits (Saxena, 1989). Besides repellence and antifeedant activities of neem, the ovipositional deterrence, growth disruption, reduced fitness of insect in contact with neem have also been reported (Schmutterer, 1995).

The present study focused on adverse effects of neem seed derivatives on the banana weevil's behavioural and physiological responses, namely adult settling response, oviposition and fecundity, egg hatchability, larval feeding, and larval growth and development. The hypothesis was that negative effects of neem materials on weevil behaviour and physiology might contribute to long-term control of the banana weevil in the field, thereby reducing weevil damage and increasing banana yields.

3. 2. Materials and Methods

In the laboratory at MPFS, 50- to 1000-g-pieces of fresh corm/pseudostem of 'Nakyetengu' were dipped for 5 to 15 min in aqueous extracts of 1, 2.5 or 5% NSP, NKP or NC; or in 1, 2.5 or 5% emulsified NO, depending on the test. The corms or pseudostems dipped in water served as controls. The studies were conducted under temperature of 20-28 °C and 55-65% relative humidity (RH).

3. 2. 1. Adult settling response

Neem-treated and control corms (~ 200g) were arranged alternatively equidistantly near the periphery of a 66-cm diameter galvanized tray. Thirty to 50 adult weevils, starved for 24 h, were released at the centre of the tray at 6 p.m. The tray was then covered with a black cloth to keep off light and prevent the weevils from escaping. The weevils could move freely in the tray and settle under the preferred corms. Weevils settled on or under treated and control corms were counted at 1-, 2-, 3-, 12-, 24-, 48-, 72- and 84-h after release. The experiment was repeated 12 times in one-choice tests *i.e.* choice between only two treatments (neem-treated and untreated corms) and in multi-choice tests *i.e.* choice between more than 2 different treatments. Data were analyzed as specified under the section 2.8.of the General Materials and

Methods.

3. 2. 2. Larval feeding

Neem materials, comprising NSP, NKP, NC, and NO were prepared as described in Section 2.4. Banana pseudostem discs (8-cm-diameter) were dipped for 5 min in 5% aqueous extracts of NSP, NKP, or NC or 5% emulsified NO and placed singly in 9-cm-diameter plastic Petri-dishes; control discs were similarly dipped in water. Laboratory-reared, 3rd-instar larvae were then released individually on each pseudostem disc in Petri dishes. Dishes for each treatment were arranged randomly in 4 replicates on a table in the laboratory. Each dish constituted a replicate and the experiment was repeated 6 times. The time each larva spent searching for a feeding site, initiating feeding on the disc and the duration to penetrate into the disc were recorded. Larval feeding-damage based on PCI, during a 72-h-period of confinement of a larva to treated or control discs was also recorded.

3. 2 .3. Larval growth and development

Freshly cut pieces of banana pseudostems (4 x 15 cm) were dipped in water (control) or in neem extracts or emulsified NO, as described above and placed singly in glass jars (6 x 18 cm). Ten 2^{nd}-instar larvae, taken from the insect culture, were released into each jar containing a treated or control pseudostem, after which the jar was closed with a screened screw-type lid. Each treatment was replicated four times; each jar with ten larvae constituted a replicate. Four days later, each jar was examined and any dead larvae recorded and gently removed. Fourteen days after the larvae were released into the jars, treated and control pseudostems were dissected and the number of larvae, pupae, and adults recorded for each treatment. Each larva, pupa, and adult was weighed individually on a Mettler balance (0.01mg sensitivity).

3. 2 .4. Oviposition and egg-hatchability

Banana fresh undamaged corms were pared to a depth of 3-5 cm to remove any banana weevil eggs laid already. Four pared corms (~500g each) were dipped for 15 min each in NSP, NKP, NC extracts, emulsified NO, or water as described above. Each corm was then placed in 10-*l*-plastic buckets into which 5 males and 5 females of the laboratory-reared weevils (sexed as described in Section 2.5) were released. Each bucket was covered with a mosquito net and then arranged randomly in a dark room. Each treatment was replicated four times; each bucket constituted a replicate. After a week the corms were removed from the buckets and visually examined for eggs laid on each corm.

To determine the effect of neem materials on hatchability, 1-day-old eggs in batches of 10 each were collected from the laboratory culture and inserted singly in 1- to 2-mm-deep slits made in a slice of neem-treated or control corms kept in Petri dishes (9 cm diameter) lined with moist filter paper. The dishes containing corm slices were arranged randomly. Each treatment was replicated 4 times; each dish constituted a replicate. Starting from the 3rd day, the corm slices were examined daily for one week to record the number of hatched eggs. Percentage hatchability was then calculated for each treatment, including the control. The experiment was repeated thrice over a period of 2 months.

3. 2 .5. Fecundity

Newly emerged females and males in batches of 40 each were kept separately on corms dipped for 15 min in 5% aqueous NSP or on untreated corms, ~1 kg each, placed in a 10-*l* bucket. After one week, females and males were paired and confined to a piece of fresh moist corm (~50 g) in a plastic container as follows:

1. Female and male from neem-treated corms
2. Female from neem-treated corm and male from untreated corm
3. Female from untreated corm and male from neem-treated corm
4. Female and male from untreated corms

The treatments, replicated 10 times, were arranged randomly and each container constituted a replicate. Females were allowed to mate with males and lay eggs. Eggs laid, if any, were counted daily up to 10 days. Egg hatchability was determined as described above.

3. 2. 6. Population build-up

Maiden, unpared banana suckers were planted outdoors in 100-*l* drums, each filled with ~95 kg of soil. One month after planting, each sucker was infested with 3, 5 or 10 pairs of females and males and thereafter 100g of NSP or 100g of NC was incorporated into the soil around each sucker. Each drum was covered with netting at the base of the plant to confine weevils (Plate 3.1). Plants infested with weevils, but not treated with neem, served as controls. Drums were arranged in a completely randomized block design; each treatment being replicated four times. Plants were irrigated at weekly intervals. At 3 months after planting, traps made from banana pseudostems were placed singly in each drum. Weevils, trapped twice at 3-day intervals, were counted and weighed. Banana plants were then uprooted and the weevil population, comprising larvae, pupae and adults, recorded and weighed using a Mettler balance (0.01mg sensitivity).

Plate 3.1. Outdoors experiment with banana plants grown in drums at MPFS. Plants were infested with known number of banana weevils and then their bases covered with netting to prevent weevils from escaping

The weevil population build-up was expressed as follow:

$$P = \frac{(Fp \times 100)}{Ip} - 100$$

Where, P = per cent population increase; Fp = final population (adults + larvae + pupae); Ip = initial population.

In a laboratory test, about one month-old male and female weevil adults in batches of 20 pairs each were released in 10-*l* plastic buckets, each containing a fresh, undamaged and pared banana corm (~2 kg each) dipped for 15 minutes in NSP extracts. In control, corms were dipped in water for 15 min each. Each bucket was covered with a mosquito net and then arranged randomly in a dark room. Each treatment was replicated four times and each bucket constituted a replicate. Corms were watered regularly to keep moisture in the bucket. After 2 months, corms were dissected and degree of weevil damage evaluated.

3. 3. Results

3. 3. 1. Adult settling response

In a free-choice test, 48 h after release, compared with untreated corms, significantly fewer weevils settled on banana corms treated with aqueous NSP extract or with emulsified NO; treatment with NC extract was less effective (Table 3.1). Under a choice test between untreated and neem-treated corms, a much higher proportion of the adults was repelled from the treated corms (Fig. 3. 1). The repellent effect was dose dependent. The higher the concentration of neem materials, the stronger was the repellence. The effect of neem remained even after 48 h (Table 3. 2, Figs 3.2 & 3.3).

3. 3. 2. Larval feeding

In comparison with feeding damage to water-treated pseudostem discs, 3rd -instar *C. sordidus* larvae fed much less on neem-treated discs (Plate 3. 2). The degree of feeding deterrency differed with different neem materials (Table 3. 3). Compared with the short time spent in locating the feeding site, initiating feeding, and boring into control disc, the larvae took much longer to locate feeding sites, to start feeding, and to bore into neem-treated discs (Table 3. 3). On NSP-treated discs, larvae spent 30 minutes (29.7±2.1) to locate the feeding site, initiated feeding in the next 14 minutes (14.0±2.2), and in another 12 minutes (11.7±0.9) bored into the discs. However, they emerged out of the discs after ~15 minutes. On NKP-treated discs, larvae spent 106 minutes (106.2±5.6) to locate the feeding site, spent another 25 minutes (24.2±2.2) to initiate feeding, and then took 22 minutes (22.0±3.1) to partially bore into the disc, but soon they retracted and fed no longer. A similar feeding pattern was observed when larvae were confined to NO-treated discs. In contrast, larvae readily started feeding on the control discs and in 4 minutes (4.7±0.9) bored deep into the discs. In about 72 h, weevil larvae caused extensive damage to the control, while little damage was done to neem-treated discs (Plate 3.2).

Larvae recovered from the control discs were mobile and vigorous, while those from neem-treated discs were sluggish and weak.

Time spent in locating feeding site and that spent to initiate feeding were significantly correlated (r = 0.88530) as well as time to initiate feeding and that spent boring into the discs (r = 0.88235)

Table 3.1. Percentage of *C. sordidus* adults settled on banana corms treated with aqueous extract of neem seed powder (NSP), cake (NC) or emulsified oil (NO) at different concentrations at 48 h after release in a multi-choice test at MPFS

Treatment	Weevils settled (%)
NSP extract 5%	8a
NC extract 5%	22ab
NO 2.5%	11a
NO 5%	6a
Water (control)	53b
P>F	0.0001
Significance:	***

Within a column, means followed by the same letter are not significantly different at ($P<0.05$) by Tukey's test. Average of 12 replicates. Each treatment had 30 weevils

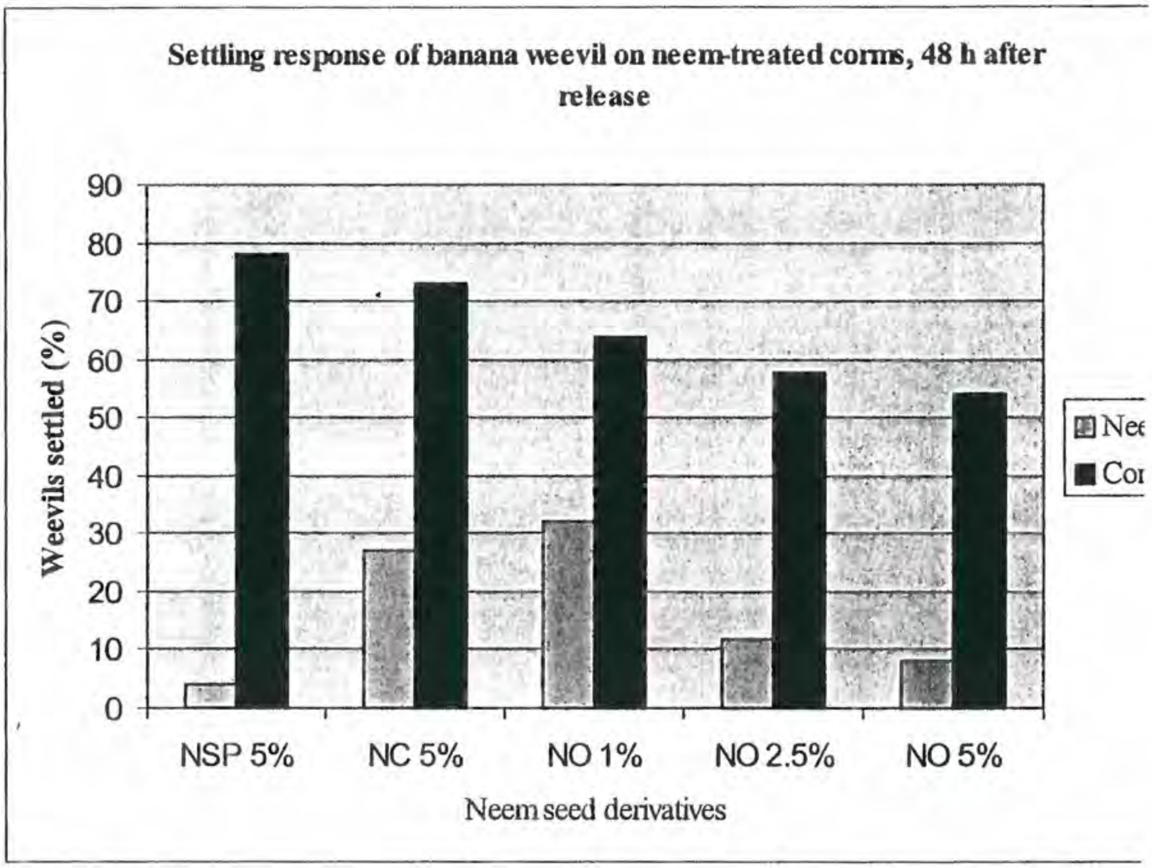


Fig. 3.1. *C. sordidus* adults settled on neem-treated and control corms at 48 h after release in a choice test at MPFS

Table 3.2. *C. sordidus* adults settled on banana pseudostem treated with emulsified neem oil (NO) at different concentrations in a multi-choice test at MPFS

	Adults (%) on treated and untreated corms at h after release in a test chamber						
Treatment	1	3	12	24	48	72	84
NO 1%	20±3.1a	20±5.7a	15±4.3a	16±5.8a	9±2.8a	12±13.0a	11±4.7a
NO 2.5%	16±9.3a	14±4.2a	8±1.4a	7±2.9a	8±1.4a	5±6.5a	16±1.5a
NO 5%	11±9.3a	14± 8.5a	17±1.4a	18±1.4a	18±5.5a	16±3.2a	20±4.7a
Water (control)	53±18.6b	52±14.2b	60±0.0b	59±5.8b	65±1.4b	67±22.7b	53±14.3b

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 12 replications; each replication had 50 adults.

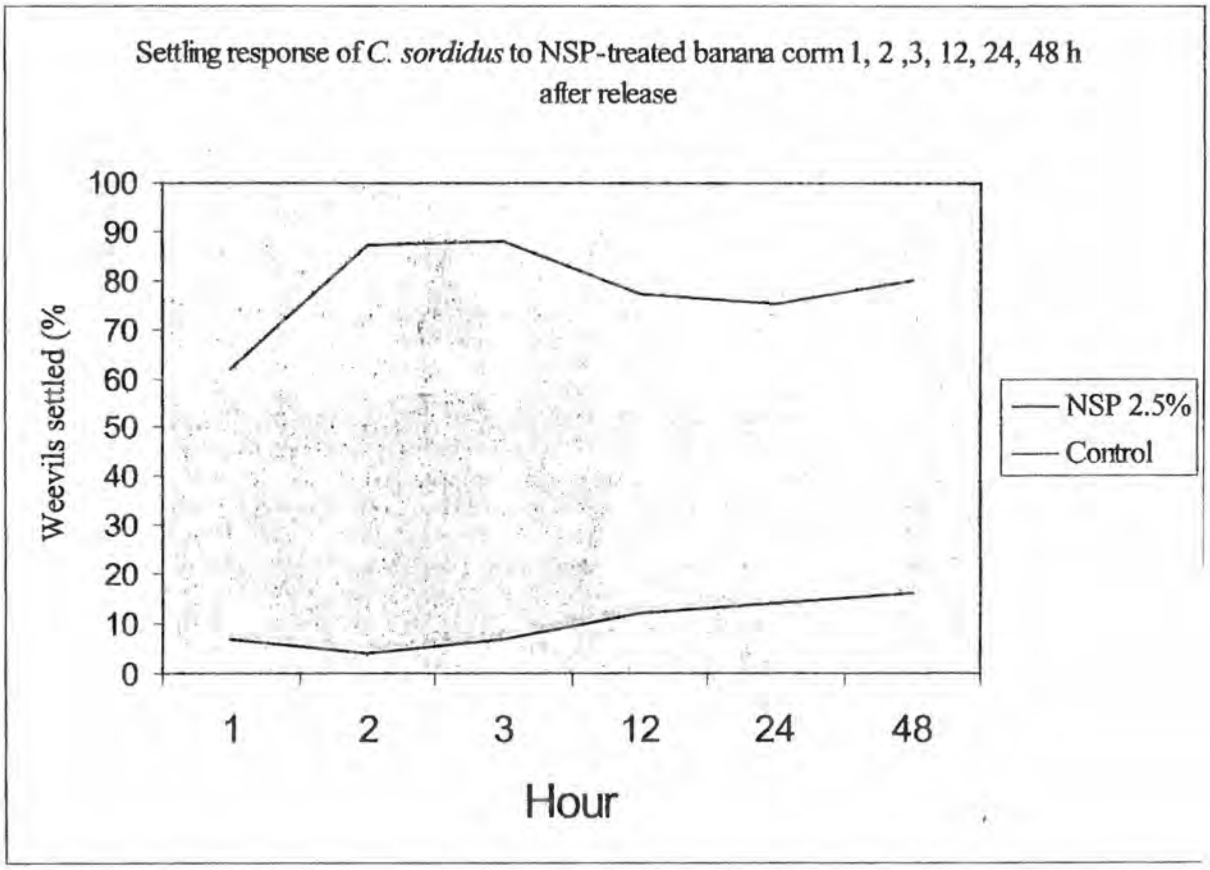


Fig. 3.2. *C. sordidus* adults settled on banana pseudostem treated with neem seed powder extract (NSP 2.5%) in a choice test at MPFS

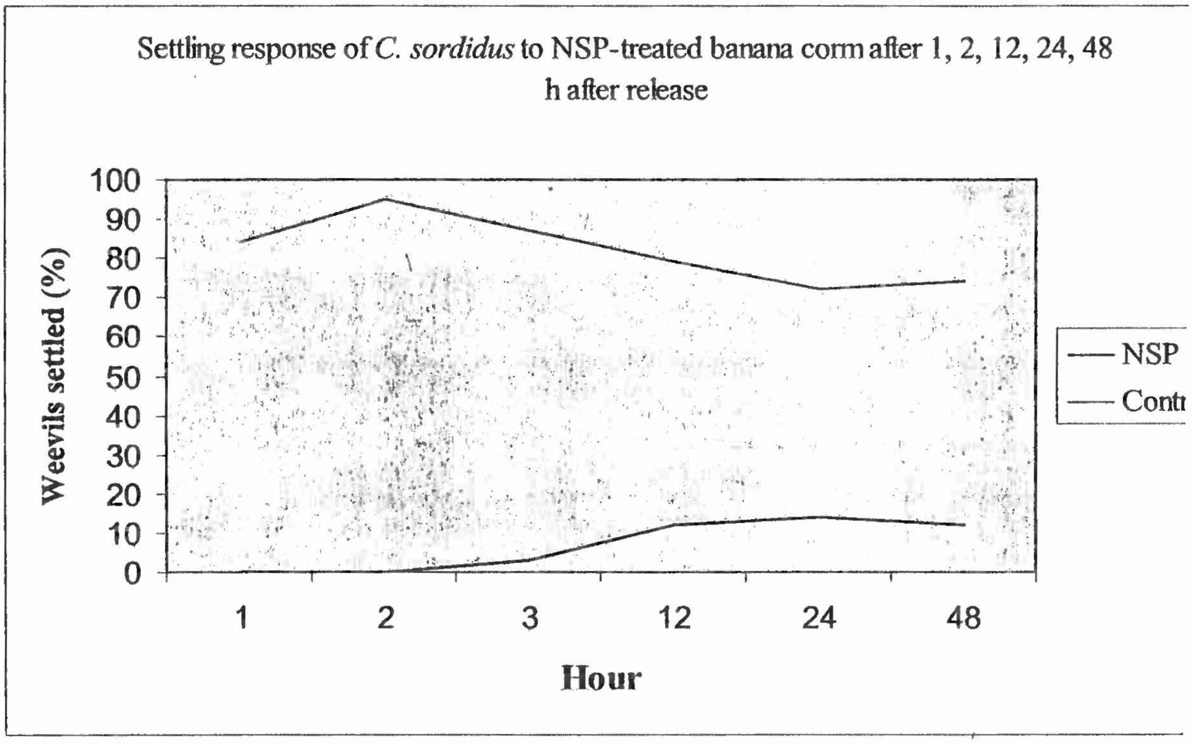


Fig. 3.3. *C. sordidus a*dults settled on banana pseudostem treated with neem seed powder extract (NSP 5%) in a choice test at MPFS

