

STUDIES ON SOIL AMENDMENT STRATEGIES AND NEEM PRODUCTS FOR
THE MANAGEMENT OF INSECT PESTS OF OKRA
(*Abelmoschus esculentus* (L.) Moench).

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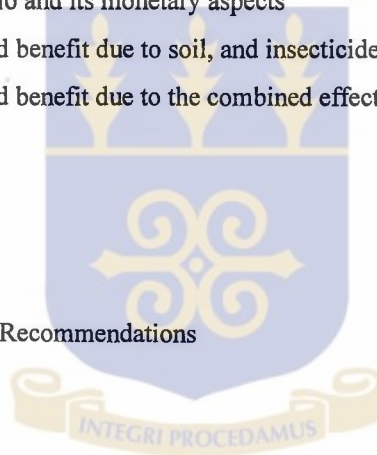
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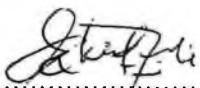


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DECLARATION

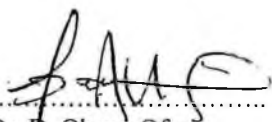
I hereby declare that, except for references to other people's work which have been duly cited, this work is the results of my own original research and that this dissertation has neither in whole or in part been presented for another degree elsewhere.



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DEDICATION

I dedicate this thesis to my children, Champion Afotey Odai and Mathew Laryea Odai, my wife, Mary Amoadu, and my mother, Mary Abukweh Laryea, for their sacrifices during this course. I was away and denied you of my comfort, yet you prayed for me to endure all hardships to complete this programme.

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LIST OF ABBREVIATIONS

ha.	Hectare
mg.	Milligram
g.	Gram
Kg.	Kilogram
g/l.	Grams per liter
et al.	And others
cm.	Centimeter
t/ha.	Tonnes per hectare
r. h.	Relative humidity
°C.	Degree celcius
ml.	Milliliter
m.	Meter
LSD.	Least Significant Difference
GMT.	Greenwich Mean Time
ANOVA.	Analysis of Variance
ANSE.	Aqueous neem seed extract
l/ha.	Liters per hectare

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ABSTRACT

The effect of different soil amendment strategies, and neem products for the management of insect pests of okra was studied in the field at the Ashaiman irrigation project site.

The insect pests encountered fell into seven orders belonging to twenty-three families. The important ones among these were *Aphis gossypii* (Glov.), *Bemesia tabaci* (Genn.), *Dysdercus* spp. *Podagrira uniformis* (Jac.), *Heliothis armigera* (Hb.) synonym *Helicoverpa armigera* (Hb.), *Sylepta derogata* (Fab.), *Anthonomus grandis* (Boh.) and *Empoasca* spp. *Calidea* spp. *Pachnoda* spp and *Riptortus* were also found attacking okra fruits in Ashaiman. The beneficial insects included *Coccinella* spp., *Odonata* spp. *Cheilomenes vicinia* (Muls.) and *Rhinocoris rapax* (L.).

The neem products were less harmful to the beneficial insects and controlled homopteran pests better than the synthetic insecticide, dimethoate. Dimethoate was less effective in managing *A. gossypii* and *B. tabaci* probably due to the development of resistance in these insects.

In the field, the compost treatments improved plant vigour and enhanced their tolerance to pest attack than the sole chemical fertilizer, and gave significantly higher response in all yield indices studied. The sole fertilizer treated plants, however, performed better than the untreated control in fruit yield, damage, and vegetative yield indices studied. The combined effects of compost and aqueous neem seed extract (ANSE) at 50 g/l enhanced okra resistance to insect pests attack, and improved yield and marginal benefit of over 100% the cost of production. ANSE was better than the formulated neem product, Neemazal at (2 ml/l), in managing the insect pests of okra, and compared favourably well with the synthetic insecticide, dimethoate 40% EC (75 ml/15l).

As a production package for okra, plants should be treated with compost prepared from cocoa husk, rice straw and poultry manure at (500 g/plant), ANSE (50 g/l) sprayed with cone nozzle is recommended.

CHAPTER ONE

1.0. GENERAL INTRODUCTION

Okra (*Abelmoschus esculentus*) (L.) Moench, (Malvaceae) is also commonly referred to as okro or lady's fingers. The crop is of African origin and has spread to other parts of the world (Sinnadurai, 1992). However, it is extensively consumed in many other Tropical areas where it is grown mainly for domestic use (Rice *et al.*, 1990). There are various varieties classified according to shape, colour, size, appearance as well as sliminess.

The slimy cultivars such as 'Asuntem' red and white are preferred for soups and stew while the thin long cultivars which are less slimy such as Clemson spineless and Perkins long pod are used as salad (Sinnadurai, 1992), particularly the tender fruits when boiled or sliced and fried (Cobbly and Steele, 1976). Okra is one of the most important vegetables widely grown in Africa for its tender fruits and leaves (Ewete *et al.*, 1980). The edible portion of the pod contains 2.0 - 2.2 % protein; 9.7 % carbohydrate; 0.2 % vitamin A (thiamin); and good source of minerals such as calcium, phosphorus and iron. (FAO, 1988; Margaret *et al.*, 1989; and Norman, 1992) The young leaves are rich in protein (2.3 - 3.0 %) and vitamin B2 (Ewete *et al.*, 1980; FAO, 1988). In West Africa, it is commonly mixed with fish, garden eggs and tomato as tasty salad. The crop is sometimes grown purposely for the seeds because of their high amounts of edible oil (Oyolu, 1983; FAO, 1988; Norman, 1992).

Where there are good opportunities for sale, okra is among the most profitable tropically restricted agricultural products, which has found regular markets in the industrialised countries (Sigmund and Gustav, 1991).

Consequently, the crop has currently gained high export potential and hence a source of foreign exchange to individuals and organisations in Ghana. However, in areas where okra is produced, the crop cannot be successfully grown without insecticide application. This is because every stage of the crop is vulnerable to insect pests attack. The crop is attacked by several insect pests and in Ghana, Critchley, (1997) observed 22 species of insect pests of 12 families in four orders attacking the okra plant in the Brong-Ahafo region alone. These include *Aphis gossypii* (Glov),

Earias biplaga (Wlk.) *Podagrica unifomis* Jac. *P. sjostedti* Jac., *Sylepta derogata* Butler. and *Dysdercus supersticiosus* (F.). Out of these, the *Podagrica* species are the most common and damaging in Ghana followed by *Aphis gossypii*, *Dysdercus supersticiosus* and larvae of *Spodoptera litoralis* (Boisd.) and *Earias biplaga* (Norman, 1992; Obeng-Ofori, 1998). From a survey conducted as part of this studies, between August and September, 2000, in some vegetable growing areas in the Accra plains (Madina, Ashaiman, Kpone and Ningo), the most common insect pests of okra identified were *Aphis gossypii* followed by *Bemisia tabaci* (Genn.) and *P. unifomis*. Attack by these pests is reported to have denied farmers any harvest in the Tolon-Kumbungu district in Northern Ghana (Asante, 1978) and Kpone in the Tema district of the Greater – Accra Region (Udzu, 1993).

As indicated earlier, most farmers rely mainly on synthetic insecticides for control of insect pests of okra. Cocktail mixtures of different pesticides sprayed at short intervals with inappropriate nozzles are used. This results in poor control of the pests. There are also adverse effects of these chemicals on the applicator, environment and consumers e.g. toxicity to beneficial and other non-target organisms, pollution of the environment, tainting of produce, toxic residue levels in produce and poisoning of operators among others. These hazards coupled with their high costs, make the sole reliance on synthetic insecticides unsuitable for protecting the crop (Soliman and Bleih, 1994). Efforts to avert these adverse effects have created much interest in the search for an integrated approach, involving botanicals, efficient means of application and other agronomic practices as new tools to protect and increase the crop tolerance against insect pests.

Neem (*Azadirachta indica*) products have been used against the major pests of okra, *A. gossypii*, *E. biplaga*, *P. uniformis* and *D. supersticiosus* with mixed successes (Schmutterer, 1995). Emosairue and Ukeh, (1998) suggested that when these sprays are applied at higher concentrations (50 g/l of water) and closer spray regimes, they may yield successful results as the synthetic insecticides. Okra has been observed to respond very well to high organic matter at the rate of 20 - 25 t/ha applied at least a fortnight before planting. Similarly, inorganic fertilizers also have positive effects on okra when applied at 250 - 300 kg/ha in the form of NPK 15-15-15 compound fertilizer (Norman, 1992).

Compost is used to improve the physical conditions and fertility of the soil. It contributes in a major way to the diversity of soil organics and organisms that are critical to humus formation and to soil and plant health (Davis, 1982). The humus affect changes in the environment of the roots such as increase in water holding capacity and gas exchange among others, thereby enhancing plant metabolism (Flaig *et al.*, 1977). Resource poor farmers usually grow okra without application of fertilizers and other soil amendments, rendering the crop more vulnerable to insect pests and diseases attack due to lack of vigour as a result of poor nutrient uptake. However, tolerance of okra to pests and diseases attack, and its performance could be increased by irrigating, manuring, or addition of fertilizer (NPK) and or decomposed organic matter. Such practices generally promote rapid growth and shorten the time that the susceptible stage of the crop would be available to pest attack, by providing the crop with greater tolerance and opportunity to compensate for insect damage (Jacob, 1990; Dent, 1991; Hugues and Philippe, 1992).