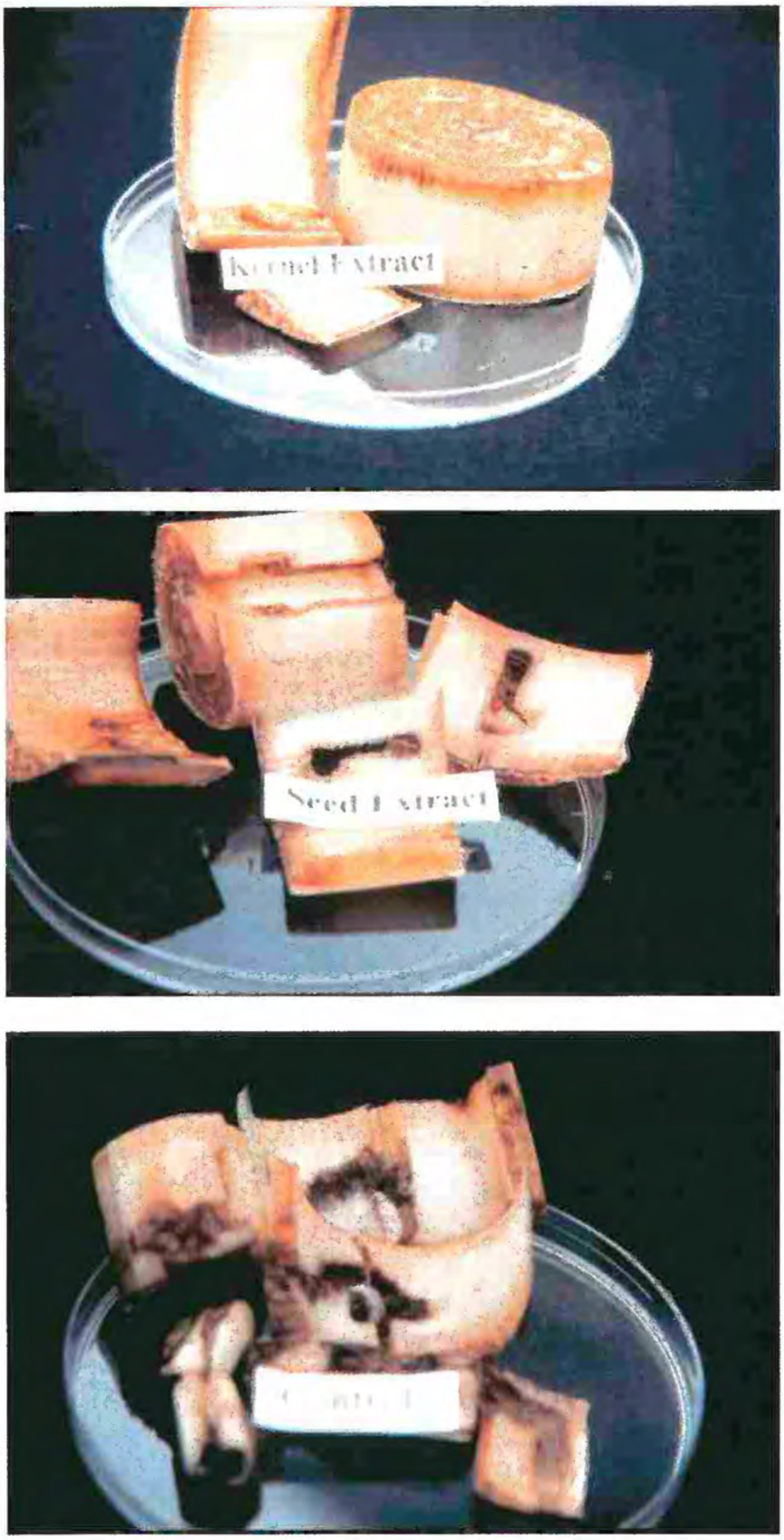


Plate 3.2. Relative feeding damage by *C. sordidus* larvae on banana pseudostem discs treated with aqueous extract of neem kernel powder or seed powder or with water (control)

Table 3.3. Feeding response of 3rd-instar *C. sordidus* larvae when confined to banana pseudostem discs treated with aqueous extract of neem seed powder (NSP), kernel powder (NKP), cake (NC) or emulsified oil (NO) at MPFS

Treatment	Time spent (min) in Locating feeding site	Initiating Feeding	Boring into disc	Damage to corm (%)
NSP 5%	29.7±2.1b	14.0±2.2b	11.7±0.9b	19±1.6b
NKP 5%	106.2±5.6a	24.2±2.2a	22.0±3.1a	15±1.2b
NC 5%	10.2±2.4c	7.2±0.8c	7.7±1.2bc	22±0.8b
NO 5%	19.0±0.9c	7.5±1.0c	7.2±0.5bc	7±1.1b
Water (control)	9.6±0.5c	4.7±0.9c	3.7±0.9c	75±2.0a
P>F	0.0001	0.0001	0.0001	0.0003
Significance:	***	***	***	***

Within columns, means followed by the same letter are not significantly different (*P*<0.05) by Student- Neuman- Keuls's test, average of 4 replicates

3. 3. 3. Larval growth and development

Although larval mortality at 4 days after confinement to neem-treated corms was relatively higher than in the control, it was not significant. However, at 14 days, cumulative larval mortality in the pseudostems treated with NSP, NKP, NO 2.5% or NO 5% was significantly higher than the untreated control (Table 3. 4). Treatment with NC 5% and NO 1% did not differ from the control. The larvae surviving in the neem-treated pseudostems had smaller body size compared with those fed on untreated corms (Plate 3. 3). Larval weight was 4 to 6 times less (60 to 80 mg/larva) in NSP, NKP, or NO-treated pseudostems than in the control. Larva in the control pseudostems weighed 300 mg (Table 3. 4). Although the NC application affected significantly the larval weight, its efficacy was less than the other neem-treatments. After 2 weeks, none of larvae on the neem-treated pseudostems reached the pupal stage. In contrast, adults were recovered only in the control and weight of the adult was not taken because of no comparison could be made with the adults from the neem treatments. Compared with vigorous and healthy larvae in the control, larvae reared in the neem-treated pseudostems were smaller and weaker (Plate 3. 3).

Table 3. 4. Effects of neem on larval development when 2nd-instar *C. sordidus* larvae were confined to banana pseudostem pieces treated with aqueous extract of neem seed powder (NSP), neem kernel powder (NKP), neem cake (NC), or emulsified neem oil (NO) after 14 days at MPFS

Treatment	Mortality (%) after 4 days	Cumulative mortality (%)	Survival (%)	Weight (mg)/ surviving larva	Adult (%)
NSP 5%	40±5.8	57±3.3b	43±3.3bc	64±7.8c	0.0±0.0b
NSK 5%	33±3.3	60±10.9b	40±5.8c	61±9.2c	0.0±0.0b
NC 5%	25±3.3	40±6.7b	60±5.8ab	188±27.7b	0.0±0.0b
NO 1%	30±5.8	43±13.5b	57±3.3ab	61±17.3c	0.0±0.0b
NO 2.5%	30±10.0	57±22.0b	43±3.3bc	81±2.1c	0.0±0.0b
NO 5%	37±3.3	50±6.7b	50±0bc	68±9.3c	0.0±0.0b
Control	17±3.3	17±3.3a	73±3.3a	297±14.5a	10.0±3.3a
P>F	0.1203	0.0009	0.0014	0.0001	0.015
Significance	NS	***	***	***	**

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Student- Neuman- Keuls's test; average of 4 replicates; 10 larvae per treatment

Plate 3.3. Comparison between body sizes of larvae reared in untreated-control (*top*) and neem-treated corms (*bottom*), respectively

3. 3. 4. Oviposition

As compared to the untreated corms, 3 to 10 times significantly fewer eggs were laid in the neem-treated corms (Fig. 3. 4). Within the neem-treatments, at the same concentration, female laid more eggs on NC (39 % of the control) while it was 9%, 14% and 12% on NKP, NSP and NO respectively. The higher the concentration , the greater the oviposition deterrence was.

In a similar experiment using only the NSP extract, only 2 eggs (0.2 eggs per female per week) were recovered in a neem-treated corm. In contrast 53 eggs were recorded in the control where a pair of 10 weevils were released (5.3 eggs per female a week). Neem materials deterred the females to oviposit eggs on the neem-treated corms while females laid more eggs on the control.

3. 3. 5. Egg hatchability

All the neem materials tested adversely affected egg hatchability. The hatchability decreased as the concentrations of NO increased. It was 3-20 times less in the neem treatments than in the control (Table 3.5). However, at the same concentration, the egg hatchability was more pronounced with application of NSP or NKP compared with the NC treatment. Also, it was observed that neem oil created a favorable media for fungus growth and this led to the rotting of eggs.

3. 3. 6. Fecundity

There were no differences in egg production in all the combinations tested with virgin weevils. The egg hatchability did not significantly differ among the treatments (Table 3.6). For all the combinations, unhatched eggs did not show the presence of eyespots.

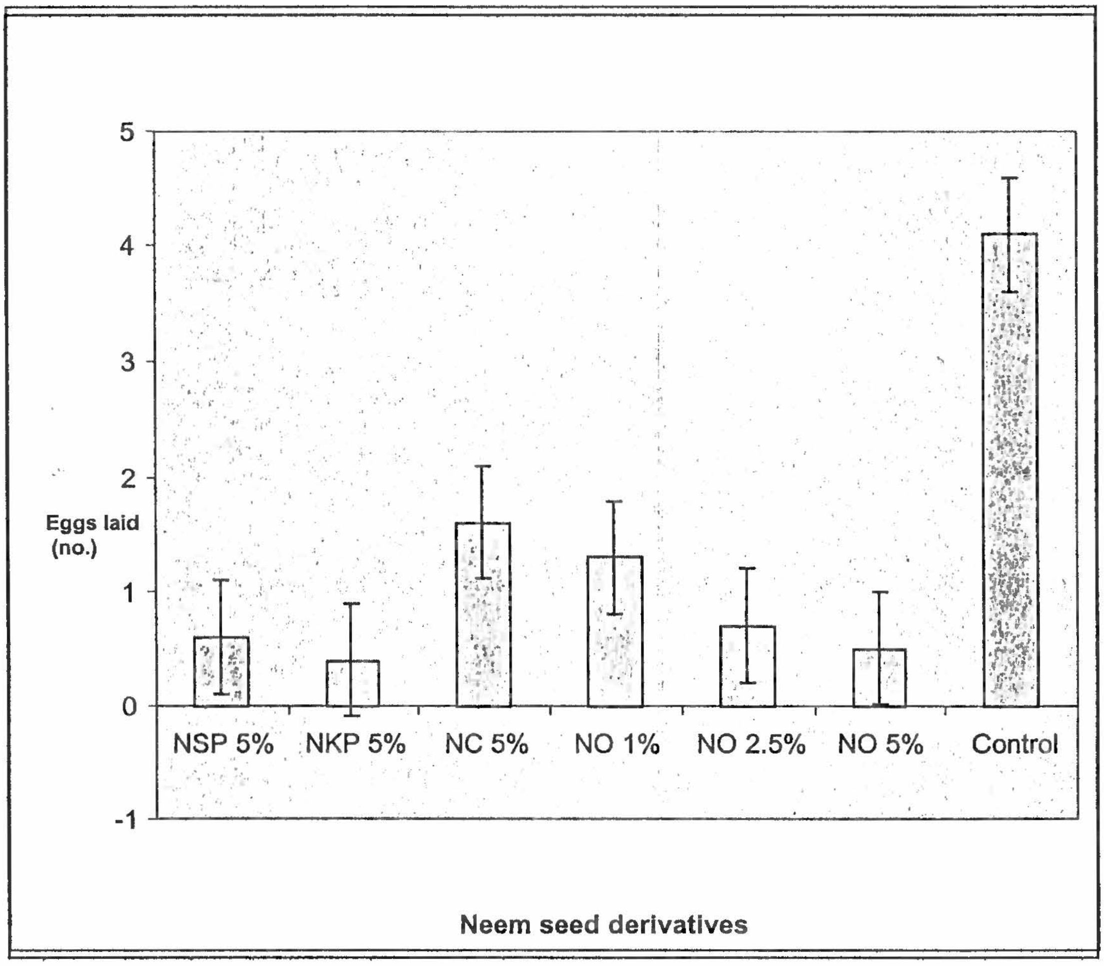


Fig. 3. 4. Effect of neem treatments on number of eggs laid by *C. sordidus* female per week on neem-treated and control corms at MPFS

Table 3. 5. Percentage hatchability of *C. sordidus* eggs inserted in a slice of banana corms treated with aqueous extract of neem seed powder (NSP), kernel powder (NKP), cake (NC), or emulsified oil (NO) at MPFS

Treatment	Eggs hatched (%)	Colour and characteristic of unhatched eggs
NSP 5%	3	Brown
NKP 5%	3	Brown
NC 5%	12	Whitish
NO 1%	13	Eggs rotten
NO 2.5%	4	Eggs rotten + fungus on the slice
NO 5%	2	Eggs rotten+ fungus on the slice
Water (control)	41	Whitish

Average of 12 replicates. Ten eggs per treatment

Table 3. 6. Effect of application of neem seed powder on the fecundity of virgin *C. sordidus* at MPFS

Treatment	Eggs laid/female (no.) per week	Egg hatchability (%)
Female treated + male untreated	0.2	21
Female and male treated	0.2	17
Female untreated + male treated	0.2	22
Female and male untreated	0.5	27

Average of 10 replicates, each replicate had 1 male and 1 female

3. 3. 7. Population build-up

Compared with the untreated control plants, at 3 month after that five or ten pair of weevils (females and males) was released, weevil population significantly decreased in NSP or NC-treated banana plants. However, the lowest population was recorded on NSP treatments (Tables 3. 7 & 3. 9). Although, the number of trapped weevils did not significantly differ among treatments, the number of adult weevils and larvae recovered in corm by dissecting was significantly higher in the control than in the neem treated plants at the initial infestations of 5 and 10 pairs (Tables 3.7 & 3.8). Weights of adult weevil, larvae or pupae were not affected by the neem treatments (Table 3. 10).

Similar results were obtained, when NSP was applied at 100g/plant at the level of 10 pairs of weevil infestation. In general, there was a trend of population increase ranging from 50 to 130% in the control while it was less than 20% in the neem-treatments (Tables 3.7- 3.9).

In the laboratory, untreated corms were heavily attacked and chewed up by the larvae while the neem-treated corms remained fresh with minor larval damage (Plate 3. 4)

Table 3.7. Effects of application of NSP or NC on *C. sordidus* population build up under controlled levels of infestations (3 males and 3 females), 2 months after infestation and neem application in drums at MPFS

Treatment g/mat	Initial weevil (no.)	Final weevil population (no.)					Population increase (%)
		Weevil trapped	Weevil in corm	Larvae	Pupae	Total	
NSP100	6	4.7±2.2	1.5±1.7	2.0±2.1	0.5±1.0	8.7±3.7	45.7±62.7
NC100	6	5.5±1.7	2.5±1.9	1.0±0.8	0.2±0.5	9.2±3.8	54.2±64.2
Control	6	8.0±6.2	3.2±4.5	2.0±1.6	0.2±0.5	13.5±5.2	125±87.0
P>F		0.5507	0.7927	0.6970	0.9079	0.3115	0.2864
Significance		NS	NS	NS	NS	NS	NS

NS: not significantly different (*P*<0.05) by Student- Neuman- Keuls's test, average of 4 replicates.

Table 3.8. Effects of application of NSP or NC on *C. sordidus* population build up under controlled level of infestations (5 pairs of male and female), 2 months after infestation and neem application

Treatment g/plant	Initial weevil population (no.)	Final weevil population (no.)					Population increase (%)
		Weevil trapped	Weevil in corm	Larvae	Pupae	Total	
NSP100	10	2.0±1.8	2.2±2.6a	0.0±0.0a	0.5±1.0	8.5±3.5a	-15.0±30a
NC100	10	7.5±3.1	2.0±1.8a	0.7±0.9a	0.2±0.5	10.5±4.7a	5.0±47a
Control	10	12.0±10	6.2±2.0b	4.0±3.6b	0.7±0.5	23±8.8b	130±88b
P>F		0.1813	0.030	0.015	0.0751	0.0138	0.016
Significance		NS	*	**	NS	**	**

Within columns, means followed by the same letter are not significantly different (*P*<0.05) level by Student- Neuman- Keuls's test, average of 4 replicates

NS = Not significant; * , **: significant (P<0.05) and (P<0.01), respectively

Table 3. 9. Effects of application of NSP at 100g/plant on weevil population build up under controlled levels of infestation (10 pairs male and female), 2 months after infestation and neem application

Treatment g/mat	Initial population (no.)	Final weevil population (no.)					
		Weevil trapped	Weevil in corm	Larvae	Pupae	Total	Population increase (%)
NSP	20	14.2±6.2	5.7±2.2a	1.2±0.7	0.2±0.2	21.2±5.0	8±25a
Control	20	19.5±10	10.7±1.8b	1.0±0.7	0.7±0.4	32.5±2.7	61±14b
P>F		0.1852	0.0363	0.9784	0.3903	0.1110	0.0243
Significance		NS	*	NS	NS	NS	*

Within columns, means followed by the same letter are not significantly different (*P*<0.05) by Student- Neuman- Keuls' test. Average of 4 replicates.

NS= not significant, * significant

Table 3. 10. Effect of application of NSP or NC on *C. sordidus* adults, larvae and pupae weight, under controlled levels of infestations recorded 2 months after infestation and neem application.

Treatment (g/plant)	Initial population (no.)	Weight (mg) of weevil Adult	Larva	Pupa
NSP100	6	67±1.7	115±1.7	146±0.6
NC100	6	72±0.9	115±0.5	118±0.3
Control	6	72±0.9	125±1.2	149±0.5
P>F		0.8140	0.4789	0.3115
Significance		NS	NS	NS
NSP100	10	62±0.9	115±1.0	150±0.7
NC100	10	72±0.9	125±0.5	105±0.4
Control	10	70±0.0	120±0.8	153±0.9
P>F		0.8743	0.2740	0.2134
Significance		NS	NS	NS

NS: not significantly different (*P*<0.05) by Student- Neuman- Keuls' test. Average of 4 replicates.

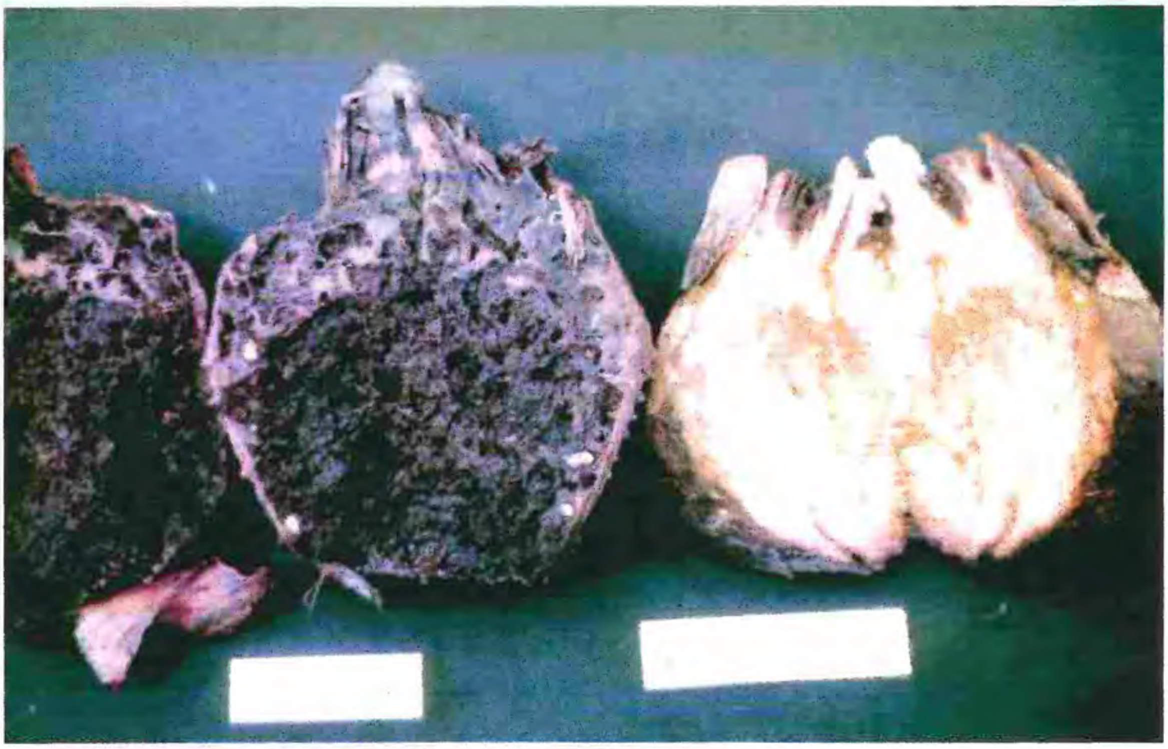


Plate 3.4. Larval damage, 2 months after release of 20 pairs of males and females of *C. sordidus* in buckets containing banana untreated (*left*) and NSP-treated corms (*right*)

3. 4. Discussion

Banana weevil adults are strongly attracted to banana corms by some odour (Treverrow *et al*., 1992) or volatiles emanating from banana plants (Ndiege *et al*., 1991). Females are attracted to corms because these constitute preferred egg laying sites and will provide food to larvae after the eggs hatch (Treverrow *et al*., 1992) and also because the males are there (Bundenberg *et al*., 1993). The entire insect cycle development occurs in the corm. This behaviour and biology of the weevil was used to its disadvantage in the present study.

Neem seed derivatives were tested for their effect as repellent, antifeedant, ovipositional deterrence, and growth regulating principles against *C. sordidus*. Results obtained suggest that adult weevils or larvae clearly discriminated untreated banana corms/pseudostems from the neem-treated ones, irrespective of the concentrations of NSP, NKP, NC or NO. This indicates the strong repellent and antifeedant effect of neem. In addition, the repellence increased with the increase of concentration. In this regard, the odour emanating from the neem material probably might be strong enough to inhibit volatiles from the corms, resulting in low settling response of weevils to the neem-treated corms. Further studies involving identification of volatile contents in neem-treated and untreated corms will be necessary.

Earlier, the repellent effect of neem against various coleopteran insects has been demonstrated (Singh, 1993), except for the banana beetle. In their study, Jilani *et al*., 1988 also found that neem preparation repelled red flour beetle and that repellence increased with the increase of concentration that is similar to the present results.

The present study also has demonstrated the antifeedant effect of neem seed derivatives. Weevil larvae avoided feeding on the neem-treated discs. Starved larvae confined to discs treated with NSP, NKP or NO extracts made small bites to the discs and stopped for a long period. The difference on feeding and boring deep into the discs was probably due to the bitterness of the tested neem materials. Likewise, reduced motility was observed for larvae that probed the neem-treated materials. Earlier, feeding deterrent effect of the neem seed extracts on *C. sordidus* has not been reported. However, similar results for other coleopteran species: *Epilachna varivestis, Diabrotica undecimpunctata* howardi, *Acalymma vittatun* (Karel, 1989; Mordue, 1993) and other insects have been reported (Saxena *et al.*, 1985; Mochizuki, 1993).