Insect pests of okra such as *P. uniformis*, feeds on the leaf, and fruit surface; the fruit borer, *Heliothis armigera* (Hub.) seriously damage flower buds and bore into the fruit while the caterpillar of the spiny bollworm, *Earias biplaga* or *E. insulana* bore into flower buds, young shoots and petioles, and maturing fruits (Kaaya, 1990). These attacks reduce the quality and yields of okra, hence it is necessary that pesticides are distributed on and within the crop's canopy using appropriate nozzle to give adequate coverage of these localized niches of the pests for efficient protection.

The use of soil amendments and neem products for any particular pest management in okra and the employment of an effective and efficient system for applying these botanicals would be paramount if yields and quality of produce are to be obtained and maintained. The main focus of this study is to evaluate integrated crop management strategies using neem products and soil amendment practices for reducing crop losses caused by insect pests of okra.

The specific objectives for this study were therefore

1. To determine insect fauna associated with okra in the Accra plains and assess their damage.
2. To determine the effects of soil amendment practices on the incidence and damage of insect pests on growth and yield of okra.

3. To determine the most effective and efficient strategy for managing the insect pests.
4. To establish a cost benefit ratio for the different strategies used.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1.THE OKRA PLANT

Okra (*Abelmoschus esculentus* (L) Moench) ,(Malvaceae) is an erect robust annual herb of up to two meters high. The leaves are large, alternate, and cordate and are divided into three to seven lobes with notched or toothed margins. The flowers are borne singly in the leaf axils on peduncles not more than 2.5 cm long with eight to ten very narrow, hairy bracteoles forming an epicalyx, which falls off before the fruit ripens (Kochhar, 1986). The flowers, which are yellow with brown centres, have shorter stamen and style (Messiaen, 1992). The fruits are long (10 - 30 cm), beaked, ridged, oblong hairy capsules, which dehisce longitudinally. The fruits colour ranges from light green, green and sometimes, red. When young, the fruits are mucilaginous and contains green or dark to black spherical but tuberculate seeds (Kochhar, 1986) with about 50 - 100 seeds per fruit (Messiaen, 1992).

2.1.2. Ecology of the plant

Okra seeds germinate only in warm soils with temperature above 16 °C (Rice *et al.*, 1990) and would not thrive where there is a continued cold spell (Kochhar, 1986). The crop grows quickly at high temperatures of 25 - 35 °C with a growth threshold temperature around 15 °C (Messiaen, 1992). It grows on a wide range of soils but well - drained, fertile soils with adequate organic material and reserves of the major elements are ideal (Rice *et al.*, 1990) particularly in a moist, friable soil with a pH between 6.0 - 6.8 (Kochhar, 1986). Good crops have been raised from soils with pH 4.5 - 7.0 (Sinnadurai, 1992).

2.1.3. Importance in small – holder and commercial farming in Ghana

In addition to the fruit being used as a vegetable, use is also made of the leaves, and stem. The leaves are used as spinach or fodder for goats, and the stem as fibre used domestically for tying firewood (Kemavor, 1977, Martin, 1982) and also as fuel wood (NARP, 1993). The high mucilage of the fruit helps to thicken soups and stews. The matured seeds are also roasted and ground as a coffee substitute in some West African countries (Martin, 1982). In the northern and upper Regions of Ghana, the fresh flower buds and leaves are also used in stews and soups (NARP, 1993).



In industry, a mucilaginous substance is prepared from the pod, which is used as plasma replacement or blood volume expander while mucilage from the stem and roots is used for clarifying sugar cane juice during jaggery manufacturing in India and for sizing paper in Malaysia and China. Also the matured pods and stems produce a fibre, which is used for textiles and paper making (Kochhar, 1986).

2.1.4. Importance in human diet

The edible portion of the fruit contains 2.0 - 2.2 % protein; 9.7 % carbohydrate; 0.2 % Vitamin A (thiamin); and a good source of minerals such as calcium, phosphorus and iron (F.A.O., 1988; Margaret *et al.*, 1989; Norman, 1992), as well as 1.0 % fibre; 0.2 % fats; 0.95 % ash, vitamins B and C and minerals especially iodine (Kochhar, 1986). The ripe seeds contain high amounts of edible oil (Oyolu, 1983) and the young leaves are also rich in protein (2.3 - 3.0%) and vitamin B2 (Ewete *et al.*, 1980).

2.2. OKRA PRODUCTION IN GHANA

In Ghana, okra is produced, sold and eaten in all the ten regions of the country. It is grown in mixed crop production system, often mixed with cassava, millet, groundnuts and other crops throughout Ghana in rainfed and small scale irrigation systems (small dams, dugouts/ponds, wells, etc. in Tamale, Bola, Bawku, Navrongo, Ada, Akumadan, Afife and Shai Hill). It is also grown as a sole crop in market gardens throughout Ghana and irrigated sites such as Ashaiman, Weija, Kpandu and Otsereko areas (NARP, 1993). Okra like other vegetables, has its production made up of 2 distinct components namely, a well paying market gardening section around the principal cities like Accra, Kumasi, Takoradi and Tamale, and a truck farming system where the crops are produced in distant places and transported in "Mummy" trucks to the cities (Sinnadurai, 1971). The local varieties commonly grown in Ghana include Labadi dwarf, Asontem red, Akatsi and Bawku red (Sinnadurai, 1992). In terms of production tonnage, Brong - Ahafo, Northern, Central, Greater Accra and Volta regions produce the bulk. (NARP, 1993).

In Ghana, since 1974, there has been a dramatic fluctuation in land area under okra production from 51,000 ha to 7,300 ha in 1983. Similarly in terms of production tonnage, the total

production from 1970 to 1991 followed a fluctuating trend, Table 1. On Regional basis, the production level and area under okra production is also indicated in Table 2.

Table 1. Okra Production in Ghana from 1970 - 1991

Year	Area under Production (' 000 Ha)	Production Tonnage (' 000 MT)
1970	27.9	101.5
1971	27.9	101.6
1972	43.5	214.4
1973	34.4	170.7
1974	51.0	252.0
1975	32.4	159.5
1976	23.3	107.6
1977	23.2	111.0
1978	14.5	69.9
1979	19.9	97.2
1980	20.5	99.0
1981	8.6	40.4
1982	10.9	46.4
1983	7.3	20.2
1984	26.0	121.0
1985	21.0	102.0
1986	30.7	146.0
1987	27.4	138.9
1988	11.2	59.6
1989	28.0	146.5
1990	-	-
1991	-	-

Source: NARP, 1993.

**Table 2. Production of okra in Ghana on a Regional Basis
(Area in '1000Ha and Tonnage in 1000 Mt)**

	REGION									
	Ashanti	Brong Ahafo	Central	Eastern	Greater Accra	Northern	Upper East	Upper West	Volta	Western
Ha	371	11629	685	-	1051	14010	-	-	2537	-
MT	1809	52710	3288	-	5348	68578	-	-	1451	-
									7	
Ha	935	11000	1559	258	533	10000	8	8	3000	98
MT	4300	52100	7400	1200	2600	49200	50	50	1420	400
									0	
Ha	500	5000	1000	-	4000	2000	200	40	2000	60
MT	2900	23000	4500	-	2600	9900	900	200	9500	300
Ha	-	-	-	-	-	-	-	-	-	-
MT	4600	53200	7300	900	2700	50500	-	-	1470	500
									0	

Source: NARP,1993.

2.2.1. Production pattern and levels of okra production

The plant begins to flower in about 40 days for early cultivars and 60 days for the late cultivars. The number of fruits produced by a plant varies from 8 to 22 depending on the cultivar. With good agronomic management and irrigation, okra plant will produce about 250 grams of fruit in a season but yield seldom exceeds 3,300 kg/ha. However under erratic rainfall, yields can be as low as 500 kg/ha though the crop can tolerate temporary drought conditions (Sinnadurai, 1992, and Critchley, 1997). Adelan (1986) reported that when okra is grown as an intercrop with maize, its yield is drastically reduced from an average of 9.4 fruits per plant in pure stand to 6.4 fruits per plant in intercropping. Messiaen (1992) also reported of yields of 7 -10 t/ha and 15 - 20 t/ha from the early and late maturing varieties respectively when grown as a sole crop and, harvesting spread over 60 - 80 days.

In the Accra plains two varieties of okra are grown. These are the early (6 weeks) and late (8 weeks) varieties. The former is whitish in colour and drought resistant whereas the latter is greenish and drought susceptible. The 6 weeks variety is normally cultivated either in September, October or November while the 8 weeks Cultiver is grown in the months of February, March and April (Kemavor, 1977). From a survey conducted by F.A.O on some major crops grown in some regions of Ghana, it was reported that in the Navrongo and Bolgatanga districts of the Upper East region, okra is grown between the months October and April. However, in the Akumadan and Kumasi districts of the Ashanti region, okra is cultivated between the months Oct – April, and January – July, while in the Asamankese and Suhum districts of the Eastern Region, okra is produced between the months October – March and April – June. Considering the Greater Accra region, the production period for okra in the districts visited are Kakasunaka, May–September; Dahwenya, May – September (rainfall) and October – April (irrigated), Weija, May –September (rainfall) and October – April (irrigated) but in Accra and Ashaiman, okra is produced all year round (F.A.O, 1997). According to Boateng (1991) there are 3 seasons for producing okra in the Ashanti region. These are major and minor rainy seasons, and the dry season. In the major season, the Asuntem variety and the long duration types are grown while in the minor season the dwarf, short duration types, are cultivated. This is because the dwarf types are able to complete their cycle within the short rains hence no irrigation is required. However in the dry season, production takes place only in the low-lying areas, valley bottoms, where the

water table is high. During this time, natural underground water is supplemented with water from wells. He also reported that the intensity of okra production decreases with the seasons hence yields in production tend to decrease with the rains in these areas of the region, Ejisu, Nkawere, Mankroso and Edujama.