Compared with the control, larvae caused less feeding damage on the neem-treated discs. This definitely will affect the insect growth and development and even may cause the insect to die following its starvation. This suggests that neem application in the field may also reduce the weevil damage. The efficacy of neem seed derivatives in the outdoors is discussed in the following chapters.

Insect physiology is affected by the food consumed during its developmental stages. Rembold, 1989 observed that immature insects exposed to neem-treated material often develop into adults that possess physical abnormalities. The present study demonstrated the growth and development inhibitor effect of NSP, NKP, NC or NO on the weevil larvae. Forty to 60% larval mortality was observed in the neem treated pseudostem. In addition, a fungus *(Rhizopus spp?)* developed in the NKP and NO treated pseudostems. The high mortality was probably due to the combined effect of neem materials, and the pathogenic fungus, and also could have been due to the larval damage during its transfer to the banana materials.

As compared to the control, in the neem-treated pseudostems, the adult stage was not achieved within a period of 3 weeks; larvae of the same age were completely different in their body size and mobility. This effect might be attributed to neem extract's inhibitory action and not due to repellent effect because larvae were confined on the treated corms.

In the present study, neem seed derivatives adversely affected weevil oviposition and fecundity as well as egg hatchability. Similar results of ovipositional deterrence of pulse beetle *Callosobruchus maculatus* have been reported with NO application in greengram (Yodav, 1985). Earlier results mentioned that eggs deposited in neem-treated plants often are less fertile and more susceptible to fungal attacks (Schmutterer, 1987). This can be explained by the modification in the endocrine control mechanisms of the insect due to the neem, resulting in its physiological changes (Rembold, 1989). In the present study, fewer eggs were laid in the neem-treated corms and the hatchability was less than 25%. Unhatched eggs from NO treatments were colonized by unidentified fungus. Pathak and Krishna (1992) reported a significant reduction in egg hatchability in a lepidopteran *Corcyra cephalonica* due to odour emanating from neem leaves. Effects of neem on the insect oviposition, fecundity, and egg hatchability have also been reported on a wide range of insect pests. The hatchability of eggs laid by *Spodoptera litura* moths treated with neem was only 25% against 75% in the control (Gujar and Mehrotra, 1984). Root dipping in 5% NKP extract reduced the oviposition of *Nephotettix virescens* 6.5 times in the treated plants as compared to the control (Abdul Kareem et *al*., 1989).

Dimetry *et al.*,1993; Sundaram and Sloane, 1995 observed a significant reduction in the number of eggs laid by two-spotted spider mite, *Tetranychus urticae* Koch and a decrease in the percentage of egg hatchability with Margosan-O (3000 ppm azadirachtin) or Neem azal-s (3500 ppm). It has been reported that insects treated with aza have degenerated or improperly developed ovaries and fat bodies (Schmutterer, 1987). Further cytological studies of the reproductive organs of weevil reared or fed on neem-treated banana material would be of great importance in understanding the physiological changes in the insect's body.

The low fecundity observed in the newly emerged banana weevil either in contact or not with neem might be due to immaturity of weevils and not to the neem treatment. Although, Pintò (1928) reported that banana weevils are able to mate and lay eggs soon after emergence, Viswanath (1979) mentioned that a pre-oviposition period of at least 20 days is needed. In the present study, the weevils could also mate soon after emergence but egg production and their viability was still very low to express the deterrent effect of neem. This suggests that the adverse effect of neem application as demonstrated earlier is more pronounced on well-developed adults than on newly emerged one.

In the outdoors tests, the neem treatments significantly reduced the weevil build-up in a period of 3 months. The treated corms might be an unfavorable site of egg-laying and consequently for larval feeding, growth and development as earlier demonstrated in the laboratory tests. However, weights of weevil adults, larvae and pupae were not adversely affected by the neem treatments in an outdoors experiment. This contrasts the findings obtained in the laboratory tests where it was observed that the weight of larvae confined in the neem treated corms for 3 weeks was about 4 times less than that reared in the control corms. This was probably due to the ambient conditions that can change the insect physiology. The effect of neem on weevil growth is likely to be pronounced after a reasonable period of repeated neem applications.

Throughout the study, among different neem treatments, at the same concentration, the effect of NKP was more pronounced. This agrees with Chen *et al.*, 1996, who reported a strong ovipositional deterrent effect of neem seed kernel extract.

These results in the present study are consistent with the previous findings as stated above. These effects may have practical importance in the long-term control of the weevil in the banana field. The deterrent effect of neem will result in weevil repellence, in reduced oviposition, in low rates of larval feeding and development and in significant low weevil population.

CHAPTER FOUR

EFFICACY OF NEEM SEED DERIVATIVES AGAINST BANANA WEEVIL AND PARASITIC NEMATODES

4. 1. Introduction

While chemical control can reduce the impact of plant pest infestations, effective pesticides are too expensive for farmers with limited resources. In addition, the prolonged use of pesticides can be hazardous to human health and the environment and may lead to pest resistance. Therefore, besides effectiveness in maintaining pest population at below the economic level, pesticide safety is an important consideration in IPM. Efficacy and safety of bioactive products from neem against arthropod pests and nematodes' species affecting food crops is well-documented (Saxena 1989, Alam 1993, Schmutterer and Singh 1995). However, little information exists on the efficacy of neem materials against banana pests. Therefore, the objective of this study was to determine the efficacy of neem seed derivatives against the banana weevil, *C. sordidus*, and parasitic nematodes, especially *P. goodeyi* and *Meloidogyne* spp.

4. 2. Materials and Methods

4.2.1. Screen house experiment

Twenty banana suckers (~50 cm heigh) were planted in *6-l* capacity pots, filled with soil mixed with decomposed cow dung (1:1). The potted plants were placed in a completely randomized design at 40 x 40 cm spacing in a screen house and were watered daily. Four weeks later, each plant was inoculated with approximately 500 banana parasitic nematodes of mixed species (mainly *P. goodeyi* and *Meloidogyne* spp.) by pouring a nematode suspension onto the soil around the plant. Nematodes used in this experiment were extracted from fresh banana roots (section 2. 7), as attempts to rear them on carrot discs were unsuccessful. The nematode suspension obtained had >75 % of *P. goodeyi*.

In addition, 5 males and 5 females of *C. sordidus* were released into each pot. Pots were then covered at the base of plants with netting to prevent weevils from escaping. The pots were divided into 5 equal groups. Two weeks after inoculation, plants in the first four groups were treated with 5g per plant of NSP, NKP, NC,and Furadan 5G respectively. Plants in the last group were untreated and served as controls.

Forty-five days after neem or Furadan applications *i.e.,* 90 days after planting, plants were gently removed from the pots and shaken to clear soil from the roots. The roots of respective plants were assessed for necrosis index on a 0 to 4 scale. For each treatment, the nematodes were extracted and counted and the weevil damage caused to corms as expressed by the PCI was also evaluated (Sections 2.6 and 2.7 of the General Materials and Methods).

4. 2. 2. Outdoors experiment

A second experiment was conducted outdoors using 100- and 200-*l* capacity oil-drums. The drums were filled with soil dug from a grassy fallow *i.e.,* virtually free from endoparasitic nematodes. About 5 kg of decomposed cattle dung and 10 kg of di-ammonium phosphate were incorporated into the soil in each 200-*l* capacity drum. The soil in 100-*l* capacity drums did not receive any fertiliser. Twenty pared and unpared suckers of each (65-80 cm high) were planted in the drums of 100-*l* capacity while 30 pared and unpared suckers of each were planted in 200-*l* capacity drums.

NSP, NKP, or NC was incorporated at 100 g per drum into the soil around the plant at planting time and then at 3-month intervals, while Furadan was applied at 40 g/plant at planting time and again after 6 months. In the neem oil (NO) treatment, suckers were dipped in 5% NO solution for 10-15 min. prior to planting. Treatment with Furadan using unpared suckers was not included in the experiment because the aim of the study was not to screen for synthetic insecticides. Furadan was used as a positive control. Also, the treatment with NO was deliberately limited to unpared suckers since in practice, oil application into the soil is uncommon. The drums were arranged in a completely randomized design with a spacing of 3 by 3 m. Ten treatments comprising of pared and unpared suckers with various neem or Furadan treatments, and the controls (unpared and untreated) were replicated 4 and 6 times in 100-*l* and in 200-*l* drums respectively; each drum constituted a replicate. Forty days after planting, 5 pairs of newly emerged male and female weevils were released in each drum. Plants were also inoculated with a mixed nematode population by pouring a suspension containing approximately 2000 nematodes into the soil around the plant for each treatment. The drums were covered with netting at the base of the plant to prevent weevils from escaping. The netting was removed during the time of both root sampling, and treatment application and was placed back after completion. Plant height, girth, nematodes and weevil populations and damage were recorded (Sections 2. 6, 2. 7 and 2. 8 of Materials and Methods) at 3-monthly intervals. Eight months after inoculation, plants in 100-*l* drums were uprooted and for each treatment the number of suckers produced, nematode population /100 g roots, weevil density, weevil damage to the corm and the weight of the plant biomass recorded.

Complementary to that, data on crop cycle and the fruit yield at harvest of the bunch in 200-*l* drum were recorded.

4. 3. Results

In potted banana plants treated with neem, nematodes caused significantly less damage to the roots than in untreated plants. Furadan-treated plants also had less root necrosis but not significantly different from the control. Although all the neem tested materials significantly supported fewer nematodes (3 to 20 times) than in untreated control plants, NSP treated-plants supported 3 to 6 times fewer nematodes than NKP and NC respectively (Table 4.1).

There was no significant difference in the weevil number (larvae, pupae and adults) recovered 45 days after neem applications among the different treatments. However, the weevil damage to the corms was significantly less in NSP, NKP or Furadan treatments. Although the reduction of nematode population and weevil damage by neem treatments was similar to that of Furadan 5G, neem cake application was comparable with the control in reducing weevil damage.

Table 4. 2. shows the effect of neem derivatives and Furadan on nematode population two and eight months after inoculation to pared and unpared suckers. Plants treated with neem seed derivatives or Furadan had significantly fewer nematodes than the untreated plants at both sampling times. Also, initially, pared suckers supported few nematodes but later they had significantly more nematodes than the unpared ones

Table 4.1. Efficacy of application of neem seed powder (NSP), kernel powder (NKP), cake (NC) against banana weevil and parasitic nematodes as compared with Furadan in screen house at MPFS

Treatment	Necrosis index (0-4 scale)	Nematodes (no.)/ 100g of roots	Weevils (no.)	PCI (%)
NSP	0.0±0.0a	500±204a	1.1±0.5	3.5±1.4a
NKP	0.3±0.25a	1500±445a	1.9±0.7	0.5±0.1a
NC	0.3±0.25a	3000±1099a	2.4±1.1	12.4±7.2ab
Furadan 5G	0.5±0.28ab	1388±616a	0.2±0.2	0.0±0.0a
Untreated-control	1.3±0.25b	10000± 1414b	3.5±2.1	22.2±8.4b
P>F	0.0207	0.0001	0.4139	0.0305
Significance	*	***	NS	*

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 4 replicates

NS = Not significant ; *, *** significant ($P<0.05$) and ($P<0.001$), respectively

Table 4. 2. Effects of application of neem seed powder (NSP), kernel powder (NKP), cake (NC), oil (NO) or Furadan on nematode density; under controlled levels of pest's infestations (suckers planted in 100- *l* capacity) at MPFS

	Nematode population (no./100 g of roots)	
Treatment	At 2 months after inoculation	At 8 months after inoculation.
Pared	1200 ± 489bc	22200 ± 3747d
Pared + Furadan	0 ± 0a	16800 ± 2135d
Pared+NC	0 ± 0a	12000 ± 2135cd
Unpared+NC	300 ± 300ab	1200 ± 0a
Pared+ NSP	0 ± 0a	22500 ± 2265d
Unpared+NSP	300 ± 300ab	3600 ± 490b
Pared +NKP	0 ± 0a	81600 ± 2351ef
Unpared+NKP	125 ± 125ab	27600 ± 3730cd
Unpared +NO	0 ± 0a	5700 ± 1025bc
Unpared/untreated	25050 ± 4057c	114000 ± 4673f
P>F	0.0001	0.0001
Significance	***	***

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 4 replicates.

*** Significant ($P<0.001$)

NSP-or NC-treated, unpared suckers significantly supported fewer nematodes (32 and 95 times, respectively) than pared NSP-or NC-treated suckers.

Table 4.3. shows the effects of neem seed derivatives and Furadan on weevil density, plant growth and plant biomass. The results indicate that there was no significant differences in plant height and girth, number of suckers produced, plant biomass or weevil density among the different treatments. However, plant biomass was greater in neem treatments than in the control and weevil damage was significantly different among treatments. Compared with the untreated control, significantly less weevil damage was caused when NKP or NC was applied to pared suckers as well as when NSP or NKP was applied to unpared sucker. In addition, plant biomass was negatively correlated with nematode population ($r = -0.137$)

Similar results were obtained in the 200-*l* drum experiment. Six months after planting, the nematode density in the neem-treated plants was reduced from 57 to 92% less than in the untreated-control. In contrast paring alone reduced nematode population by 5% only. However, no significant difference was observed between nematode population in pared- or unpared neem-treated plants (Table 4. 4). Also there was no significant difference in plant height and girth, and weevil population build-up among the different treatments. The maximum effect of neem treatments was recorded at flowering stage. Nematodes in the neem-treated banana plants were significantly reduced. In contrast, the nematode population in Furadan-treated plants was significantly higher than in neem-treated plants and at par with that in untreated plants.

Table 4. 3. Effects of application of neem seed powder (NSP), kernel powder (NKP), cake (NC), oil (NO) or Furadan on plant height, girth, number of suckers, plant biomass and weevil damage at 10 months after planting under controlled levels of pests infestation in 100-*l* capacity drums at MPFS

Treatment	Plant height (cm)	Plant girth (cm)	Sucker (no.)	Biomass (kg)	Weevils (no.)/plant	PCI (%)
Pared	98±3.9	38±2.0	1±0.2	12.0±1.4	7.7±2.3	33 ±12abc
Pared+ Furadan	89±8.6	33±3.3	2±1.9	11.6±1.9	4.2±1.2	60±17.2bc
Pared+NSP	92±6.6	36±1.9	1±0.7	13.3±1.5	6.2±0.9	31.3±9.4abc
Unpared+NSP	95±1.4	35±1.6	2±0.4	15.9±2.8	6.7±2.3	12.5±1.7a
Pared+NKP	93±2.5	36±1.2	3±0.4	15.5±1.4	7.2±3.1	17.5±3.5ab
Unpared+NKP	87±1.3	33±1.6	3±0.5	13.4±1.6	7.7±2.5	25.7±12.0ab
Pared+NC	106±8.9	39±3.0	2±0.4	15.8±0.6	6.2±0.7	10.5±2.4a
Unpared+NC	79±6.6	31±1.9	2±0.6	13.4±0.6	6.0±1.0	32.5±7.8abc
Unpared+NO	89±1.3	35±0.5	2±0.2	12.4±1.5	8.0±2.7	28.7±13.4abc
Control	72±3.9	29±2.3	2±0.2	10.5±1.4	4.5±3.1	75.0±16.7c
P>F	0.066	0.564	0.763	0.074	0.762	0.001
Significance	NS	NS	NS	NS	NS	***

Within columns, means followed by the same letter are not significantly different (P<0.05) by Tukey's test. Average of 4 replicates, *** significant (P<0.001)

Table 4. 4. Effect of application of neem seed powder (NSP), kernel powder (NKP), cake (NC), oil (NO) or Furadan on banana plant height and girth, and weevils and nematodes density at 6 months after planting under controlled pests levels of infestation in 200-*l* capacity drums at MPFS

Treatment	Girth (cm)	Height (cm)	Weevils (no./ drum)	Nematodes (no.)/100g roots)	Nematode Reduction
Pared+NC	34.6±1.9	86.3±9.4	4.6±1.9	973±314a	92
Unpared+NC	33.1±1.4	84.9±8.5	4.5±1.7	4773±1758ab	61
Pared+NSP	33.8±1.7	85.4±8.7	4.5±1.9	3380±2112ab	73
Unpared+NSP	33.4±1.7	83.9±9.2	6.6±0.6	5280±1083ab	57
Pared+NKP	32.1±1.4	80.0±6.5	5.3±1.5	3693±2112ab	70
Unpared+NKP	31.5±1.9	80.4±9.5	3.3±0.8	2780±1083ab	77
Pared+Furadan	32.4±1.7	81.0±8.8	7.3±2.2	3993±1664ab	68
Pared	33.7±2.1	86.9±9.0	10.5±3.0	11680±4095b	5
Unpared+NO	33.0±1.9	80.4±7.6	7.5±1.7	1610±696ab	87
Untreated	34.5±1.4	85.9±8.3	6.5±1.6	12279±4095b	0
P>F	0.560	0.714	0.571	0.0001	
Significance	NS	NS	NS	***	

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 6 replicates. NS= not significant; *** significant at ($P<0.001$)

The unpared plants treated with NC or pared plants treated with NSP flowered earlier than plants from other treatments. Although, the weevil population did not significantly differ among treatments in 200-*l* capacity drum, the weevil damage (PCI) recorded at harvest was significantly reduced in neem treatments and was on a par with Furadan treatments. The larval feeding deep into the corm (PCI inner) was 4-8 times less in NC and NSP treated plants compared with the control (Table 4. 5). Except with the applications of NKP and NO that were toxic to the banana plants, there was a trend of increased fruit yield with the neem applications, ranging from 62 to 125% over the untreated-control plants. Higher fruit yield was obtained with NSP and NC-treated plants in this order (Table 4. 6).

Similarly, the results obtained in 100-*l* drum experiment, plant heights, girths, necrosis index, suckers produced in the 200-*l* drum experiment did not significantly differ among treatments. Likewise, in both experiments and for each treatment, root galls were not observed. In general, neem-treated plants were vigorous, healthier and produced more suckers with deep green leaves, while most of the untreated plants dried up before fruiting. Plant girth and plant height were significantly correlated ($r = +0.793$) at $P<0.01$.

In general, application of neem materials to the banana plants significantly reduced weevil damage and the nematode population. The nematode population in the bananas planted in the drums was composed of ~60% *P goodeyi,* ~35% *Meloidogyne* spp. and < 5% *R. similis, Helicotylenchus multicinctus* and *Hoplolaimus* spp (Fig. 4.1).

Table 4. 5. Effects of application of neem seed powder (NSP), kernel powder (NKP), cake (NC), oil (NO) or Furadan on crop cycle, nematode population at flowering, weevil damage and fruit yield under controlled pests level infestation in 200-*l* capacity drums at MPFS

Treatment	Days to flower	Nematodes (no.)/100g roots	PCI inner (%)	PCI outer (%)	Fruit yield (g/bunch)
Pared	363±10cd	58433±9746b	43±11a	62±10.1b	1500±543
Pared +Furadan	369±6.5d	64033±13684b	33±4.4a	37±6.0a	2233±512
Pared +NSP	330±9.9ab	12800±2005a	15±4.9a	22±6.7a	2400±585
Unpared+NSP	350±3.2bcd	15667±3399a	18±6.0a	23±6.6a	1733±607
Pared+NKP	350±0.4bcd	11000±2675a	15±2.8a	22±3.3a	583±369
Unpared+NKP	353±1.1bcd	9333±2606a	23±8.8a	30±8.6a	1433±930
Pared+NC	343±5.8abc	4700±673a	10±0.0a	17±4.4a	2333±862
Unpared+NC	326±0.7a	6200±2156a	10±0.0a	12±2.3a	2200±766
Unpared +NO	348±3.7bcd	12600±3814a	15±5.0a	23±6.6a	1083±757
Unpared-contl	363±2.7cd	76997±1950b	77±14b	87±7.2c	1066±356
P>F	0.0001	0.0001	0.0001	0.0001	0.518
Significance	***	***	***	***	NS

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 6 replicates and 6 plants per treatment

NS= not significant; *** significant ($P<0.001$)

Table 4. 6. Beneficial effect of application of neem seed powder (NSP), kernel powder (NKP), cake (NC), neem oil (NO) or Furadan on bunch weight and general improvement in yield on pared or unpared banana suckers of 'Nakyetengu' grown in 200-*l* capacity drums under controlled levels of the banana weevil and nematodes infestation at MPFS

Treatment	Fruit yield (g/bunch)	Yield increase over control (%)
Pared	1500±543	40
Pared +Furadan	2233±512	109
Pared +NSP	2400±585	125
Unpared+NSP	1733±607	62
Pared+NKP	583±369	-56
Unpared+NKP	1433±930	34
Pared+NC	2333±862	118
Unpared+NC	2200±766	106
Unpared +NO	1083±757	2
Unpared/untreated (control)	1066±356	0

Six plants per treatment

Analysis of the total nematode population in the drum experiments observation according to species showed that *P. goodeyi* and *Meloidogyne* spp. were the predominant species infesting banana plants (Fig 4.1). These species appeared to be highly sensitive to treatment with NC or NSP

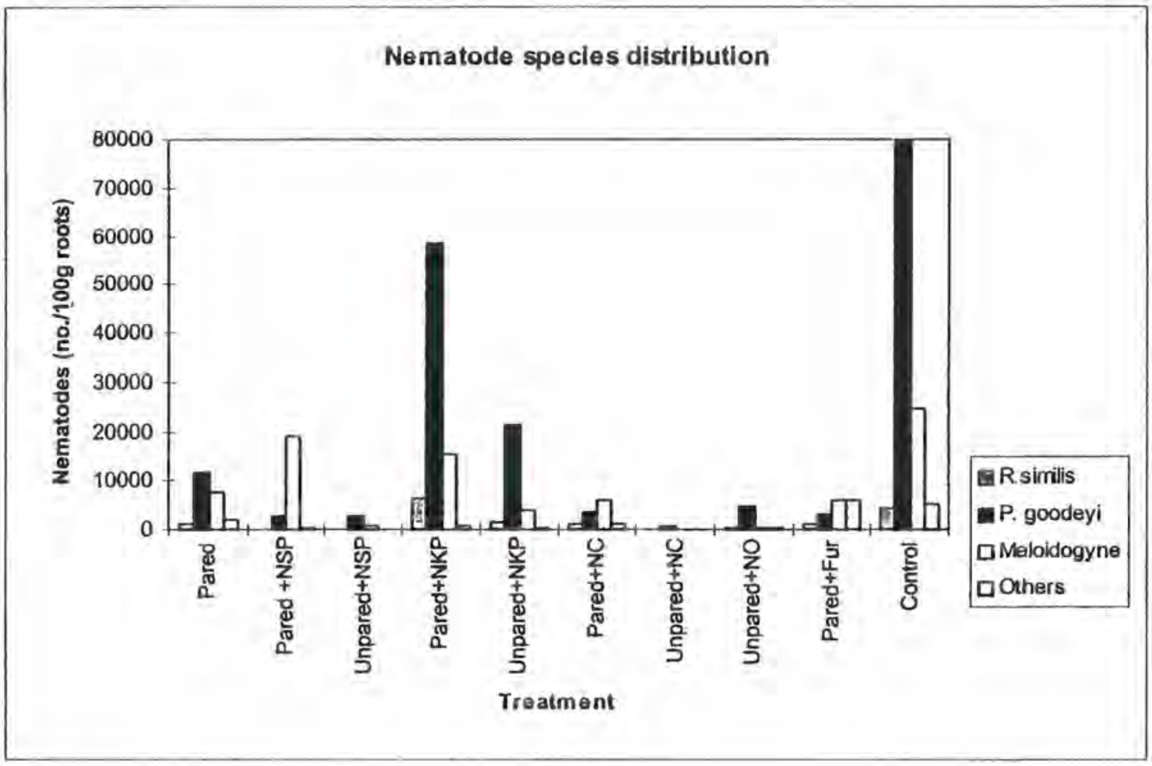


Fig. 4. 1. Relative distribution of nematode species in the banana roots 240 days after inoculation with a mixed population of 2000 nematodes per plant and the application of neem seed derivatives in drums at MPFS

4. 4. Discussion

Losses caused by *C. sordidus* are variable and can reach 100% in a field with a high weevil infestation (Mitchell, 1980). The same number of weevils may cause different levels of damage to the banana corm depending on the host vigour at the time of attack (Southwood, 1978). The banana weevil and nematodes are very often found together attacking the same plant. Therefore, it is difficult to determine the relationship between pest numbers and damage (Stanton, 1994). The highly toxic chlorinated hydrocarbon; organophosphate or carbamate insecticides have been effectively used against the weevil (Vilardebo *et al.*, 1974). Furadan has been commonly used against both *C. sordidus* and nematodes in bananas plantations (Mitchell, 1980).