The National okra, and some Asian vegetable production patterns and levels under different growing conditions are in Table 3.

Table 3 Asian Vegetable Production Patterns and Production Levels in Ghana

VEGETABLE	Yield	Yield,	Potential	Time of Planting		Time of Harvesting		Gestation Period (Days)	Water requirement (mm)	Plant Population (' 000)Plts/Ha
	Rainfed (T/HA)	Irrigated (T/HA)	Yield, Rainfed (T/HA)	North	South	North	South			
Cabbage	12.5	25	18.75	Dec/Jan	Dec/Jan	Feb/Mar	Feb/Mar	90	1500-2000	30000-55000
Carrots	8	30	20		Dec/Jan		Feb/Mar	90	600-1000	450000
Garden eggs	8	22	15		April/May		July/Aug	90	1000-2000	31000
Lettuce	5	15	10		Dec/Jan		Feb/ Mar	60	1500-2000	150000
Melon (Agusi)	12	55	27.5							
Okra	8	15	12.5	April/May	April/May	June/July	June/July	60		35000
Pepper	15	22.5	20	July	-do-	Aug/Sept	-do-	90	600-1500	35000-40000
Pumpking leaves	8	10	10	April/May		June/July				
Talinum leaves						June/July		60	1000-2000	

Source: PPMED, 2001

2.2.2. Production constraints

In Ghana, low yields in okra are attributed to several production constraints among which low soil fertility, and damage caused by insect pests are most critical (Hayase, 2001). Damage caused by insect pests has been reported as the major constraint (Sinnadurai, 1971; Critchley, 1997). Tindal (1965) reported of okra being attacked by several insect species in Ghana. These include *Sylepta derogata* (F.), *Dysdercus supersticiosus* (F.), *Aphis gossypii* (Glov.) and *Podagrica uniformis* (Jac.). Critchley (1997) reported of 22 insect pests from 12 families in four orders (Coleoptera, Hemiptera, Lepidoptera and Orthoptera) attacking okra in Brong-Ahafo region of Ghana. Of these, the most important are the flea beetles, *Podagrica uniformis* Jacoby and *P. sjostedti* Jacoby, followed by aphids, *A. gossypii* Glover, cotton stainers, *Dysdercus supersticiosus* (Fab) and Lepidopteran caterpillars, *Sylepta derogata* (Fab.) and *Heliothis armigera* (Hub.). The blister beetle, *Mylabris* spp., feeds on the flowers, reducing the number of fruits formed, while both adults and nymphs of *A. gossypii* suck sap from young leaves and buds, thus reducing the efficiency of the leaves.

Nymphs and adults Leaf hoppers, *Empoasca* spp., attack leaves and cause their edges to curl down and become chlorotic. The leaf-footed bug, *Anoplocnemis curvipes* (Fab.) (both nymphs and adults), attacks new shoots and developing fruits to cause distortion of leaves and poor development of fruits, and their attack is similar to that of the coreid bug, *Riptortus tenuicorinis* Dall. The shield bug, *Halomorpha annulinornis* Sign., and the green stink bug, *Nezera viridula* (L), both attack developing pods and suck sap from leaves causing local necrosis.

The adults and nymphs of the cotton stainer, *Dysdercus supersticiosus* (Fab.), pierce and suck pods which then shrivel, and cause reduction in seed viability. However, the larvae of *Anomis flava* (Fab.) feed on the leaves causing severe defoliation, while adult crickets, *Oecanthus* spp., attack and bite a pear-shaped hole in the leaf. The leaf roller, *Sylepta derogata* (Fab.), attacks the leaves, which they cover in webbing as the leaves curl and droop.

(Asante, (1978) observed that *A. gossypii* Glov. (Aphididae) was most prevalent and occurred in small colonies, mostly confined to the under surface of leaves, sucking sap, and causing appreciable damage. However, the cotton whitefly, *Bemisia tabaci* Genn. (Aleyroidae) occurred in low numbers and suck sap from the underside of leaves. He also observed *Prodenia litura* (F.)

(Noctuidae) on old plants feeding on the upper side of young leaves causing appreciable damage, similar to that of *Aegocera rectilinea* Bdv. (Noctuidae). *P. uniformis* was found feeding on the fruits and flowers, and are responsible for virus - induced mosaic in okra (Lana *et al.*, 1974). Tables 4 and 5 present some of the important insect pests that attack the crop in Ghana.

However, the constraints vary based on the production area. For example in the Anlo-District of the Volta region, lack of extension services, pest infestation and high cost of seeds are the major constraints facing the okra industry (Gilbert, 1990). However, in the Akatsi district, okra production has been limited also by lack of extension officers to educate farmers in farm management practices like fertilizer and insecticide application, harvesting time and frequency in order to increase yield (Paul, 1991). An F.A.O survey in some okra producing areas in Ghana recorded the following: In the Upper East region, Bolgatanga and Navrongo district, access to quality seed, fluctuations in market prices, low soil fertility, insect pests and diseases were the major problem hindering okra production. But, in the Bongo district also of the Upper East region, the problem was rather related to limited arable land area, lack of money to buy inputs and post-harvest storage. In the Ashanti region, however, okra production was found to be hampered by fluctuation in market prices, lack of good roads, pests and diseases attack. In the Asamankese district of the Eastern region, lack of quality seeds, good farming land, money to buy agro - chemicals, and price fluctuation were noted whilst Vegetables farmers in Dodowa, Kakasunaka, Dohwenya, Weija and Accra of the Greater Accra region complained of root knot nematodes, lack of quality seeds, insect pests and diseases, erratic rainfall, limited access to credit for inputs and labour, poor access to land, insect pest resistance, lack of water pumping machines and abuse of pesticide (F.A.O, 1997).

Research has had little impact on the production of okra in Ghana. This is because only limited research findings have been available to farmers. Consequently there has been little adoption of okra production technology by farmers. Even though technological interventions in seed quality, fruit maturity and quality indices as well as post harvest loss control are available. Other bottlenecks are high cost of agrochemicals and or methods for pest and diseases control (NARP, 1993), and presence of soil born diseases and inadequate nutrient management practices. (Ofosu-Budu *et al.*, 1998).

Table 4 . Insect pests recorded on okra in Ghana

Insect pest	Order	Family
<i>Anomis flava</i> F.	Lepidoptera	Noctuidae
<i>Lagria cuprina</i> Thoms.	Coleoptera	Lagriidae
<i>Podagrica uniformis</i> Jac.	Coleoptera	Chrysomelidae
<i>Ootheca mutabilis</i> Sahl.	Coleoptera	Chrysomelidae
<i>Podagrica sjostedti</i> Jac.	Coleoptera	Chrysomelidae
<i>Chasmina camilla</i> Druce.	Lepidoptera	Noctuidae
<i>Comsophila flava</i> Druce.	Lepidoptera	Noctuidae
<i>Lagria villosa</i> F.	Coleoptera	Lagriidae
<i>Mylabris temporalis</i> Wellem.	Coleoptera	Meloidae
<i>Mylabris adbominalis</i>	Coleoptera	Meloidae
<i>Labidognatha</i> sp	Coleoptera	Scolytidae
<i>Aphis gossypii</i> Glov.	Homoptera	Aphididae
<i>Bemisia tabaci</i> Genn.	Homoptera	Aleyroididae
<i>Locris maculata</i> F.	Homoptera	Cercopidae
<i>Dysdercus supersticiosus</i> F.	Hemiptera	Pyrrhocoridae
<i>Sylepta derogata</i> (F.)	Lepidoptera	Pyrelidae
<i>Prodenia litura</i> (F.)	Lepidoptera	Noctuidae
<i>Aegocera rectilinea</i> Bdv.	Lepidoptera	Noctuidae
<i>Plutella maculipennis</i> (curtis)	Lepidoptera	Noctuidae

Source: (Forsyth, 1962; Gupta, 1971; Asante, 1978).

Table 5. Major and minor insect pests of okra in Ghana and their damage

Common Name	Scientific Name	Parts Attacked
Major pest		
Flea beetle	<i>Podagrica uniformis</i> Jac.	Roots and leaves
White fly	<i>Bemisia tabaci</i> Genn.	Leaves
American bollworm	<i>Heliothis armigera</i> Hub.	Flower and pods
Cotton aphids	<i>Aphids gossypii</i> Glov.	Leaves
Minor pests		
Weevils	<i>Coryssopus fulvescens</i> F. <i>Mecysolbus crassirostris</i> F.	Stems and roots Stems and growing shoots
Leaf beetle	<i>Ootheca mutabilis</i> (Salhlberg)	Leaves
Long-jointed beetle	<i>Lagrica cuprina</i> (Thoms.) <i>L. vilosa</i> F.	Leaves Leaves
Jassids	<i>Empoasca</i> spp	Leaves
Semi-looper	<i>Anomis (cosmophilla) flava</i> (F.)	Leaves
Noctuid Moths	<i>Chasmina camilla</i> (Meyr)	Leaves
Leaf roller	<i>Sylepta derogata</i> (F)	Leaves and pod
Seed bug	<i>Oxycaraenus</i> spp	Developing seed
Stink or Shield bug	<i>Nezera viridula</i> (L)	Pods
Cotton stainer	<i>Dysdercus supersticiosus</i> (L)	Slender stems, pods
Diamond-back	<i>Plutella maculipennis</i> (L)	Leaves
Root Knot	<i>Meloidogyne</i> spp	Roots
Nematode		

Source: Anon (2000).