In recent years, neem products have proven effective against nematodes attacking vegetables and legumes (Alam, 1991; Bridge, 1996). Neem cake has been found to be an effective nematicide and gave even better control when combined with synthetic nematicides (Alam, 1993). Although reports on the efficacy of neem derivatives against coleopterans exist (Schmutterer and Singh 1995), no specific studies have been done on the banana weevil control.

In the present study, the efficacy of soil applications of azadirachtin-rich NSP or NC in reducing *C. sordidus* damage along with *P. goodeyi* and *Meloidogyne* spp. infestation in the banana plants was demonstrated in the tests conducted in drums. The neem treatment did not adversely affect the adult weevil population, but significantly reduced larval damage. However, NSP reduced the total weevil population (larvae, pupae and adults)(cf. 3.3.7). In the screen house, 3 months after planting, the nematode damage was negligible even in the control plants, probably due to the low nematode pathogenicity. Also, the inoculum used might not have been enough to cause visible damage within 45 days. Sarah and Fallas (1996) found a direct relationship between the reproductive fitness of nematodes, i.e. multiplication rate in the root tissue and the pathogenicity, *i.e.* induced damage to roots and that nematodes from higher altitudes are reported to be less pathogenic. In the present study, the multiplication rate was also reduced in the neem treatments as compared to the control; 75% of nematodes in the neem-treated plants were at the juvenile stage, while in the untreated control more than 90% were already adults. These observations indicate the effect of neem on nematode multiplication and development. In this regárd, the mobility, penetration and reproduction of nematode, and egg hatchability were probably affected by neem application, as reported by Mojumder (1995), resulting in a significant reduction of nematode population in the neem treated plants. Nematode density in untreated plant was 20 times more than in the NSP treated plants.

Results in outdoors tests were in agreement with those obtained in the screen house and were in conformity with the earlier reports of decreased infestations of *M. incognita* Chitwood and *Tylenchorhynchus brassicae* Siddiqi, following NC application in vegetables and legumes (Mishra *et al.*, 1989; Alam, 1991; Mojumder, 1995). GTZ (1996) also reported that NC application reduced to a considerable extent, the reproduction and population density of numerous insect and nematodes species. Also, Mehta (1997) reported the reduction of *Pratylenchus zeae* Graham infestation in sugarcane with NC application.

The present study demonstrated for the first time the effectiveness of NSP against *C. sordidus* and nematodes, *P. goodeyi* and *Meloidogyne* spp. attacking banana In addition, results suggest that with NSP or NC soil applications, the labour intensive practice of paring and hot water treatment of banana prior to planting could be avoided, leading to substantial time saving and money to the banana growers. In fact, the weevil damage was on a par with both unpared and pared suckers treated with NSP or NC. Complementary to that, unpared suckers treated with NSP or NC supported fewer nematodes compared to NSP or NC-pared-treated suckers. Equal control of *R. similis* was obtained with the use of banana suckers treated with NC alone and also its combination with paring and hot water treatment, thus agreeing with Ravichandra and Krishnappa, 1985 findings. On the other hand, no significant difference in the nematode density was observed in both unpared and pared banana suckers when they were treated with hot water or with Furadan. Mbwana (1992) reported similar findings. However, this is in contradiction with findings by Sheela *et al.* , (1996), who observed in India only a maximal *R. similis* reduction at 6 months after planting in NC-treated pared and hot water treated suckers. The contradiction might be due to differences in banana cultivars, aza content in the cake used and the experimental conditions.

The present finding that NC application caused a reduction in nematode population and in weevil damage, similar to that with Furadan 5G, concurs with similar observations by Mehta (1997) in which NC application reduced *P. zeae* population in sugarcane fields as effectively as with Furadan.

Eight months after incorporation into the soil, NSP or NC was still effective against nematodes, while the nematicidal activity of Furadan seemed to decline. This concurs with an earlier report by Davide (1992) indicating that Furadan 3G controlled *R. similis* for 3 months, but thereafter it's effectiveness gradually declined.

Dipping rhizomes of suckers in a nematicide solution is one way of disinfecting the planting material (Sarah 1989). In the present study, dipping suckers in 5% NO emulsion did reduce nematode populations, but NO treatment was phytotoxic to the banana plant. Charles (1995) also reported reduction of nematode population when suckers were dipped in NO at 0.1 or 0.2% for 10 min, but did not mention phytotoxicity. This could be attributed possibly to use of neem oil at low concentration.

The application of NKP was also toxic to the banana plant. In some cases, it caused the banana plants to dry up or the inflorescence to fail emerge "Chokethroat symptom" (Plate 4.1). In fact, being rich in oil, NKP may have interfered with water absorption and assimilation of nutrients by the banana plant.

In the present study, NSP- or NC-treated banana plants appeared much healthier than untreated control plants. The enhanced vigour of these plants may have been due to reduced weevil damage and nematode infestations, and possibly due to the nutritive value of NSP or NC. Neem cake is rich in organic matter (N, 5.5-7.1%; P, 1.1%; K, 1.5%) and has been used as a manure by farmers in India (Ketkar, 1976). Yield reduction expressed in bunch weight varied with different levels of pest infestation and inoculum. However, no significant correlation was found between plant growth and yield, weevil number and corm damage. Therefore, it can be inferred that relative increase in height, girth and biomass of banana plants associated with the application

Plate 4.1. "Chokethroat" symptom in a banana plant due to phytotoxicity caused by neem kernel powder treatment *(drum experiment)* at MPFS

of neem materials in an 8-month period could have been due to the manurial/ phytotonic effect of neem.

The high level of nematode density observed in the control plants in the present study indicates that sandy soils are ideal for parasitic nematode multiplication as reported by Sarah (1989) and Luc *et al.*, (1990). When banana plants were grown in sandy soil, NSP or NC treatment protected the plants against pests, resulting in increased plant biomass and a strong root system. This also explains differences in nematode population in plants grown in 100-*l* capacity drums without amendment and in plants receiving organic and mineral fertiliser.

Certainly one should not expect significant differences in plant growth or fruit yield in plants grown in drums. However, implications of this study are meaningful in the banana pest management and field trials could confirm the results obtained in this study.

CHAPTER FIVE

FIELD EFFICACY OF SELECTED NEEM SEED DERIVATIVES AGAINST *C. SORDIDUS* AND PARASITIC NEMATODES: METHODS, RATES AND FREQUENCY OF APPLICATION

5. 1. Introduction

The organophosphate and carbamate insecticides have been used successfully for the control of the banana weevil and nematodes (Mitchell, 1980; Treverrow *et al.*, 1991). However, reliance on synthetic pesticides for crop pest control has frequently resulted in insecticide resistance and resurgence of target pest populations, partly due to destruction of natural enemies (Lowery and Isman, 1995). This has lead to the search for alternative methods of pest control. Recently, much effort has been devoted to neem as an alternative to synthetic pesticides (Schmutterer, 1995). In the present study, efficacy of NSP and NC against the banana weevil and parasitic nematodes was demonstrated in screen house and outdoors tests (Chapter 4). The next objective was to confirm under field conditions the efficacy of selected neem materials and to determine the effective methods, frequency and rates of applications.

Pesticides can be applied directly to the soil surface or around the base of plants as dusts, granules, dry powders, fumigants and soil drenching Aqueous extracts are applied by spraying, especially against pests attacking aerial parts of the plant, while powders are commonly applied into the soil against soil-inhabiting organisms.

The hypothesis was that soil amendment with powdered neem seed derivatives could be the most effective and practical method for the control of the banana weevil and parasitic nematodes.

The economic return of a pest control method would depend on the rate, the method, and the frequency of pesticide application (Sarah, 1990). Furadan has been used at 60g/plant twice or thrice a year, but it is still far too expensive for resource poor farmers. While neem derivatives could be potential substitutes for pesticides, little information exists on the effective rates and frequency of its applications. Nair (1981) used NC at 400g/banana plant at planting and again after 4 months. Mojumder (1995) recommended NC application at 100-120 kg/ha for the control of plant parasitic nematodes. Nevertheless, no information exists on the rate of NSP application. Findings in Chapter 4 showed that both NKP and NO were toxic to the banana plants. Consequently, they were excluded from further tests. Determination of methods, rates and frequency of applications was therefore confined to NSP and NC. Furadan was included for comparison as an insecticide-nematicide (Mitchell, 1980) standard positive check. Efficacy of NSP and NC applications on fruit yield and economic analysis is discussed in Chapter 6.

5. 2. Materials and Methods

5. 2. 1. Methods of application

Application of aqueous neem products (soil drench) was compared with direct soil application of NSP or NC against banana weevil and nematodes in a screen-house. Methods were the same as in section 4. 2. 1. The square root transformation of pest infestation and damage data was performed. Means were grouped following SNK test.

5. 2 .2. Frequency of application

The experiment was conducted outdoors in 100-*l* capacity drums (40 x 55 cm) containing soil mixed with ~5 kg of composted farm manure, into which unpared suckers were planted. NSP was incorporated at 100 g/drum into the soil around the base of plants at planting time and then at 1-, 2-, 3-, 4-, 5-, and 6-month-intervals. Seven treatments, including the untreated control, were replicated 5 times in a completely randomized design. Each drum constituted a replicate. Forty days after planting, each plant was infested with 5 pairs of newly emerged female and male banana weevils and with a mixed population of nematodes (>90% *P. goodeyi*) by pouring a suspension of 2000 nematodes into the soil around the plant. Each drum was covered with a mosquito net at the base of the plant to keep weevils in the drum. Plant height, girth and the population of nematodes were recorded at 3-month-intervals. Twelve months after planting, banana plants were uprooted from the respective drums and for each treatment, the number, and the vigour of suckers were recorded on a 1 to 4 scale (1 = peeper sucker, i.e. just emerged above the ground; 2 = sucker with lanceolate leaves; 3 = 50-75 cm tall sucker with large leaves; 4 = ~100 cm tall sucker with large leaves). Nematode damage, i.e. root necrosis index, was scored on a 0-4 scale (section 2.7. of General Materials and Methods) and root density on a 0-5 scale (0 = absence of roots, 1 = few roots, 5 = abundant roots in the corm). The nematode population/100g roots, number of weevils, weevil damage (PCI), and the plant biomass weight were recorded.

5. 2. 3. Rates of application

After land preparation, the field at MPFS and farmers' fields at Oyugis and Kabondo were planted with unpared suckers of 'Nakyetengu' at 3 x 3 m spacing in April 1997. Suckers were collected from nematode- and weevil-infested fields. The physical structure, organic matter of soil and initial pest's infestation level in the three fields is described in Section 2. 1. of the General Materials and Methods.

At Oyugis and Kabondo fields, nine treatments comprising NSP and NC applications at 60, 80 or 100g/mat, Furadan at 60g/mat, and NC at 30g +Furadan at 30g/mat, and the untreated control were laid out in completely randomized blocks replicated 4 times. The rates of neem materials application considered the recommended doses of Furadan (synthetic insecticide-nematicide). NSP, NC or NC+Furadan was applied at planting then at 4-month intervals. Furadan alone was applied at planting and then at 6-month intervals.

Neem materials at higher rates (200-400 g/mat) were not tested in farmers' fields as they could be phytotoxic and cause fruit loss. They were, however, tested at research station at MPFS. NSP and NC were applied at 200, 300 or 400 g/mat at planting and thereafter every 6 months. Each treatment was replicated 3 times in randomized block design. Each planting hole received ~10 kg of composted farm manure. Pest infestation was determined regularly *i.e.* 2-3 weeks before and after treatment. Banana weevils were trapped (section 2.5), counted and removed from the field. Nematodes were extracted from the roots and population density/100g of root determined for each treatment, as in section 2.7 of General Materials and Methods.

The crop was managed as described in Section 2. 3 of the General Materials and

Methods. Suckers uprooted at flowering at Kabondo were weighed and nematode population in sucker roots determined. Percentage of established and flowered plants, plant height and girth, outer and inner PCI, bunch weight and number of fingers from all plants were recorded for the three sites. Data on plant growth (height, girth) was transformed to square roots before ANOVA was done. Logarithmic transformation was done on data on nematode population and weevil damage prior to ANOVA.

5. 3. Results

5. 3. 1. Methods of application

Results presented in Table 5. 1. show that weevil damage (PCI) was reduced equally by both soil-drenching and by the application of NSP and NC powder. Weevil damage was significantly less in neem treated plants than in the control.

Application of NSP and NC powder resulted in lowest PCI followed by application of NSP and NC aqueous solutions that was on a par with Furadan., Although, the nematode damage (necrosis index) did not differ among treatments, nematode population significantly decreased with NSP or NC applications around the base of the plant. NSP and NC powder treated plants had the lowest nematode density followec by NSP and NC aqueous solutions and Furadan application. The untreated contro had significantly the highest nematode population.

5. 3. 2. Frequency of application

Compared with the control, NSP significantly reduced damage by weevils an nematode population regardless of the frequency of application (Table 5.2). Howevei the lowest nematode populations were recorded when NSP was applied once in 1, 2, and 4 months. Although the weevil adult density did not differ among treatment larval damage was more when NSP was applied once in 5- or once in 6 months (Table 5. 2). Similarly, monthly application of NSP resulted in significantly taller plants with greater girth. Others parameters such as number of suckers, weevil infestation and plant biomass did not differ among the neem treatments (Tables 5.2 & 5. 3). Increased frequency of NSP application tended to increase the plant biomass, root density and vigour of suckers (Table 5.3 & Plate 5.1). The nematode population increased with time regardless of the frequency of NSP application (Fig. 5. 1). However, when NSP was applied once in one, two, three and four 4 months, the nematode population was significantly less than when applied once in five and six months and in the control where no NSP was applied.

5. 3. 3. Rates of application

Table 5. 4 shows the percentage of established and flowered plants at Oyugis. Eighty to 90% of neem-treated and 60% of control suckers got established.

Table 5.5 shows the percentage of flowered plants at MPFS. All plants in this area and at Kabondo were established one month after planting. Some plants treated with NSP or NC at high rates dried up before fruiting possibly because of phytotoxicity and flooding. Also, some of the control plants died as a result of flooding.

Within the same site, plant height, girth, number of suckers at flowering, weevil population and crop cycle did not significantly differ among the treatments during the first crop (Tables 5.5 & 5.6). Although there was no interaction effect between plant growth stage and treatments, a linear correlation between the plant height and girth increase was observed over the 12-month period (Figs. 5. 2 & 5. 3). The crop cycle at Kabondo and MPFS lasted ~12 months and more than 17 months at Oyugis.

Table 5.1. Comparative effect of application of powdered neem seed (NSP) or cake (NC) and soil drench application of NSP or NC on the control of banana weevil and nematodes in the screen house at MPFS.

Treatment/plant	Necrosis index (0-4)	Nematodes (no.)/100g root	PCI (%)
NSP 15g	0.2±0.2	705±298a	0.7±0.5a
NSP extract 5%	0.2±0.2	9950±1575c	2.2±0.6ab
NC 15g	0.2±0.2	3000±775b	1.2±0.5a
NC extract 5%	0.2±0.2	8100±574c	2.7±0.8ab
Furadan 5g	0.0±0.0	9300±1024c	1.0±0.7a
Untreated (control)	1.2±0.5	16800±1766d	5.0±1.1b
P>F	0.075	0.0001	0.0009
Significance	NS	***	***

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 4 replicates.

NS: Not significant; ***: significant ($P<0.001$)

Table 5. 2. Frequency of application of neem seed powder (NSP) and its effect on nematode root damage, nematode population, weevil density and damage to 'Nakyetengu" banana, at 12 months after planting in drums at MPFS

Treatment	Necrosis index (0-4)	Nematodes (no.)/100g roots	Weevils (no.)/drum	PCI inner %)	PCI Outer (%)
Once a month	1.8±0.7ab	888±168a	2.2±0.3	7.0±2.3a	10±4.4a
Once 2 months	1.4±0.5a	2592±488a	3.1±1.2	6.2±2.7a	10±3.2a
Once 3 months	1.2±0.3a	1896±252a	2.3±0.9	6.4±1.9a	12±3.7a
Once 4 months	2.4±1.2ab	2880±558a	2.1±1.1	5.6±2.6a	11±4.1a
Once 5 months	2.6±1.8ab	6036±854b	2.0±0.8	20±4.8ab	20±9.4abc
Once 6 months	3.0±2.5b	7428±1322b	2.1±1.2	21±11ab	33±11.7bc
Control	3.2±2.1b	13558±1238c	3.2±2.2	31±13b	52±16.3c
P>F	0.0004	0.0001	0.531	0.057	0.0006
Significance	***	***	NS	*	***

Within columns means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 5 replicates.

NS: Not significant ; *, *** : significant ($P<0.05$) and ($P<0.001$), respectively

Table 5.3. Effects of frequency of application of neem seed powder (NSP) on plant height, girth, root density, sucker and biomass of banana plant grown in drums at 12 months after planting at MPFS

Treatment	Plant height (cm)	Plant girth (cm)	Root density (0-5)	Sucker (no.)	Sucker vigor (1-4)	Plant biomass (kg)
Once a month	110±5a	43±1.5a	4±0.3a	3.2±1.1	4. 0±0.2a	15.2±6.1ab
Once in 2 months	97±3.2ab	39±1.1a	4±0.3a	3.4±0.9	4. 0±0.1a	16. 9±7.9a
Once in 3 months	105±6.4ab	38±2.5ab	3.8±0.4ab	3.4±0.8	4. 0±0.2a	15.3±5.2ab
Once in 4 months	96±2.3ab	36±2.2ab	3.8±1ab	2.9±1.2	3.0 ±0.7ab	15.1±7.1ab
Once in 5 months	95±2.5ab	37±1.9ab	3.4 ±1.5bc	2.4±1.7	3. 2±0.3ab	13.4±4.1ab
Once in 6 months	87±5.3b	33±1.3b	2. 6±1.9bc	3.8±0.9	2. 6±0.4b	11.7±6.1ab
Untreated-control	89±5.1b	31±1.4b	2. 4±2.0bc	2.2±1.2	2. 0±0.2b	8.3±4.2b
P>F	0.014	0.0022	0.0001	0.253	0.001	0.029
Significance	**	***	***	NS	***	*

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Tukey's test. Average of 5 replicates.