2.2.3. Economics of okra production

The viability of okra production as an enterprise varies according to the location, the season and the management practices adopted. In the coastal savanna zone, it has been estimated that about 250.2% returns on investment can be realised on a hectare of okra while in the forest zone, a return on investment of 231.3% is achieved on one hectare of okra under proper soil and pest management practices (PPMED, 2001). Returns from okra production can further be increased by using more labour especially for applying fertilizers, spraying insecticides, weeding and harvesting the crop (Kemavor, 1977). Gilbert, (1990) reported that applying fertilizer and pesticides makes okra production a profitable enterprise with over 100% return on investment at the Anlo district. In an earlier work, Obeng-Ofori (1982) reported of over 100% returns from okra production per hectare when 2.0g Furadan 5G was applied per plant with a cost - potential benefit ratio of less than one. However, Sackey (1999) reported that the use of aqueous neem seed extract applied at 50g/litre of water for the management of insect pests of okra yielded over 153% returns on the investment while the untreated control which yielded a loss of 12%. Ofofu-Budu (in-press) has recently recorded over 200% turnover on okra grown in compost at Asamankese in the Eastern Region. Consequently, he commended okra production in this area as a viable enterprise especially when the crop is grown in compost.

2.2.4. Marketing constraints

Marketing of okra in Ghana is saddled with a lot of problems, which hamper the development of the okra industry. Storage of fresh vegetables like okra is limited, and often during peak harvests, market prices drop. In other situations, access to the market is a constraint due to either poor state of secondary roads or lack of transport (FAO, 1997). Vegetable characteristics such as size, shape or tenderness like any other foodstuff in the country lack standardization. For example, only departmental stores and kiosks use scales for weighing the okra. This makes it difficult to formulate policy on their prices. The perishable nature of okra is also a menace to its farmers. Poor processing and storage facilities, lack of marketing finances, grading and standardization are also key constraints to okra marketing in Ghana. Poor marketing information system, which also hinders proper allocation of resources in vegetable production, leads to poor distribution of the vegetable (Tarimo, 1977; Boateng, 1991; FAO, 1997).

2.3. OKRA CROP MANAGEMENT PRACTICES

The current management practices in okra take the form of an integration of several cultural, chemical and soil factors.

2.3.1. Current soil management practices

Currently okra farmers in Ghana manage their soils with both inorganic and organic fertilizers with the view to increasing yield of the crop. The use of these as nutrient sources for vegetables have been widely investigated (Sinnadurai, 1992; Norman, 1992).

2.3.1.1. *Use of inorganic fertilizers*

These are chemical substances that are applied to soil to increase crop yields by providing one or more of the elements that are essential plant nutrients. They increase yield and promote plant's growth by supplying more plant nutrients than organic manures in the cycle of growth and decay. Consequently with good farming practices, much of the extra plant nutrients that are bought can be maintained in circulation, thereby raising cropping potential or fertility of the land. In addition, fertilizers lessen the cost of production per tonne since they raise yields without a correspondingly large increase in total costs per hectare (Cooke, 1982). In the Near East, selected agricultural practices for vegetable cultivation which also aims to manage insect pests at reduced pesticide application by farmers include balanced fertilization to address nutritional deficiencies, and irrigation to prevent water stress (Anon, 2000). All these stimulate plant growth, and enhance the plant resistance to, or tolerance of, pests and diseases. This practice has proved very successful and has now become an important component of Integrated Pest Management (IPM) strategies for vegetable production (Lebeek and Lenteren, 1992).

Cultivated crops are weakened by poor nourishment, and even if they show no deficiency symptoms such as chlorosis, stunting, leaf or fruit fall, they tend to be more prone to significant pests damage because the plants lack vigour. Vigorous plants are well - fed and regularly watered, hence are able to replace the sap sucked up by aphids, and are strong enough to develop new shoots and leaves. Chemical fertilizers speed up plant growth and increase yields, however, they often cover plant resistance and make them more attractive to pests. Consequently, farmers who feed their crops exclusively on chemical fertilizers, and on nitrogenous fertilizers in particular have to use pesticides in order to compensate for the low resistance of their crops. On

the other hand, crops grown on organic materials like compost or manures, obtain a range of nutrients that they need to thrive and withstand the attacks of microorganisms and insect pests (Hugues and Philippe, 1992).

Davis (1982) reported that the positive effect of mineral fertilizers depends upon well-regulated humus husbandry. Consequently, the growth of crops and therefore the yield of harvests depend upon the soil physical and mechanical properties as well as the inorganic and organic soil matter. Jacob (1990) reported that a well-timed and adequate application of fertilizer treatment promotes early and fast development of the crop, enabling it to recover more easily from insect pests attack. He indicated also that well nourished plants are more tolerant to attacks by various diseases and pests, and because of their vigorous growth, they recover better from any injuries suffered.