NS: Not significant; *, ** , ***: significant ($P<0.05$), ($P<0.01$) and ($P<0.001$) respectively

Plate 5.1. Comparison between root system and vigour of suckers of 12-month-old untreated (control) and neem-treated banana plants grown in drums in which neem seed powder was applied at 4-month intervals

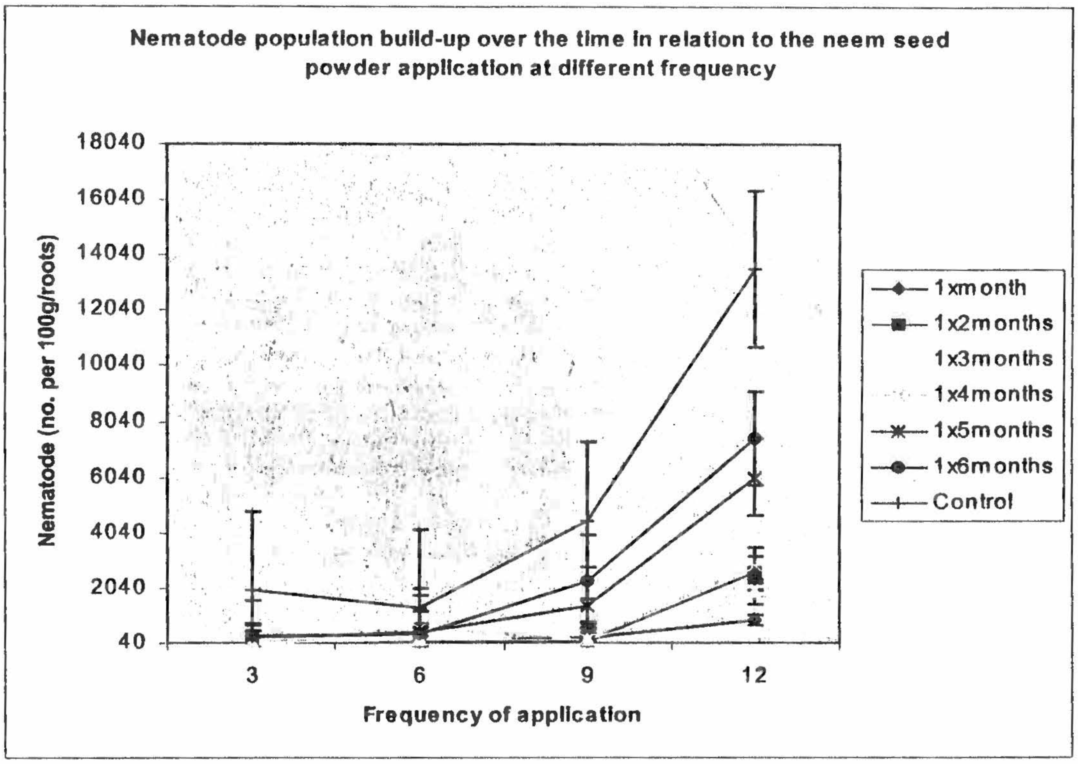


Fig. 5. 1. Effect of frequency of application of neem seed powder (NSP) on nematode population build up at 3, 6, 9, and 12 months after planting banana in drums at MPFS

Generally, at each rate of the application of NSP or NC, nematode damage and density and weevil damage were significantly less than in the untreated control, but did not differ among the neem treatments. However, pest infestation and damage differed at Kabondo, Oyugis, and MPFS (Tables 5.7 - 5.10). Compared with untreated controls, nematodes caused much less damage in the neem-treated plants (Table 5.10). Also, depending on the rate of application, nematode density decreased by 47-93% at Oyugis and 88-97% at Kabondo in neem-treated plants.

Table 5. 4. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan on the banana plant establishment and crop cycle in a field heavily infested with banana weevil and nematodes at Oyugis

Treatment (g/mat)	Percent of plant established 1 month after planting	Percent of flowered Plant	Crop cycle (days to harvest)
NSP 60	83.5±9.5	75.0±6.0	534±30
NSP 80	91.7±8.2	91.7±8.2	543±32
NSP 100	91.7±8.2	91.7±8.2	485±11
NC 60	83.5±9.5	66.5±19.3	542±26
NC 80	91.7±8.2	91.7±13.6	509±24
NC 100	91.7±8.2	91.7±8.2	542±22
Furadan 60	91.7±8.2	75.0±16.0	515±18
NC+Furadan 30:30	100.0±0.0	75.2±16.0	540±22
Control-untreated	66.7±13.6	33.0±0.0	541±45
P>F	0.3805	0.233	0.8032
Significance	NS	NS	NS

NS: Not significant different (P<0.05) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

Table 5.5. Effects of neem seed powder (NSP) or cake (NC) at high rates of application (200, 300 and 400 g/plant) on banana plant growth at flowering at MPFS (1st crop)

Treatment (g/mat)	Plant flowered (%)	Height (cm)	Girth (cm)	Sucker (no.)
NSP 200	100±0.0	181±13	60±4	2.0±4.0
NSP 300	33±0.0	179±0.0	59±3	2.5±0.0
NSP 400	55±22	161±12	52±6	0.6±0.6
NC 200	78±11	149±17	51±4	2.0±0.5
NC 300	78±22	160±10	56±3	1.3±0.6
NC 400	67±0.0	185±0.0	60±0	1.0±0.0
Control	17±17	111±15	44±2	1.0±1.0
P>F	0.23	0.123	0.384	0.530
Significance	NS	NS	NS	NS

NS: not significant different *(P*<0.05) by Student-Neuman-Keuls test. Average of 3 replicates and 12 plants per treatment.

Table 5.6. Effects of application neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan on plant growth at flowering and crop cycle of banana plants grown at Kabondo (1st crop)

Treatment (g/mat)	Plant height (cm)	Plant girth (cm)	Sucker (no./plant)	Crop cycle (days)
NSP 60	234±6.6	64.7±1.8	2.0±0.3	365±17
NSP 80	235±10.3	63.5±4.7	2.5±0.7	377±21
NSP 100	236±6.6	64.2±5.1	2.5±0.6	369±27
NC 60	234±12.0	65.5±3.0	2.5±0.7	361±19
NC 80	238±6.0	66.5±1.2	2.2±0.9	370±15
NC 100	232±19.0	67.2±3.9	2.5±0.3	378±22
Furadan 60	229±7.9	65.2±1.7	2.5±0.3	356±14
NC+Furadan 30:30	234±15.6	66.2±3.7	2.2±0.4	379±19
Control	235±15.4	65.5±5.2	2.3±0.3	376±17
P>F	0.127	0.562	0.741	0.357
Significance	NS	NS	NS	NS

NS: not significant different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

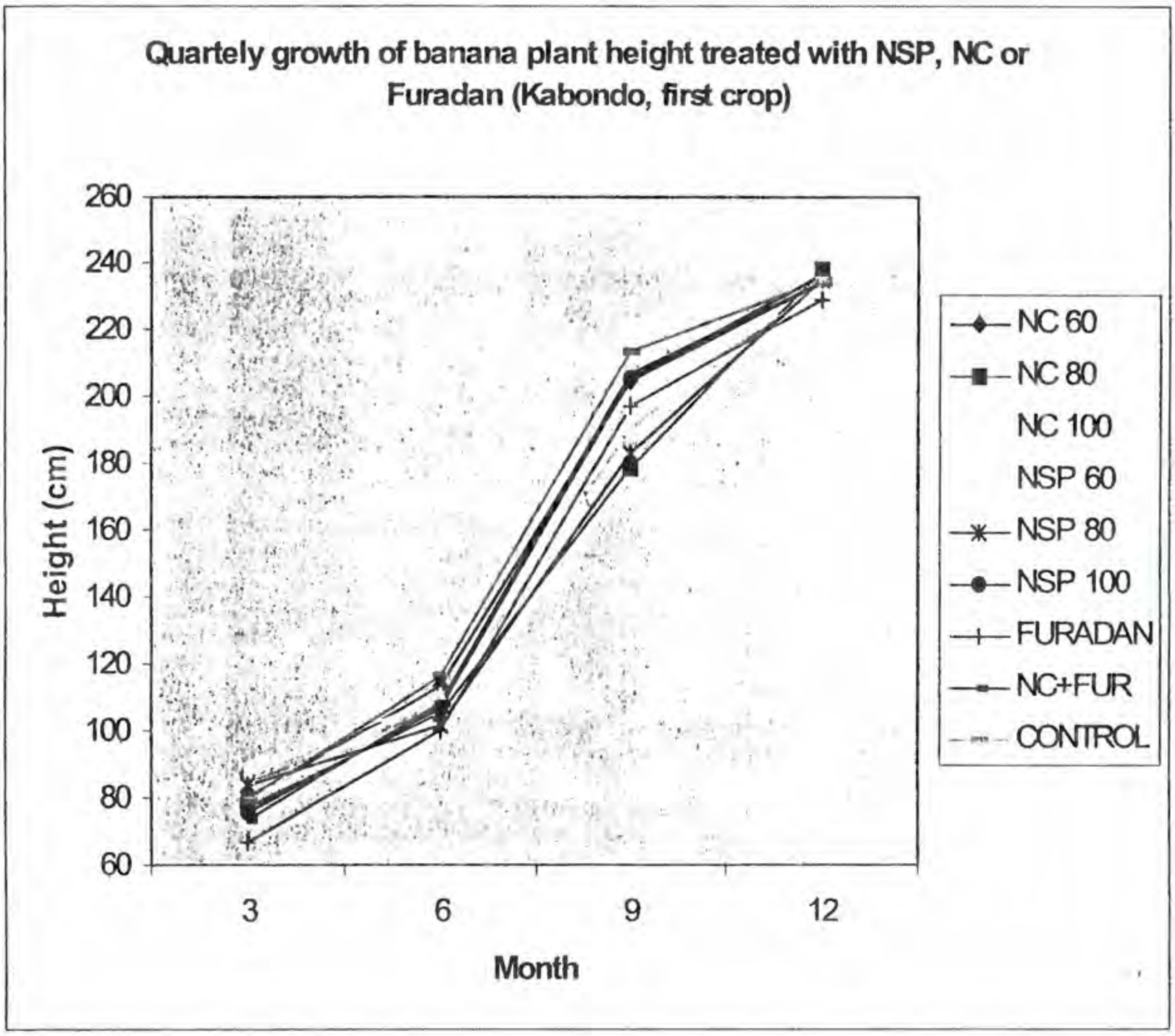


Fig. 5. 2. Quarterly growth of the banana plant height treated with neem seed powder (NSP), cake (NC), Furadan or NC+Furadan at Kabondo (1st crop)

NC+FUR= NC+ Furadan (30:30)

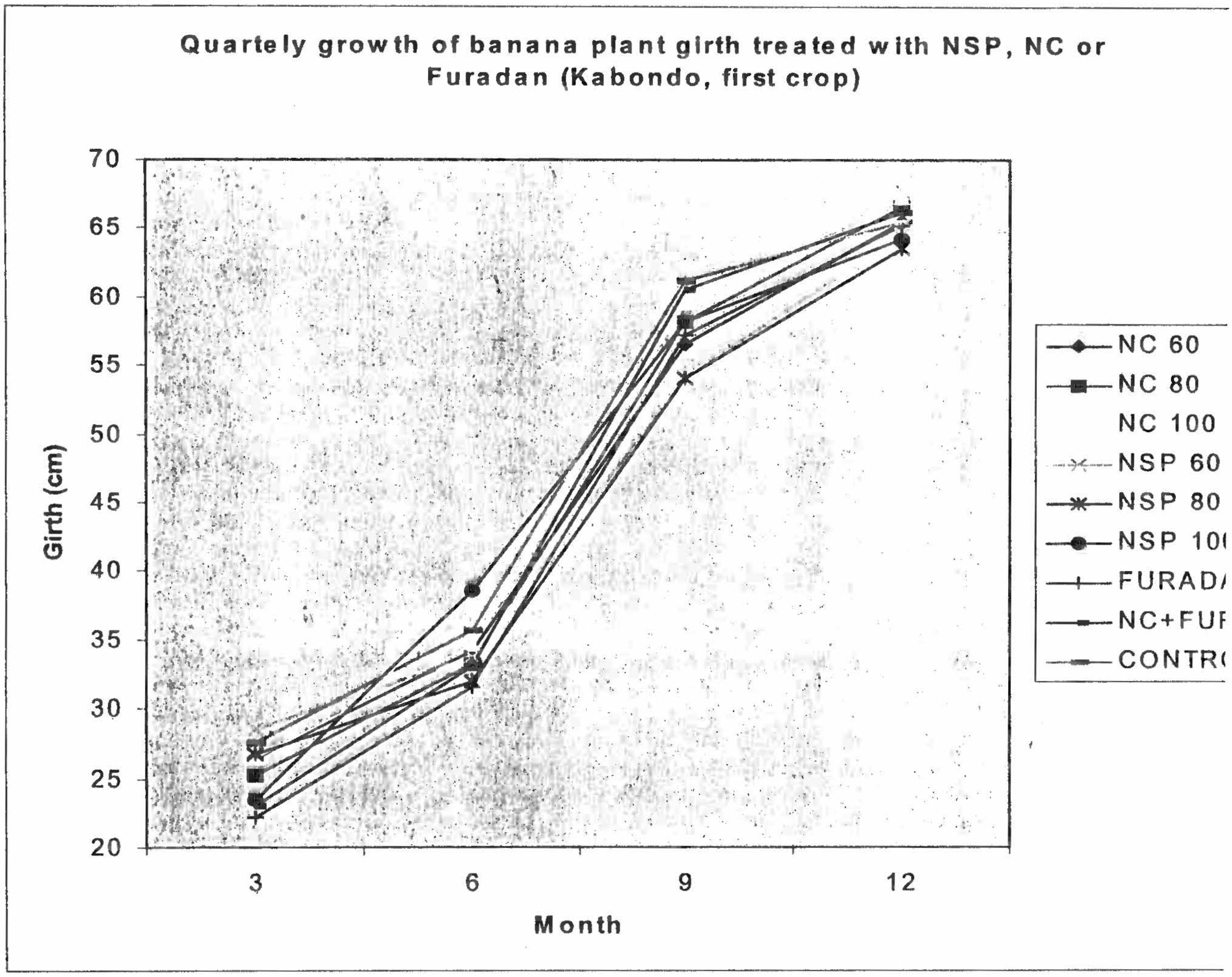


Fig. 5.3. Quarterly growth of the banana plant girth treated with neem seed powder (NSP), cake (NC), Furadan or NC+Furadan at Kabondo (1st crop)

NC+FUR= NC+ Furadan (30:30)

Table 5.7. Effects of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan application to the soil at different rates on nematode population, nematode damage, weevil density and damage in banana plants grown at Kabondo (1st crop)

Treatment (g/mat)	Necrosis index (0-4)	Nematodes (no.)/100g root	Weevils (no.)/plot	PCI inner (%)	PCI outer (%)
NSP 60	0.0±0.0a	1860±862a	3.5±3.6	0.8±0.3a	0.1±1.6a
NSP 80	0.3±0.1a	780±409a	1.7±2.8	0.0±0.0a	0.8±0.6a
NSP 100	0.1±0.1a	1920±999a	2.0±2.4	0.0±0.0a	0.1±0.1a
NC 60	0.6±0.3ab	1440±391a	2.7±3.5	0.5±0.4a	2.0±1.2a
NC 80	0.2±0.1a	580±145a	5.0±1.6	0.0±0.0a	0.5±0.4a
NC 100	0.2±0.1a	1860±716a	1.7±1.5	0.0±0.0a	0.1±0.1a
Furadan 60	0.5±0.1a	1080±634a	1.7±1.7	0.5±0.2a	2.8±1.3a
NC+Furadan 30:30	0.3±0.1ab	720±1064a	0.2±0.5	0.8±0.5a	4.3±1.4a
Control	1.1±0.5b	16680±2910b	2.7±0.9	4.5±2.0b	12 ±3.3b
P>F	0.0234	0.0001	0.749	0.043	0.0013
Significance	*	***	NS	*	***

Within columns means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment. NS: Not significant; *, **, ***: significant ($P<0.05$), ($P<0.01$) and ($P<0.001$) respectively.

Table 5.8. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on nematode and weevil infestation and damage at Oyugis (1st crop)

Treatment g/mat	Necrosis index (0-4)	Nematodes (no.) /100g roots	Weevils (no.)/plot	PCI inner (%)	PCI outer (%)
NSP 60	1.3±0.6a	4200±600ab	3±0.7	1.7±1.1ab	4.5±1.4ab
NSP 80	1.4±0.9a	12300±754c	3±0.7	1.0±1.0ab	2.5±1.6a
NSP 100	1.8±0.2a	2100±574a	3±0.4	0.2±0.2ab	1.0±0.7a
NC 60	1.4±0.7a	8200±295bc	3±0.7	1.7±0.7ab	4.5±1.9ab
NC 80	1.5±0.4a	9600±979bc	3±0.5	1.5±1.1ab	4.2±2.6ab
NC 100	1.0±0.0a	13150±2275c	4±0.5	0.0±0.0a	0.7±0.4a
Furadan 60	1.0±0.3a	13300±1300c	2±0.8	2.2±1.6ab	6.7±2.9ab
NC+Furadan 30:30	1.2±0.2a	9600±979bc	2±0.4	5.0±3.3ab	12.±4.9ab
Control	2.7±0.4b	31200±2019d	3±0.7	7.5±1.8b	26±13.2b
P>F Significance	0.015 **	0.0001 ***	0.62 NS	0.03 *	0.006 **

Within columns means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NS: Not significant; *, **, ***: significant ($P<0.05$), ($P<0.01$) and ($P<0.001$) respectively

Table 5.9. Effects of application of neem seed powder (NSP) or cake (NC) at high rates of 200, 300, or 400 g/plant on *C. sordidus* and nematode infestation and damage to banana plant at MPFS (1st crop)

Treatment (g/mat)	Necrosis index (0-4)	Nematodes (no.)/100g roots	Weevils (no.)/plot	PCI inner (%)	PCI outer (%)
NSP 200	2.1±1.7a	2800±800bc	3±1.5	8.0±3.0ab	14±1.0ab
NSP 300	1.2±0.9a	480±120a	4±0.9	7.0±0.0ab	15±0.0ab
NSP 400	0.7±0.2a	1200±346ab	3±1.9	1.3±0.8a	4±0.5a
NC 200	0.5±0.5a	4400±400c	4±0.6	7.3±2.3ab	11±2.3ab
NC 300	1.0±0.7a	5066±267c	5±1.4	4.0±2.0ab	8±2ab
NC 400	0.0±0.0a	3200±1058bc	3±0.7	0.0±0.8a	7±0ab
Control	3.2±1.3b	34666±705d	4±0.5	31 ±14.5b	48±27b
P>F	0.014	0.0001	0.504	0.019	0.042
Significance	**	***	NS	**	*

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 3 replicates and 12 plants per treatment.

NS: Not significant; *, **, ***: significant ($P<0.05$), ($P<0.01$) and ($P<0.001$) respectively.

Table 5.10. Effects of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan applied at different rates at Oyugis and Kabondo on nematode population reduction (1st crop)

Treatment (g/mat)	*Percent reduction in nematode population at	
	Kabondo	Oyugis
NSP 60	89	87
NSP 80	95	60
NSP 100	88	93
NC 60	91	74
NC 80	97	69
NC 100	89	58
Furadan 60	94	57
NC+ Furadan 30:30	96	69
Control (untreated)	0	0

* The percentage is calculated from Tables 5.7 & 5.8. as follows.

$100 - \frac{(\text{nematode in control} \times 100)}{X}$, where X = nematodes in the respective treatment

Application of NSP and NC to banana mats also significantly reduced the nematode infestation in the suckers but did not increase their biomass (Table 5.11). In general, there was no correlation between plant girth, height, nematode population and the number of trapped weevils at flowering stage. However, at Kabondo, there was a positive correlation (r = 0.9058) between plant height and girth , number of suckers and biomass (r = 0.7958), 12 months after planting (Table 5.12).

During the 1st crop cycle at Kabondo, there was no significant difference between fruit yield, fingers or hands of bunch for plants applied with NSP or NC at different rates (Table 5.13). However, application of NC at 60 g/mat and NSP at 80 g/mat yielded significantly heavier bunch than the control. Also, the application of NC at 80g/mat led to production of significantly more fingers per bunch.

Similar results were obtained at Oyugis. Fruit yields in NSP-treated and NC-treated plants were significantly greater than the control regardless of the rate of application; but there was no significant difference among the neem treatments (Table 5.14). Both, at Kabondo and Oyugis, Furadan alone or in combination with NC equally increased banana fruit yield on a par with neem the treatments (Tables 5.13 & 5.14). Fruit yields with application of NSP and NC at 100 g/mat were greater than that with NSP and NC at 60 or 80 g/mat. Fruit yield and number of fingers was significantly higher than that obtained in-control at MPFS, when NSP and NC were applied at more than 100 g per plant; but there was no significant difference among the neem treatments (Table 5. 15)

Table 5.11. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan on biomass of banana suckers and nematode density in plants grown at Kabondo (1st crop)

Treatment (g/mat)	Sucker biomass (g)	Nematodes (no.)/100g roots
NSP 60	7699±851	122±15.1a
NSP 80	14092±611	92±4.8a
NSP 100	8719±720	68±14.0a
NC 60	8850±409	235±24.1a
NC 80	9288±634	244±29.0a
NC 100	11733±879	112±8.8a
Furadan 60	9125±587	72±14.7a
NC+Furadan 30:30	5253±413	106±16.6a
Control	7481±529	1020±32.8b
P>F	0.0768	0.0134
Significance	NS	**

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NS: Not significant; **: significant ($P<0.01$)

Table 5.12. Correlation between growth parameters of suckers at Kabondo (1st crop)

Parameters	r
Number of sucker and height	0.4667 **
Number of sucker and girth	0.2896
Number of sucker and biomass	0.7958***
Number of sucker and root density	0.0971
Height and root density	0.0642
Height and biomass	0.37972
Height and girth	0.9058 ***

** = Significant different (*P*< 0.01)

*** = Significant different (*P*< 0.001)

Table 5.13. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on the banana fruit yield at Kabondo (1st crop)

Treatment (g/mat)	Hands (no.)/bunch	Fingers (no.)/ bunch	Fruit yield (kg/ha)
NSP 60	7.5±0.2	125.1±4.6ab	15391±784ab
NSP 80	7.5±0.2	126.0±4.9ab	18241±830a
NSP 100	6.8±0.2	114.5±4.8ab	14941±779ab
NC 60	7.8±0.4	126.3±7.6ab	18278±1040a
NC 80	7.8±0.3	129.6±5.2a	17765±890ab
NC 100	7.8±0.2	125.1±3.9ab	16821±749ab
Furadan 60	7.1±0.1	118.5±5.6ab	15400±789ab
NC+Furadan 30:30	7.3±0.2	116.3±4.0ab	15243±1307ab
Control	6.1±0.3	96.3±5.6b	12155±683b
P>F	0.075	0.045	0.0413
Significance	NS	*	*

Within columns, means followed by the same letter are not significantly different (P<0.05) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NS: Not significant; * : significant (P<0.05)

Table 5.14. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on banana yield under high banana pest infestation at Oyugis (1st crop)

Treatment (g/mat)	Hands (no.)/bunch	Fingers (no.)/bunch	Yield (kg/ha)
NSP 60	4.5±0.6	61±13.6	5957±2548ab
NSP 80	4.7±1.0	60±17.4	7537±2172ab
NSP 100	5.5±0.2	83±8.1	10903±1100a
NC 60	5.5±0.6	66±8.6	5957±2472ab
NC 80	4.0±0.4	45±5.3	3597±737b
NC 100	6.0±0.0	82±2.7	9152±885ab
Furadan 60	4.2±0.2	53±0.8	4987±742ab
NC+Furadan 30:30	4.2±0.4	57±9.1	5830±1323ab
Control	3.7±0.2	43±3.0	812±243c
P>F	0.064	0.0543	0.0005
Significance	NS	NS	***

Within columns means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment. NS: Not significant: ***: significant ($P<0.001$)

Table 5.15. Effects of application of neem seed powder (NSP) or cake (NC) at high rates of 200, 300 or 400 g/plant on the banana fruit yield, MPFS (1st crop)

Treatment (g/mat)	Hands (no.)/bunch	Fingers (no.)/ bunch	Yield (kg/ bunch)
NSP 200	6.0±0.0	93.5±6.5a	12850±2650a
NSP 300	6.0±0.0	101.0±0.0a	11100±0.0a
NSP 400	5.6±0.6	84.0±18.2a	10164±1922a
NC 200	4.6±1.2	68.6±19.5a	7667±3179a
NC 300	5.3±0.3	79.3±11.7a	9233±1876a
NC 400	4.0±0.0	50.0±0.0a	6500±0.0a
Control	4.5±0.5	26.0±6.0b	4250±750b
P>F	0.705	0.0213	0.0145
Significance	NS	*	**

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 3 replicates and 12 plants per treatment.

NS: Not significant: *, ** :significant ($P<0.05$) and ($P<0.01$) respectively

Compared with the 1st crop, during the 2nd crop cycle, roots from the neem-treated plants were less damaged by nematodes (necrosis index <1). Also neem application continued to maintain the nematode population well below the economic threshold level, while nematode population continued to build up in the untreated plants (Table 5.16). The nematode population was significantly higher in the Furadan-treated plants than in plants treated with the combination of NC+ Furadan. Plants treated with NSP or NC at various rates supported significantly less nematode numbers than in the control, but the neem treatments did not differ among themselves.

The number of trapped weevils during the 2nd crop (~1/plant) as well as larval damage (<3%) continued to be low among the various neem treatments (Table 5.16). However, significant differences were observed in some treatments. Larval feeding activity in the interior of corms (PCI inner) was nil in the neem- and Furadan-treated plants. In contrast, the peripheral damage to corm (PCI outer) was significantly less in the neem-treated plants than in the control. Plants treated with NSP at 60 or 100g/mat or with NC at 80g/mat were totally free from larval damage (PCI = 0). Consequently, the neem-treated plants and suckers were much healthier and had deep-green leaves. The number of suckers, plant girth and crop cycle significantly differed among treatments (Table 5.17). Compared with the 1st crop, a relative increase in plant height and girth was observed in the 2nd crop (Fig. 5.4).

Compared with the yield obtained in the 1st crop, fruit yield in the 2nd crop was higher in all the treatments, except in the Furadan-treated plants (Tables 5.18 & 5.19).

Table 5.16. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on pest infestation and damage of banana at Kabondo (2nd crop)

Treatment (g/mat)	Necrosis Index (0-4)	Nematode (no.)/100g roots	Weevils (no.)/plant	PCI outer (%)
NSP 60	0.3±0.2ab	3533±333ab	3.0±0.6b	0.0±0.0a
NSP 80	0.0±0.0a	2667±675a	0.2±0.2a	0.7±0.7a
NSP 100	0.0±0.0a	1800±268a	0.8±0.5ab	0.0±0.0a
NC 60	0.0±0.0a	2233±167a	1.8±0.6ab	0.2±0.2a
NC 80	0.5±0.2ab	4733±949ab	2.1±0.9ab	0.0±0.0a
NC 100	0.0±0.0a	3530±313ab	1.0±0.4ab	2.3±1.5ab
Furadan 60	0.8±0.3ab	7273±219b	0.5±0.2a	3.0±1.0ab
NC+Furadan 30:30	0.3±0.2ab	2800±252a	0.5±0.5a	1.2±0.7a
Control	1.1±0.4b	29533±1574c	0.3±0.3a	5.6±2.0b
P>F	0.011	0.0001	0.043	0.0033
Significance	**	***	*	**

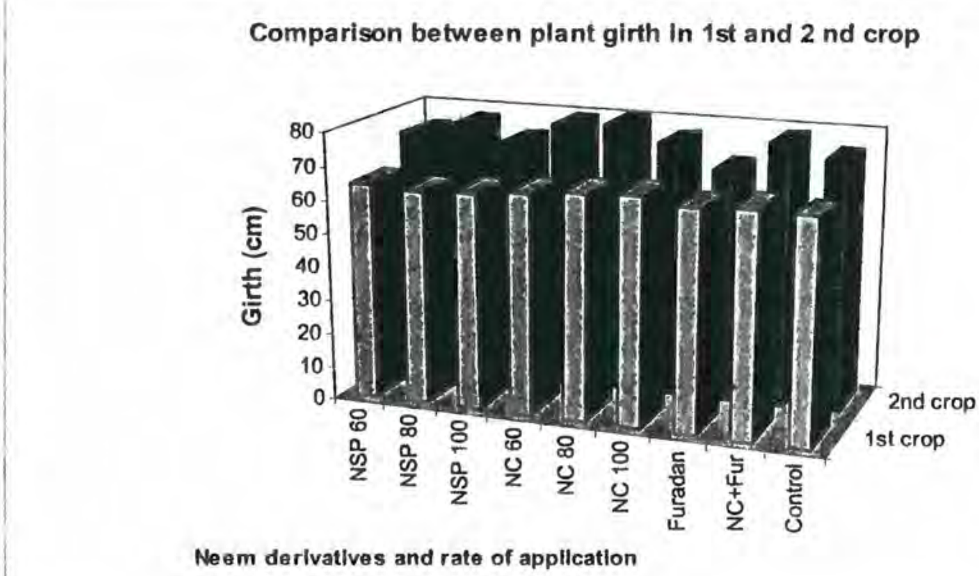
Within columns, means followed by the same letter are not significantly different (*P*<0.05) by Student-Neuman-Keuls Test. Average of 4 replicates and 16 plants per treatment. NS: Not significant; *, **, ***: significant (*P*<0.05),(*P*<0.01) and (*P*<0.001), respectively

Table 5.17. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on growth of banana plants grown at Kabondo (2nd crop)

Treatment (g/mat)	Plant height (cm)	Plant girth (cm)	Suckers (no.)/plant	Crop cycle (days)
NSP 60	268±6	74±1.9ab	3.3±0.5a	541±12ab
NSP 80	278±5	77±1.9a	3.3±0.6a	531±7.5ab
NSP 100	261±1	73±0.9ab	2.3±0.3ab	570±6.4b
NC 60	277±4	79±1.7a	2.8±0.4a	490±31a
NC 80	275±4	80±1.5a	3.3±0.3a	535±8.0ab
NC 100	261±7	76±1.8a	1.5±0.2b	569±9.0b
Furadan 60	262±4	69±0.9b	2.3±0.5ab	573±10.0b
NC+Furadan 30:30	277±3	78±0.7a	2.0±0.3ab	502±15.0a
Control	265±6	74±1.2ab	1.6±0.3b	543±6.0ab
P>F	0.067	0.005	0.0129	0.0005
Significance	NS	**	**	***

Within columns, means followed by the same letter are not significantly different (*P*<0.05) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NS: Not significant; **, ***: significant (*P*<0.01) and (*P*<0.001), respectively



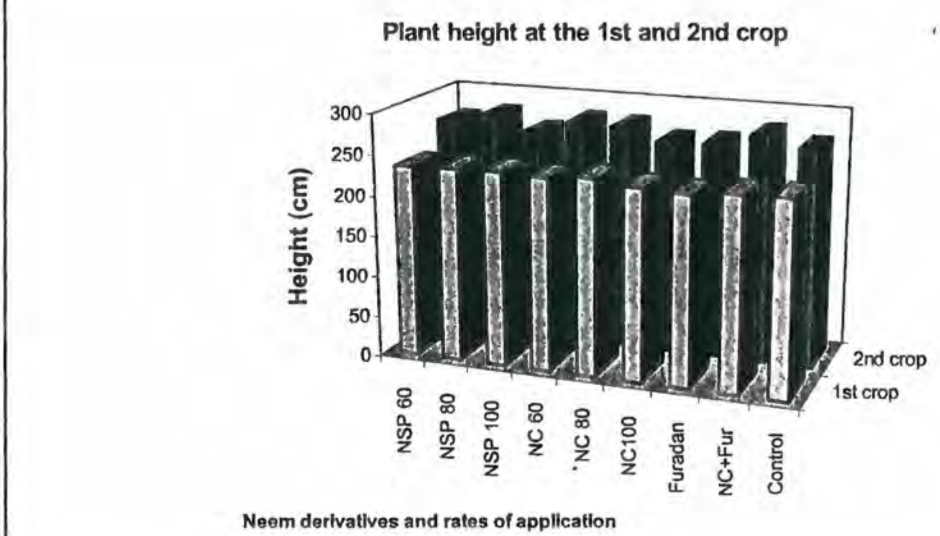


Fig. 5.4. Plant height and girth increase in the 2nd crop cycle following neem and Furadan treatments at Kabondo

Table 5.18. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan at different rates on the banana fruit yield at Kabondo (2nd crop)

Treatment (g/mat)	Hands (no.)/bunch	Fingers (no.)/bunch	Fruit yield (kg/ha)
NSP 60	7.2±0.7	116.1±13.8	19864±2142ab
NSP 80	8.3±0.2	141.0±2.5	24438±1565a
NSP 100	7.7±0.6	130.0±6.0	19873±2740ab
NC 60	8.0±0.2	133.3±5.7	24622±1270a
NC 80	8.7±0.4	149.3±7.7	26978±1789a
NC 100	7.3±0.3	108.8±10.6	18682±2142ab
Furadan 60	7.0±0.0	105.5±4.5	15070±550b
NC+Furadan 30:30	8.1±0.3	131.1±6.7	24017±764a
Control	7.4±0.4	116.0±13.7	15326±1907b
P>F	0.1077	0.0506	0.0023
Significance	NS	NS	**

Within columns, means followed by the same letter are not significantly different ($P<0.05$) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NS: Not significant; **: significant ($P<0.01$)

Table 5.19. Efficacy of neem seed powder (NSP), cake (NC), Furadan or combination of NC and Furadan application at 4 month-intervals on fruit yield (1st and 2nd crop) at Kabondo

Treatment	Fruit yield (Kg/ha)	
	First crop	Second crop
NSP 60	15391±1447ab	19864±2142ab
NSP 80	18241±1253a	24438±1565a
NSP 100	14941±1312ab	19873±2740ab
NC 60	18278±1134a	24622±1270a
NC 80	17765±1445ab	26978±1789a
NC 100	16821±1312ab	18682±2142ab
Furadan 60	15400 ±1008ab	15070±550b
NC+Furadan 30:30	15243±1290ab	24017±1764a
Control	12155±1467b	15326±1907b

Within columns, means followed by the same letter are not significantly different (P<0.05) by Student-Neuman-Keuls test. Average of 4 replicates and 16 plants per treatment.

NC+Furadan treatment produced bunches 1.5 times heavier during the 2nd crop than during the 1st crop. Data of the 2nd crop at Oyugis could not be analysed because control plants dried up due to high pest load. Likewise the 2nd crop data at MPFS could not be analysed as plants applied with neem treatments at high the rates died of phytotoxicity

5. 4. Discussion

The present study has demonstrated the superiority of soil application of NSP and NC over aqueous neem extracts against the banana weevil and nematodes. The use of extracts involves fetching of water, preparing the suspension and filtration. More labour and equipment are thus needed. In contrast, application of neem materials to the soil is simple and does not need extra equipment. NSP and NC are particularly attractive to use in areas where availability of water and spray equipment is limiting.

Viswanath and Channabasavanna (1981) also reported the superiority of direct application of granular insecticides over their emulsions against *C. sordidus*. Even for pests attacking leaves, Saxena *et al*.,(1984) reported that soil incorporation of NC or other neem derivatives in lowland rice is better than foliar application. Indeed, the neem powder decomposes slowly and therefore it remains effective much longer (Alam, 1993). Therefore, direct soil application of NSP or NC is advisable against the banana weevil and parasitic nematodes.

The efficacy of NSP application against the banana weevil and parasitic nematodes at various intervals has been demonstrated. Results suggest that the application of NSP once in 1, 2, 3 or 4 months equally controlled the banana pests. Therefore, NSP application once in 4 months *i.e.* thrice a year might have a practical and economic significance. Mathew *et al.*,(1996) reported a good control of the banana pseudostem borer, *Odioporus longicollus*, when they applied neem seed extract at monthly intervals. Such frequent application of neem materials is uneconomical. Little information exists on the frequency of application of neem materials, particularly for banana pest management, but it has been mentioned that residual effect of oil cakes in soil against nematodes affecting tomato lasts for 2-3 months (Siddiqui and Alam, 1991). This is in conformity with findings of the present study. Indeed, the efficacy of NSP application declined after 4 months and onward. Likewise, recommended synthetic pesticides are applied 2-3 times a year for controlling banana weevil and nematodes (Mitchell, 1980; Sarah *et al.*, 1988).

Regarding plant growth; results indicate that increase in plant growth and vigour might be seen from the 2nd crop cycle onward since banana is a perennial crop. After 12 months, enhanced vigour of suckers and increased density of roots and plant biomass tended to increase with frequency of neem application. Even 2 applications a year might be enough to keep the pests below the economic threshold level (ETL). Preferably, neem materials should be applied at the beginning and at the end of the rainy season.

Infested suckers are the principal source of weevil and nematode dispersal from place to place (Harris, 1947; Gowen, 1995), while the use of clean planting materials ensures good crop establishment (Feakin, 1971). Banana suckers used in the present study were obtained from the infested fields. Those suckers were not pared nor treated with hot water before planting as a prophylactic measure against the banana weevil and nematodes. Consequently, the relative low plant establishment observed at

Oyugis field could be attributed to the high initial pest population (~120000 nematodes/100 g of root and 6 weevil per trap). High levels of infestation in newly planted bananas can kill young shoots and prevent crop establishment (Mitchell, 1980). Nematode-infested banana suckers generally have fewer secondary and tertiary roots and die soon after planting (Davide, 1996). The situation can be exacerbated by poor soil fertility as observed at Oyugis. In contrast, NSP-, NC-and Furadan-treated banana suckers established well, indicating the value of application of NSP or NC in reducing the pest infestation. Banana plant establishment was maximal at Kabondo and MPFS, probably due to combined effect of neem, good soil fertility and moderate levels of initial pest infestation. Although, immigration by weevils can lead to high infestation and damage within a relatively short period (Speijer *et al.*, 1993), neem application proved an effective barrier to colonisation of banana fields, especially at Kabondo.

Compared with control the plants, NSP or NC significantly reduced the weevil damage and nematode population in all fields irrespective of rates of application. This confirms the findings in outdoors experiments reported in Chapter 4. It is likely that nematodes were inactivated or killed by neem derivatives. Subramanian and Selvaraj (1988) reported that application of root extracts of African marigold *Tagetes patula* inactivated and killed *R. similis*.

Control measures may not be needed immediately if pest infestation level is below ETL. In the present study, even application of NSP or NC at 60-100g/plant controlled the pests. However, at Kabondo, in some banana plants treated with NSP at 100g/mat, the inflorescence failed to emerge, possibly due to phytotoxicity. Application of NC did not show any adverse effects on the banana plants. Phytotoxic effect of NSP may dissipate with time and with the increase in plant biomass. This suggests that application of NSP at 80g/mat is preferable during the first crop and could be increased to 100g/mat in subsequent crops. The type of soil in which the crop is grown could also influence phytotoxicity. According to Sundaram *et al.*, (1995), the amount of absorbed azadirachtin varies with soil type and pH. In the present study, aza absorption was probably more at Kabondo (fertile soil; pH = 6) than at Oyugis (pH = 5.2). Application of NSP at 100g/plant was not toxic to banana plant in the less fertile field at Oyugis and led to higher fruit yield. However, application of NSP or NC at >100g/plant, though effective against pest damage, caused drying up in >50% of plants before or after fruiting. The 'chokethroat' symptom was frequently observed at flowering stage at MPFS in plants applied with NSP or NC at high rates. Also, flooding of the field at MPFS might have affected the plant growth. It is known that saturation and higher water tables adversely affect banana root growth and lower the fruit yield (Lassoudière and Martin-Prével, 1974). Phytotoxicity has also been reported in tomato plants applied with NC at high rates (IARI, 1993).

Generally, recommended rates of applications of neem materials for nematode control depend on the crop, pathogens and type of soil (Mojumder, 1995). In the present study, the rates of application of 60-100 kg/ha of NSP and NC found effective against banana pests were far lower than those (400-2000 kg NC/ha) recommended for pest control in other crops. In India, Reddy et *al.*, (1997) used NC at 400 kg/ha against *R. similis* in bananas. Sharma et *al.*, (1996) used NC at 1500 kg/ha against nematodes attacking tomato crop, while Ali (1995) used NC at 1000 kg/ha to control

M. javanica in greengram. Schmutterer and Hellpap (1989) reported that, in India, NC was applied at 1700 kg/ha against nematodes attacking chickpea. Likewise, NC at 400 kg/ha was used against *Heterodera cajani* in pigeonpea (Sobita, 1997). In rice, application of NC at 1000 kg/ha controlled the rice root nematode *Hirschmanniella* spp., while in sugarcane NC at 2000 kg /ha was effective against sugarcane nematodes (Jonathan and Pandiarajan, 1991). These reports did not mention the problem of phytotoxicity. The azadirachtin content varies with seed origin and the way the seed is crushed or processed (Saxena, 1989). NC used in the present study was high in azadirachtin content (5,800 ppm), that may not be the case in other studies. Further investigations will be helpful in determining the cause of phytotoxicity.

Little information exists on the use of NSP against the banana weevil and nematodes. In the present study, application of NSP reduced the damage caused by the weevil and nematodes to <25% in 'Nakyetengu,' a highly susceptible banana cultivar. Fogain (1996) reported that in susceptible cultivars root damage caused by nematodes exceeds 50%, while <5% in resistant cultivars. This indicates the efficacy of NSP in bananas against nematodes and weevil.

The efficacy of NSP or NC in bananas against nematodes is clearly validated in the present study. Control of bananas pests using neem seed derivatives was often accompanied with increased banana plant growth and vigour, particularly in the second crop, and could have rendered banana plants more tolerant of the damage by weevil and nematodes. Weevil and nematodes damage in neem treated plants even in untreated plants in the 2nd crop was lower than that in the 1st crop. This reduced damage even in the control was probably due to the prolonged effect of neem treatments. Weevils in the neem treated plots or those immigrating from the treated plots after being in contact with neem products to untreated plots were unable to multiply or to feed on untreated corms. This insect behaviour was demonstrated in the laboratory tests (Chapter 3). On the other hand, unless the inoculum is very high, one could not expect severe nematode damage in a 2-year old banana field. Severe nematode damage in banana was observed starting from 4 years after planting (Stanton, 1994).

In Chapter 4, it was also described that NSP and NC applications were as effective as Furadan in reducing the weevil damage and nematode population. In this study, Furadan applied at 30g/mat in combination with NC at 30g/mat was also as effective as Furadan at 60g/mat. These results are in conformity with similar other studies conducted against insect pests (Abdul Kareem et *al*., 1989). Alam (1993) also reported the effectiveness of neem powder against plant parasitic nematodes either singly or in combination with nematicides. However, it was found that the efficacy of Furadan against banana pests declined in the second crop at Kabondo. Davis *et al.*, (1993) also reported that carbofuran and other nematicides were inadequate for the long term control of banana nematodes and their frequent use could make them vulnerable to enhanced microbial degradation. This demonstrates the advantage of application of neem materials over synthetic insecticides

The crop cycle for the eastern African highland bananas is 12-18 months (Karamura and Karamura, 1995). The banana crop cycle at Oyugis was about 17 months that was 5 months longer than the crop cycle at Kabondo, indicating that the crop cycle is influenced by the pest infestation, which was higher at Oyugis. The banana plants treated with NSP or NC were harvested 27-56 days earlier than the untreated plants at Oyugis. This trend was also recorded at Kabondo in the second crop. This is in conformity with Gowen (1995) who also observed that nematicide-treated banana plants were harvested up to 30 days sooner than the untreated plants.

The use of neem seed derivatives against *C. sordidus* and banana parasitic nematodes could replace the synthetic pesticides once their economic benefits are demonstrated. The analysis is discused in the following chapter 6.

CHAPTER SIX

INCREASED BANANA FRUIT YIELD AND ECONOMIC BENEFIT OF NEEM APPLICATION IN BANANA PESTS MANAGEMENT

6. 1. Introduction

Pesticides are applied to control pests with expectation of increased yields, and thereby bring about economic gains to growers. Chemical control of banana weevil and nematodes is generally practiced in commercial plantations (Feakin, 1971) but seldom by small-scale farmers (Gowen, 1993; Speijer *et al.*, 1993; Bridge, 1996). Pest management studies indicate that application of insecticides and nematicides against *C. sordidus* and nematodes results in banana fruit yield increase (Kehé, 1988; Vilardebó *et al.*, 1988; Fogain, 1996). The present study has shown that the use of neem materials, such as powdered neem seed or cake is also effective against banana pests and results in increased fruit yield (Chapters 3-5). However, from a practical standpoint the use of neem materials, either alone or in combination with pesticides, should be cost-effective thereby minimize pest resistance problems (Chiu, 1989).

Therefore, a cost-benefit analysis was done in the present study using neem materials in comparison with the recommended pesticide Furadan.

6. 2. Materials and Methods

Yield data used for this analysis were collected from trials conducted at MPFS, Kabondo and Oyugis fields. Data for the 2nd crop were obtained only from

Kabondo site as control plants in trials at Oyugis and at MPFS dried-up before fruiting. Economic analysis was based on the cost of neem materials, cost of Furadan and its application, and the gain in fruit yield, as other crop management measures were common to all the treatments. Locally, per kilo, NSP is sold at KSh 60, NC at KSh 100, Furadan 5G at KSh 350, banana fruit at KSh 6 (US$ 1 = KSh 60). Neem or Furadan application requires 11 man-days per ha at KSh 100 per man-day. One hectare field has ~1100 banana plants at the spacing of 3 x 3 m.

6 . 3. Results

At Kabondo, during the 1st crop, application of NSP and NC at 60 to 100 g per plant significantly reduced the weevil damage and nematode density, resulting in increased fruit yield. Similar results were obtained with the application of Furadan alone or in combination with NC. The effectiveness of neem and Furadan treatments persisted even in the 2nd crop cycle and led to additional increases in fruit yield (Table 6.1, Plate 6.1). In the 2nd crop, the fruit yield from the plants treated with NC+Furadan was 1.6 times more than that from the Furadan-treated plants. However, the yield in Furadan treatment was 2% less than the yield in the control plants (Table 6.2).

The fruit yield increase in NSP-and NC-treated plants over the control, irrespective of the application rates, was from 23 to 50%. Heavier bunches were obtained when NC was applied at 60g/ mat. The yield improvement in the 2^{nd} crop ranged between 22 to 76%.

Table 6.1. Application of neem seed powder (NSP), cake (NC), Furadan or combination of NC+Furadan to banana plants against nematodes and weevils and its effect on the banana yield in a fertile soil at Kabondo during two cropping seasons*

Treatment (g/mat)	Nematodes (no.)/100g roots (1st crop)	Nematodes (no.)/100g roots (2nd crop)	PCI (%) 1st crop	PCI %) 2nd crop	Yield 1st crop (kg/ha)	Yield 2nd crop (kg/ha)
NSP 60	1860a	3533ab	0.1b	0.0a	15391ab	19864a
NSP 80	780a	2667a	0.8b	0.7a	18241a	24438a
NSP 100	1920a	1800a	0.1b	0.0a	14941ab	19873a
NC 60	1440a	2233a	2.0b	0.2a	18278a	24622a
NC 80	580a	4733ab	0.5b	0.0a	17765ab	26978a
NC 100	1860a	3530ab	0.1b	2.3ab	16821ab	18682a
Furadan 60	1080a	7273b	2.8b	3.0ab	15400ab	15070b
NC+Fur30:30	3720a	2800a	4.3b	1.2a	15243ab	24017a
Control	16680b	29533c	11.8a	5.6b	12155b	15326b

NC+FUR= NC+Furadan

Within columns, means followed by a same letter are not significantly different at $P<0.05$ level by SNK's Test; average of 4 replicates and 16 plants per treatment.

*Summary of Tables 5.7, 5.13, 5.16 & 5.18

Plate 6.1. Banana bunches harvested from neem-treated plants in farmers' fields at Kabondo *(top)* and at Oyugis *(bottom)* in western Kenya. Note the small size of bunches harvested from untreated (control) plants.

Table 6.2. Effects of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC+Furadan on the banana fruit yield from mother and following daughter plants in a fertile soil at Kabondo

Treatment (g/mat)	Yield in 1st crop		Yield in 2nd crop		Yield improvement after 2 crops (%)
	kg/ha	% over control	kg/ha	% over control	
NSP 60	15391	27	19864	30	29
NSP 80	18241	50	24438	59	34
NSP 100	14941	23	19873	30	33
NC 60	18278	50	24622	61	35
NC 80	17765	46	26978	76	52
NC 100	16821	38	18682	22	11
Furadan 60	15400	27	15070	-2	-2
NC+Fur 30:30	15243	25	24017	57	57
Control	12155	0	15326	0	26

NC+Fur = NC+Furadan

Compared with the yield obtained in the 1st crop, the yield increase in the 2nd crop ranged from 11 to 52 %. Heavier bunches were obtained with the application of NC at 80g per plant. Application of mixed NC+Furadan improved the yield up to 57%. In contrast, pest control efficacy of Furadan declined with a corresponding decline in fruit yield, which was less than 2% than in the control.

Tables 6.3- 6. 6 show the cost benefit of neem and Furadan application in a fertile soil with moderate pest infestation at Kabondo, in poor soil at Oyugis and in a good soil where high rates of neem derivatives were applied at MPFS. At Kabondo, cost: benefit analysis showed a net gain over the control when NSP and NC were applied at 80 g per plant in the 1st crop (Table 6.3). In some cases, the profit was even more than US$ 500 per ha in the 2nd crop. Application of NC+Furadan mixture gave a net gain over the control. Compared with the control, application of Furadan alone did not confer any benefit and, in fact, led to a loss of US$ 827 per ha (Table 6.4).

Likewise, at Oyugis, application of NSP or NC at 60-100 g per mat conferred economic gain, while use of Furadan led to a loss of US$ 622 per ha. Application of NC+Furadan mixture did not seem to confer any distinct yield benefit in the 1st crop (Table 6.5), but the treatment was beneficial in the 2nd crop. At MPFS, the application of NSP at 200 g per plant was the most economically beneficial treatment (Table 6.6).

Table 6.3. Analysis of cost-effectiveness of application of neem seed powder (NSP), cake (NC), Furadan or combination of NC+Furadan against the banana weevil and nematodes in bananas in a fertile soil at Kabondo (1st crop)

Treatment (g/plant)	Annual Aplication (no.)	Cost of Product ($/ha)[1]	Cost of Application ($/ha)[1]	Total Cost ($/ha)[1]	Yield kg/ha	Yield Value ($/ha)[1]	Net gain ($/ha)
NSP 60	4	264	72	336	15391	1539	1203
NSP 80	4	352	72	424	18241	1824	1400
NSP 100	4	440	72	512	14941	1494	982
NC 60	4	396	72	468	18270	1827	1359
NC 80	4	528	72	600	17765	1777	1177
NC 100	4	660	72	732	16821	1682	950
Furadan 60	3	1148	54	1202	15400	1540	338
NC+Furadan30:30	4	964	72	1036	15240	1524	488
Control	0	0	0	0	12155	1216	1216

[1]Approximate cost of a kilo of Furadan is US$ 5.8, NSP US$ 1, NC US$ 1.5. Cost of labour (11 man-days) for applying neem or Furadan is US$ 18 per ha; price of banana fruit US$ 0.1 per kg.

Table 6.4. Analysis of cost-effectiveness of neem seed powder (NSP), cake (NC), Furadan or combination of NC+Furadan application against the banana weevil and nematodes at Kabondo (2nd crop)

Treatment (g/plant)	Annual application (no.)	Cost of Product ($/ha)[1]	Cost of application ($/ha)[1]	Total cost ($/ha)[1]	Yield (kg/ha)	Yield Value ($/ha)[1]	Net gain ($/ha)
NSP 60	3	198	54	252	19864	1986	1734
NSP 80	3	264	54	318	24438	2444	2126
NSP 100	3	330	54	384	19873	1987	1603
NC 60	3	297	54	351	24622	2462	2111
NC 80	3	396	54	450	26978	2698	2248
NC 100	3	495	54	549	18682	1868	1319
Furadan 60	2	765	36	801	15070	1507	706
NC+Furadan 30:30	3	723	54	777	24017	2402	1625
Control	0	0	0	0	15326	1533	1533

[1]Approximate cost of a kilo of Furadan is US$ 5.8, NSP US$ 1, NC US$ 1.5. Cost of labour (11 man-days) for applying neem or Furadan is US$ 18 per her; price of banana fruit US$ 0.1 per kg.

Table 6.5. Analysis of cost-effectiveness of neem seed powder (NSP), cake (NC), Furadan or combination of NC+Furadan application against the banana weevil and nematodes in a poor soil at Oyugis (1st crop)

Treatment (g/plant)	Annual application (no.)	Cost of Product ($/ha)[1]	Cost of Application ($/ha)[1]	Total cost ($/ha)[1]	Yield (kg/ha)	Yield Value ($/ha)[1]	Net gain ($/ha)
NSP 60	4	264	72	336	5957	596	260
NSP 80	4	352	72	424	7537	754	330
NSP 100	4	440	72	512	10903	1090	578
NC 60	4	396	72	468	5957	596	128
NC 80	4	528	72	600	3597	360	-240
NC 100	4	660	72	732	9152	915	183
Furadan 60	3	1148	54	1202	4987	499	-703
NC+Furadan 30:30	4	964	72	1036	5830	583	-453
Control	0	0	0	0	812	81	81

[1]Approximate cost of a kilo of Furadan is US$ 5.8, NSP US$ 1, NC US$ 1.5. Cost of labour (11 man-days) for applying neem or Furadan is US$ 18 per ha; price of banana fruit US$ 0.1 per kg.

Table 6.6. Analysis of cost-effectiveness of neem seed powder (NSP) or cake (NC) applied at high rates against the banana weevil and nematodes at MPFS (1st crop)

Treatment (g/mat)	Annual application (no.)	Cost of Products ($/ha)[1]	Cost of Application ($/ha)[1]	Total cost ($/ha)[1]	Yield (kg/ha)	Yield Value ($/ha)[1]	Net Gain ($/ha)
NSP 200	2	440	36	476	14135	1414	938
NSP 300	2	660	36	696	6207	620	-76
NSP 400	2	880	36	916	6149	615	-301
NC 200	2	660	36	696	6578	658	-38
NC 300	2	990	36	1026	7921	792	-234
NC 400	2	1320	36	1356	4790	479	-877
Control	0	0	0	0	794	79	79

[1]Approximate cost of a kilo of NSP is US$ 1 and US$ 1.5 for NC. Cost of labour (11 man-days) for applying neem is US$ 18 per ha and the price of banana fruit US$ 0.1/ kg.

6. 4. Discussion

Higher fruit yields in banana are generally obtained as a result of vigorous vegetative plant growth (Quénéhervé, 1993), while weevil damage reduces the bunch size, causing yield loss (Rukazambuga, 1996). Babatola (1988) reported that application of carbofuran or Oxamyl in a 5-year-old plantain field significantly reduced the nematode population and led to yield increase.

The present study showed that neem application significantly decreased the pest population and damage and resulted in increased fruit yield. Soil fertility and good crop management might have contributed to the banana yield increase in trials conducted at Kabondo. Soil application of neem cake is known to improve the soil structure and hence plant growth (Ketkar, 1976; GTZ, 1996). Heavier bunches were obtained at Kabondo (fertile soil), and at MPFS where the soil was amended with cow dung manure at planting. Yield improvement at Kabondo was up to 50% in the 1^{st} and 76% in the 2^{nd} crop, while Furadan treatment improved yield only up to 27% in the 1st crop. Gowen (1993) reported that 30-40% yield improvement occurred with nematicide application in 2-year-old Cavendish (AAA). Depending on the soil type, yield improvement with nematicide application in Cavendish banana varied between 29-275%; being 275% in clay soil (Gowen, 1995).

Similarly, yield increases of more than 500% were also recorded in 'Nakyetengu' cultivar with neem application at Oyugis (clay-loam soil), whereas the control bunches weighed less than 2 kg per bunch. Under optimal conditions 'Nakyetengu' can produce bunches weighing between 15 to 20 kg per bunch. This was probably due to the high pest infestation and low soil fertility.

At Kabondo, after 2 years' period, under good soil fertility, highly promising net gain was achieved with neem application at 4-month intervals, *i.e.* 4 applications for the 1st crop and 3 applications during the 2nd crop. However, neem application to plants grown in poor soil at Oyugis and under extremely high pest load was uneconomical. Likewise, at MPFS, neem application became uneconomical as high doses were applied. In addition, the field got flooded due to heavy rains causing plants to dry up. Application of nematicides in poorly drained fields is usually uneconomical (Stover and Simmonds 1987).

Application of Furadan alone in the banana plantation did not improve the fruit yield. In contrast, its combination with NC improved the yield up to 57% in the 2nd crop at Kabondo. The net gain was much higher than that obtained with Furadan alone. Unlike NC whose efficacy is known to persist for longer duration, as it remained effective against plant parasitic nematode even in subsequent crop (Alam, 1993), Furadan was found ineffective after some time because it was broken down by soil microorganisms (Guzman *et al.*, 1994). This agrees with results obtained in the present study on the management of banana nematodes and weevil.

Similarly, the effect of mixing NC and Furadan has been demonstrated for other plant pests. Abdul Kareem *et al.*, (1989a) found that application of NC+Furadan or Furadan alone were equal and caused 96-100% mortality of leafhopper *Nephotettix* at a half of recommended doses. In India, the use of neem seed kernel extract against tobacco caterpillar was 5 times less expensive than any synthetic recommended insecticide (Lowery, 1992). Therefore, the use of neem offers an appropriate alternative to synthetic insecticides.

The cost of production, rates and frequency of neem derivative applications are parameters to consider in the economic analysis. Neem cake is obtained after oil has been expelled from seeds or kernels using oil expellers (Hellpap and Dreyer, 1995). Seed and kernel powder are obtained by manually pounding seeds or kernels with a large mortar and pestle. This makes seed powder inexpensive compared with cakes. Therefore, the annual application of NC at above 500 kg per ha as reported by Jonathan and Pandiarajan (1991), Ali (1995), Sharma *et al.*, (1996), will be probably economically unjustifiable.

The present study put a maximum of US $ 72 for buying neem materials. The total cost including the neem applications was US $ 600/ha. The figures approach those reported by GTZ (1996) which indicated that costs of seed alone for one treatment vary between US$ 5 and US $ 20 per hectare. Similarly, Davide (1994) reported that in the Philippines, about US $ 600 are annually spent for nematicides and their application in bananas per hectare.

The findings of the present study indicate that the yield losses in bananas due to weevil and nematode attack can be effectively and economically reduced by the soil application of NSP or NC at the rates of 60-100 g/ plant at 4 monthly-intervals. The combination of NC with synthetic insecticide is feasible, and may be cost effective and minimize pest resistance problems but the combination is still less advantageous than neem seed products alone.

CHAPTER SEVEN

GENERAL DISCUSSION, CONCLUSIONS AND POSSIBLE FUTURE AREAS OF RESEARCH

7. 1. General discussion and conclusions

It is obvious that the banana weevil and nematodes cause serious damage to banana plants worldwide, resulting in various degrees of fruit yield losses. Losses can be prevented by effective and sustainable pest control methods. Unfortunately, few advantageous banana pest management practices for the small-scale poor farmers so far have been developed. Banana cultivars resistant to *C. sordidus* and parasitic nematodes are limited. Although biotechnology has permitted the production of pest-free planting material (Israeli *et al.*, 1995), most farmers cannot afford the vitro plants and therefore continue to use infested suckers. Paring and hot water treatment of banana suckers before planting are tiresome. Weevil trapping is labour intensive (Allard *et al.*, 1993) and ineffective (Ostmark, 1974; Gold *et al.*, 1994). Effective pesticides are too expensive and hazardous to human health and the environment.

The present study clearly demonstrated repellent and feeding deterrent effects of neem materials against *C. sordidus* in the laboratory. Neem products also inhibited weevil oviposition, fecundity, egg hatchability and larval development. Powdered neem seed and cake applications controlled the weevils' build-up. Although similar results have been reported against other notorious insects, no such information existed before on the banana weevil.

Speculations on the behaviour and physiology of the banana parasitic nematodes in contact with neem, such as failure of nematodes to penetrate the roots, low motility, reduced oviposition and egg hatchability, and reduced feeding activity were made in the present study, but these need to be confirmed by further studies.

Results of the present study indicate that paring and hot water treatments of banana suckers prior to planting could be unnecessary with neem treatments. Application of NSP or NC at 60-100 g per plant significantly reduced the pest load and damage while applications NSP and NC at doses above 100 g per plant or NKP and oil were phytotoxic. Neem applications at planting and then at 4 month-intervals were the most advantageous. Neem application in a fertile soil under moderate banana pest infestation resulted in significant reduction of pests and in increased fruit yield.

Results obtained are consistent and support those obtained earlier by others with neem seed derivatives, specifically in the nematode control. Field trials with neem materials have shown not only a decrease in damage by pests but an increase in banana fruit yields when compared with the use of recommended synthetic insecticides. In brief, the mechanism of banana pest control using neem materials as described in the present study can be explained as follows: few weevil adults are attracted to the banana neem-treated plants. The settled weevils on the treated corms will lay few eggs and egg hatchabilility is drastically reduced. Therefore, less number of larvae will emerge from eggs. The emerged ones will be weak or deformed and unable to feed on the treated corms and eventually die. As a result, less damage will be done to the plant, healthier plants will be produced with subsequent yield increase (Fig. 7.1). Similarly, root nematode population will be significantly reduced as well as root damage, resulting in healthy and strong root system, normal plant growth and increased fruit yield. With continued neem applications at recommended intervals, it is expected that the pest will be reduced to its harmless level.

However, due to lack of banana tissue-cultured plantlets; suckers used throughout the study were not homogenous. Although randomization of experiments partially avoided biased results, the shortage of land for experiments was another constraint. Application of neem or Furadan at planting could be unnecessary with banana vitro-plantlets. This could well reduce the number of neem application from 4 to 3, as no preventive measures would then be needed. Consequently, the net gain could be higher than that reported in the present work.

Nematodes *Steinernema* spp. and *Heterorhabditis* spp. are capable of destroying the *C. sordidus* larvae (Treverrow *et al.*, 1991; Figueroa *et al.*, 1993; Peña *et al.*, 1993) and then can be used for the control. Twelve eggs predators of *C. sordidus* have been identified in the rhizophere of the banana root system in western Kenya (Koppenhöfer *et al.*,1992). The present study reported significant reduction of weevil damage and parasitic nematode density as a result of soil applications of NSP, NC or Furadan. One may think that soil application of neem may have some adverse effects on entomopathogenic nematodes or other soil inhabiting beneficial organisms.

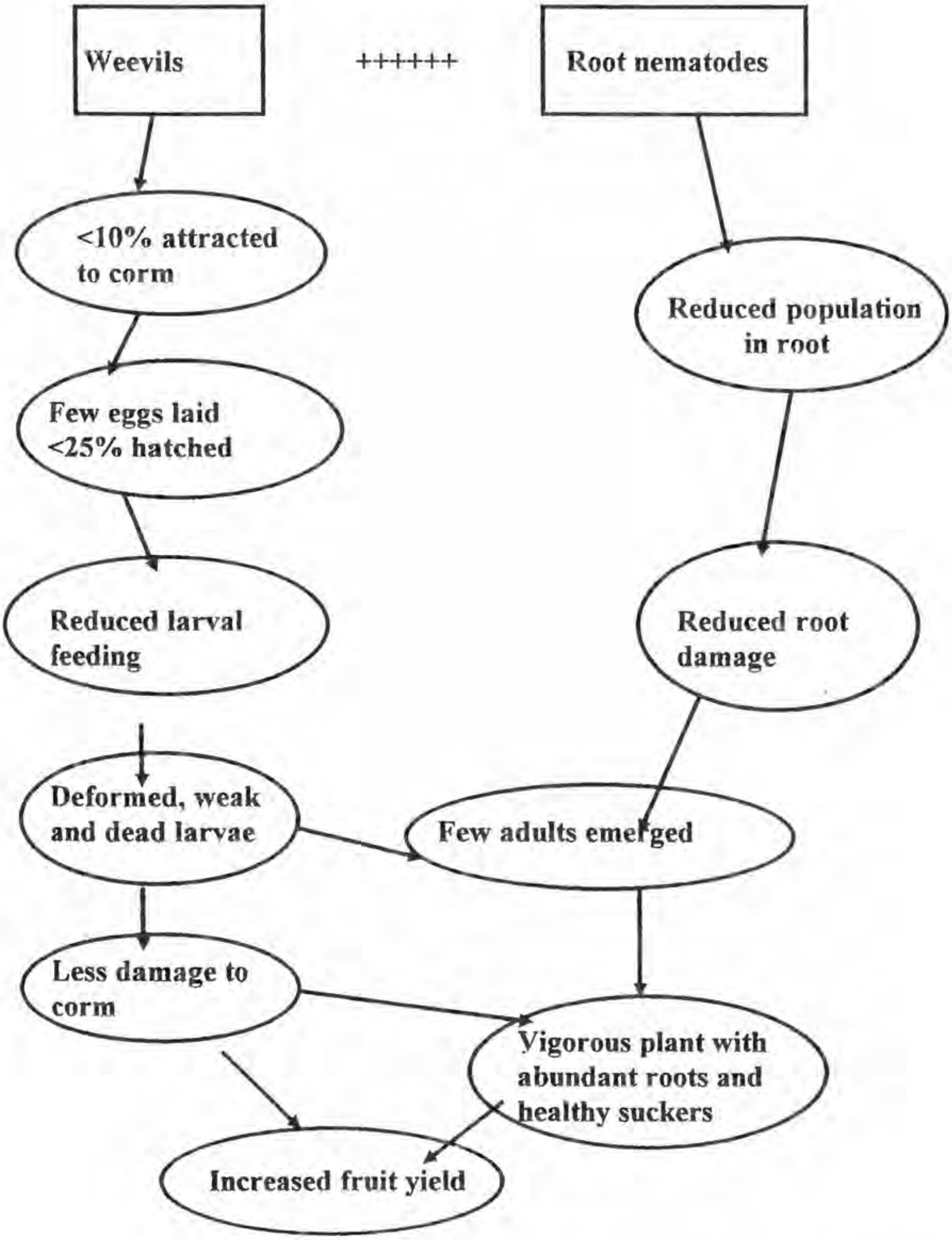


Fig. 7.1. Behavioural and physiological changes of banana pests in plants tr with neem materials and their effects on plant health and fruit yield

Indeed, neem products at higher concentrations are not completely safe for all stages of beneficial organisms, specially nematodes and insects (Rovesti and Deseo, 1989; Schmutterer, 1997). Also, in the laboratory, Sauphanor *et al.*, (1995) did not observe adverse effects of azadirachtin on mortality, weight, food intake or fecundity of european earwing, *Forficula auricularia* L. In another study, conducted in Kenya, Owino *et al.*, (1993) found that neem stimulated egg parasitism of *M. javanica* in tomato. Certainly, natural extracts with selective modes of action are expected to be less harmful to beneficial organisms than the broad-spectrum synthetic pesticides. The effect of neem application in the banana IPM on beneficial soil organisms should be undertaken.

Valette (1996) found that bacteria were associated with banana nematodes in the infection process. Mishra and Gupta (1992) reported that neem cake reduced populations of plant parasitic nematodes and increased soil bacteria *Rhizobium* population in soybean. The antifungal properties of neem derivatives have also been reported. For instance, in India, neem seed kernel extract effectively controlled rust, *Puccinia arachidis* in groundnut (Usman *et al.*, 1991). Similarly, Jagannathan and Narasimhan (1988) observed inhibition of fungal spore germination and mycelial growth following aza application. Therefore, probably, neem seed derivative applications in bananas against weevil and parasitic nematodes could also contribute to reduction of soil borne fungus and bacteria affecting the banana plant. Indeed, *C. sordidus* is often found in association with the banana fusarium wilt, *Fusarium oxysporum* f. cubense (Lindqvist, 1981). Other soil-borne fungi such as *Cylindrocarpon musae*, *Fusarium* spp were also isolated from lesions caused by *P.*

goodeyi or *R. similis* (Pinochet, 1996). From the above observations, the hypothesis that soil application of NSP or NC could control the Panama disease *F. oxysporium f. cubense* and perhaps the Moko disease *Pseudomonas solanacearum* in bananas should be investigated.

Although Walker *et al*., (1983) and Speijer *et al*., (1993) had diverse opinions on the interrelationship between weevil and nematode infestation, it is believed that nematodes and weevils are often found together in the same plant. Therefore, the findings that application of NSP or NC can control the two pests are of practical importance.

Mateille (1992) and Valette (1996) stated that accumulation of phenolic compounds in the banana roots might reduce nematode multiplication and slow down the pathogen increase. On the other hand, Perry (1996) found that plant parasitic nematodes use chemoreceptors to locate their hosts even for mating. The effect of neem on the banana root chemoreception is worthwhile to understand.

Compared with the untreated plants, NSP or NC treated plants had more vigorous and healthier plants with deep green leaves. Chlorophyll content and other chemical matters in the neem treated and untreated banana plants should be studied.

The findings reported in this study, that natural products obtained from neem significantly reduce banana weevils and parasitic nematodes load and damage on a par with synthetic pesticides should contribute to a drastic reduction in the use of highly poisonous and hazardous pesticides. Unlike synthetic pesticides, at high pest's infestation and under good soil fertility, application of powdered neem seed or cake reduced banana pests and improved the fruit yield. Also, these results should have practical importance worldwide.

Throughout our experiments, either in laboratory or in the fields, the effect of neem cake application against weevil was less than that conferred by NSP application. This makes the use of NSP more efficient and economical. NSP is easier to prepare (seed crushing) while NC is obtained after the oil has been expelled (long process).

Compared with the application of Furadan against banana weevil and nematodes, application of NSPand NC were far cheaper. It requires annually ~ 300 kg/ha of NSP (~ US $25) against 120 kg of Furadan (~US $650). A full-grown neem tree gives about 30 kg of dried seeds. Due to the land shortage, in general, in a farm, banana occupies less than one hectare. Therefore, 10 neem trees suffice for a farmer to control efficiently banana weevil and nematodes.

Although, several scientists have demonstrated the efficacy of neem products against some coleopterans and parasitic nematodes attacking crops, little has been done on bananas. The present study to my knowledge is the first dealing with banana pest as a complex.

A particular attention was given to soil applications of NSP and NC. Unlike chemical methods, banana pest management with powdered neem seed requires neither special equipment nor extra capital investment by farmers. The low or negligible cost of neem derivatives could be a blessing for cash-strapped farmer's worldwide (Saxena and Kidiavai, 1997). Furthermore, target pests' species are controlled, and beneficial organisms are relatively less insensitive to the neem application than synthetic pesticides (Lowery and Isman, 1995). Therefore, I believed as has been stated by Simmonds *et al.*, (1992) that the next generation of pesticides for use in next century will most likely be based on secondary metabolites isolated from fungi and high plants. Unlike many synthetic pesticides, botanical compounds are usually biodegradables and are potentially environmentally safer.

This awareness of neem's potential for the banana weevil and parasitic nematodes complex needs to be created, particularly in the banana growing areas and where neem trees are readily available. Likewise, the intensification of neem tree planting where the tree thrives should be pursued. However, the following research areas have to be explored in depth.

7. 2. Possible areas for future research

- Effects of neem seed derivatives against the banana weevil and parasitic nematodes using in vitro tissue-cultured banana plantlets.
- Effects of neem treatments on the behaviour and physiology of key banana parasitic nematodes.
- Effects of soil application of powdered neem seed or cake on banana root microbiota, particularly beneficial nematodes.
- Potential of neem material applications for the management of the fusarium wilt and the moko diseases in bananas.
- Persistence of neem seed powder and cake in banana root system.

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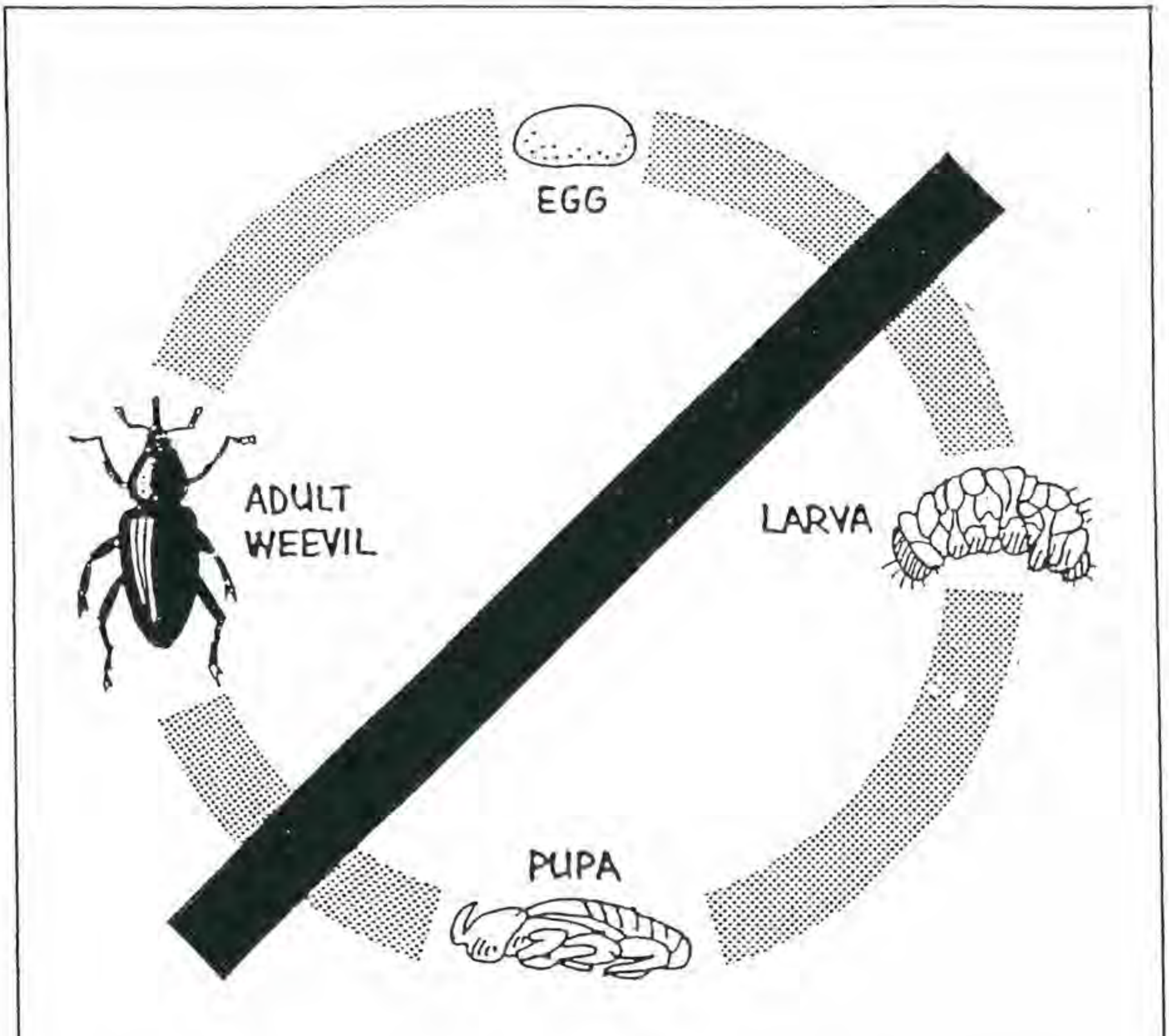
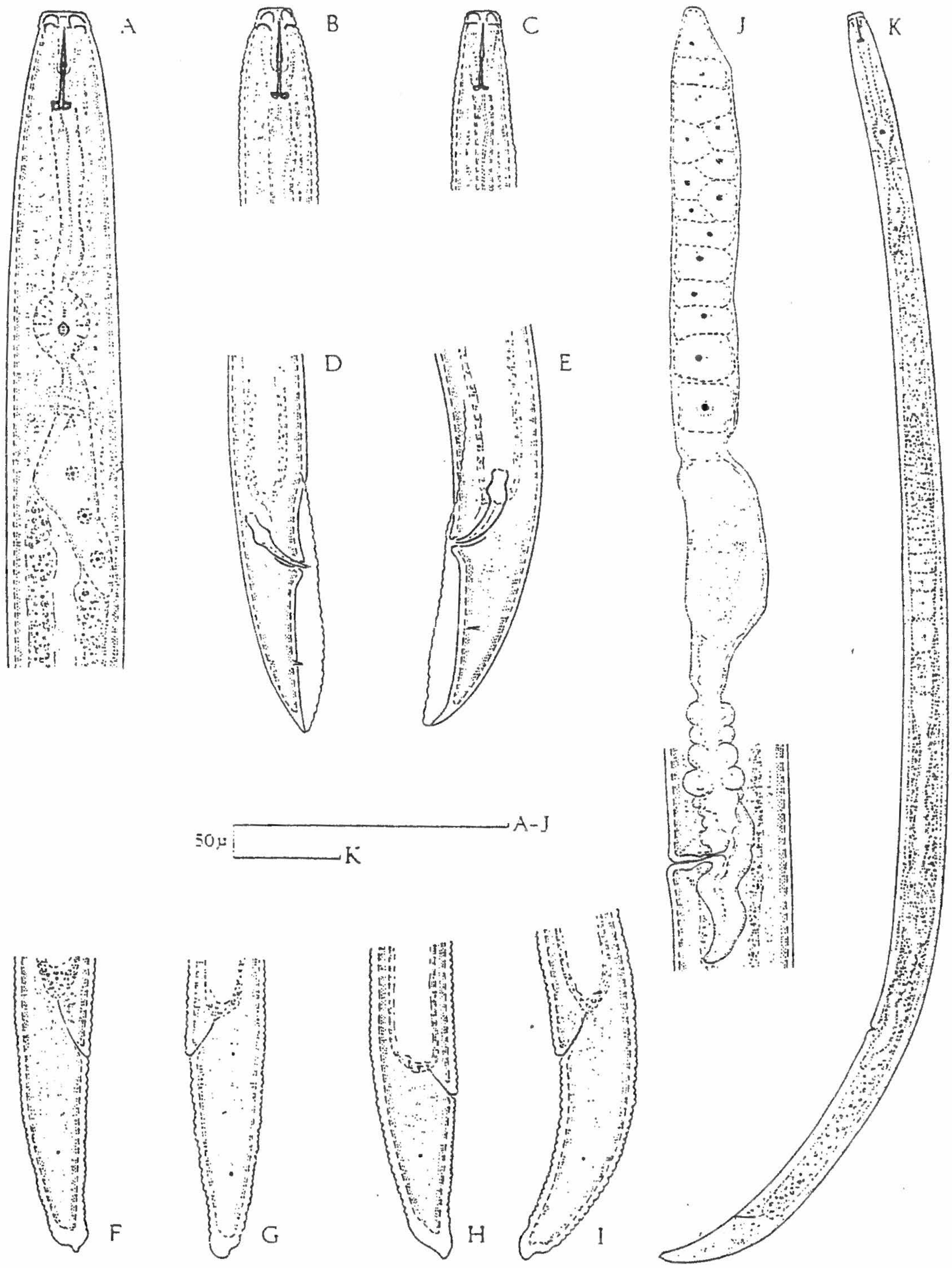
Appendix 1. Life stage of the banana weeevil, *Cosmopolites sordidus* Germar



Adults live hidden in various plant debris around the base of the banana plant; **eggs** are laid superficially (~ 3 mm depth) in the corm; **larvae** bore deep into the corm and **pupae** from which **adults** will emerge are also in the corm

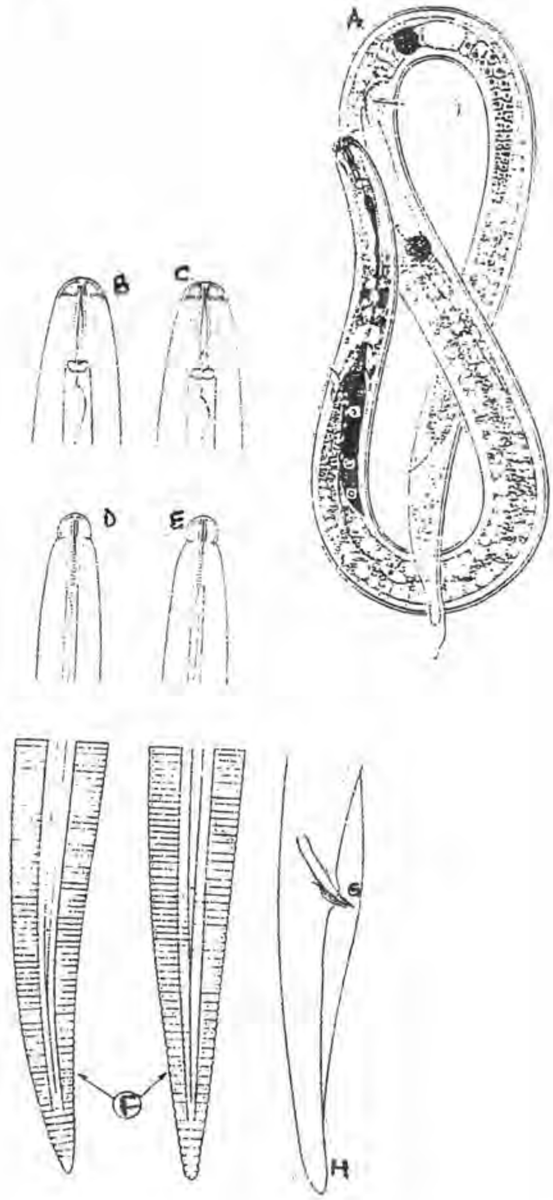
Appendix 2. Morphological characters of the banana root lesion nematode *Pratylenchus goodeyi* Sher & Allen (CIH Descriptions of Plant-parasitic Nematodes, set 8, No. 120. C.A.B. International, Wallingford, UK)



A. Female oesophagus B. Female head C. Male head D, E. Male tails

F-I. Female tails J. Female genital tract K. Entire female

Appendix 3. Morphological characters of the banana burrowing nematode *Radopholus similis* Thorne (Luc *et al.* 1990)



A. Entire female	B,C. Female head	D,E. Male head
F. Female tails	G. Spicule	H. Male tail

Appendix 4a. Weevils settled under corms treated with neem oil (NO 1%) and untreated corms at 48 h after release in a choice test.

Period (hour)	Treatment	Weevil settled (%)	Prob >T
1	Control	64.4±7.79	0.06 NS
	Treated	23.5±4.88	
2	Control	67.4±7.66	0.03*
	Treated	22.8±5.09	
3	Control	70.4±7.41	0.04 *
	Treated	28.2±6.19	
12	Control	78.0±9.07	0.009**
	Treated	22.0±8.04	
24	Control	70.0±8.60	0.01**
	Treated	27.6±6.66	
48	Control	42.4±6.26	0.7 NS
	Treated	35.4±6.02	

NS, *, **,***: not significant, significant at 0.05, 0.01 and 0.001 respectively (T-test). Average of 9 replicates; 50 weevils released. In general there was a significant difference between untreated and treated corms at the same period. The repellent effect was weaker as from 48 h after release.

Appendix 4 b. Weevils settled under corms treated with neem oil (NO 2.5%) and untreated corms at 48 h after release in a choice test.

Period (hour)	Treatment	Weevil settled (%)	Prob >T
1	Control	71.2±7.76	0.002**
	Treated	11.2±2.47	
2	Control	78.6±8.07	0.0008***
	Treated	9.1±2.61	
3	Control	68.2±8.07	0.005**
	Treated	11.6±3.46	
12	Control	75.6±7.44	0.03*
	Treated	16.8±3.72	
24	Control	76.6±8.37	0.05*
	Treated	17.6±3.48	
48	Control	61.6±7.17	0.07 NS
	Treated	25.2±5.82	

NS, *, **,***: not significant, significant at 0.05, 0.01 and 0.001 respectively (T-test). Average of 9 replicates; 50 weevils released. In general there was a significant difference between untreated and treated corms at the same period. The repellent effect was weaker as from 48 h after release.

Appendix 4 c. Weevils settled under corms treated with neem oil (NO 5%) and untreated corms at 48 h after release in a choice test.

Period (hour)	Treatment	Weevil settled (%)	Prob >T
1	Control	48.1±8.42	0.02*
	Treated	23.0±5.36	
2	Control	61.8±6.63	0.02*
	Treated	19.6±5.04	
3	Control	51.1±7.66	0.11 NS
	Treated	21.4±4.43	
12	Control	72.4±7.84	0.002**
	Treated	12.4±2.03	
24	Control	66.6±9.04	0.03*
	Treated	20.0±2.74	
48	Control	73.0±11.30	0.02*
	Treated	14.1±3.56	

NS, *, **,***: not significant, significant at 0.05, 0.01 and 0.001 respectively (T-test). Average of 9 replicates; 50 weevils released. In general there was a significant difference between untreated and treated corms at the same period. The repellent effect persists even after 48 h.

Appendix 5. Effect of application of NSP, NC, Furadan or combination of NC+Furadan at different rates in a highly infested farmer's field at oyugis on banana weevil population (1st crop)

Treatment	No. weevil/plot
NSP 60	34.4±7.24
NSP 80	37.4±7.19
NSP 100	30.8±4.72
NC 60	41.0±7.11
NC 100	43.4±5.05
NC 80	32.0±4.85
NC+Furadan	27.2±5.39
Furadan	26.4±7.83
Control	42.4±6.94
P=0.05	NS

Means of 4 plots. Traps were laid in each plant. However, the number of plants established was inequal among treatments implying that the number of traps was also inequal.

Appendix 6. Effect of application of NSP, NC, Furadan or NC+Furadan at different rates on the growth of sucker, and nematode population in suckers at flowering (Kabondo, 1st crop).

Treatment (g/mat)	Sucker (no.)	Height of sucker (cm)	Girth of sucker (cm)	Weight of 6 roots of 15 cm lenght (g)	Nematodes in sucker (no./100 g/root)	Nematodes in mother plant (no./100 g/root)	Sucker biomass (g)
NSP 60	2.5	155.6	49.9	39	384a	1860a	7200
NSP 80	2.7	161.2	50.6	44	480a	780a	14500
NSP 100	2.2	144.6	45.7	44	480a	1920a	13500
NC 60	2.5	161.2	52.2	50	480a	1440a	8700
NC 80	2.2	160.2	52.5	35	240a	580a	8700
NC 100	2.2	154.2	50.2	48	480a	1860a	12700
Furadan	2.5	123.4	40.2	39	4920ab	1080a	5500
NC+Fur	3.0	157.8	47.7	41	960a	720a	8500
Control	2.2	118.6	32.1	32	6960b	16680b	6700
	NS	NS	NS	NS	**	**	NS

NS= Not significant
** = significant at P<0.01%

Compared with the nematode density in the mother plant, fewer nematodes were extracted from roots of suckers, except in Furadan and NC+ Furadan where the density in suckers was higher than in mother plants. There was no significant difference among treatments in root lenght, weight, number or biomass of suckers