2.3.1.2. *Use of compost*

Compost as a component of organic farming involves the return of organic matter to the soil. It involves adding only products in their naturally occurring states to the soil. Some organic farming systems have produced good yields through increasing plant tolerance to insect pests and diseases, (Cooke, 1982). Muchena (1991) reported that majority of small-scale vegetable farmers in Zimbabwe use kraal manure, poultry manure and compost in the nursery and at planting for fertilizing and controlling insect and diseases. He stated further that a research is needed to make this improved practice cost effective and attractive to the financial resource poor farmers. Keya, (1978) reported that in East Africa, a growing potential source of organic materials (compost) and pretreated dried sewage is being used in vegetable farms in Nairobi with promising results, whilst in Tanzania, the productivity of vegetables is increased by using compost, lime and N.P.K. fertilizer. The compost increases the pH, changeable Ca, K and Mg, (Le Mare, 1972). The U.S. department of Agriculture observed that in Maryland, vegetable seedlings produced with compost were of better quality, had more developed root systems, and were transplanted with lower mortality and matured earlier than those grown only with inorganic fertilizer. Consequently through the proper use of compost, it is possible to grow wide variety of both horticultural and vegetable crops (Parr *et al.*, 1982). Compost contributes in a major way to the diversity of soil organic matter and living organisms critical to humus formation and to soil and plant health (Davis, 1982).

Organic matter when broken down into humus has direct and indirect effects on growth and yield of crops. The humic substances (mainly higher molecular weight parts) affect changes in the environment of the roots by changing physical and chemical properties like water holding capacity, gas exchange and others which lead to better growth of the crop, resulting in yield increases. The low molecular weight organic compounds from the compost results in increased plant metabolism. Phenolic compounds formed by lignin degradation or microbial syntheses are responsible for the resistance of crops to frost, drought, pests and diseases, (Flaig *et al.*, 1977). The application of organic matter or inorganic fertilizers alone gave unsatisfactory results in numerous vegetable experiments, but by combining both treatments, yield increases of up to 100 % were obtained, (Jacob, 1990). Noah (1998) also reported from his work on the effect of compost in nutrient uptake, fruit yield and yield component, fruit quality and disease incidence in tomato that no significant difference occurred among compost related treatments on marketable fruit yield and nutrient uptake but were significantly different from the untreated control and sole fertilizer treatments. On the effects of compost on yields, and vigour in cabbage, *Brassica oleracea*, var *capitata*, Ofoosu - Budu (unpublished) reported that plants grown in compost yielded heavier heads of at least 1.0kg/plant, grew vigorously and had more greener leaves compared to the fertilizer and the control treatments. Also according to Ofoosu - Budu, (unpublished) significant yield increase was realized when tomato seedlings were raised in compost and transplanted to the field at flower initiation under semi – deciduous forest condition. Consequently, by increasing the organic matter content of the growing medium and by improving soil moisture through irrigation, the number of infected plants was reduced and higher yields were produced in vegetables.

2.4. PEST MANAGEMENT IN OKRA

2.4.1. Use of chemical pesticides

Insect pest are responsible for reducing productivity and gross output in agriculture consequently losses due to these pests must be eliminated in order to increase yields (Hill, 1987). To achieve higher productivity, okra farmers have depended heavily on the use of synthetic insecticides to combat insect pest, diseases and nematodes. David (1964) reported that Thiometon at 0.1% applied twice at fortnight interval to one-month-old plants effectively controlled the leaf hopper, *Empoasca devastans* D. (Homoptera: Cicadellidae). Yazdani (1971) also found that four

organophosphates, demeton, phosphamidon, diazinon and parathion were very efficient at 0.02% concentration for the control of the spotted bollworm, *Earias fabia* Stoll. (Lepidoptera: Noctuidae) which caused considerable economic losses to cotton and okra in Tanzania. Rivivasan and Gowder (1973) indicated that spraying endosulfan 0.7 % or sevimol 0.01% three times controlled aphids, leafhoppers and fruit borers, which are serious pest of okra. Dipel (*Bacillus thuringiensis* var. *thuringiensis* Berliner) when applied at the rate of 0.56 - 1.12 kg/ha was suitable alternative for the control of Lepidopterous larvae associated when okra is grown for leaves and fruits (Taylor, 1974). According to Obeng-Ofori (1982), okra treated with 2g Furadan 5G per plant was protected against insect pests and parasitic nematodes, and resulted in higher yields. In Nigeria, Egwantu (1982) also reported from field trials that Furadan performed better in reducing infestation of okra plants by *Podagrica uniformis* and *P. sjostedti* than carbaryl, formetenate and phosmet, and resulted in higher yields. Letchnimanane and Paramasivan (1974) also reported that dusts of 0.1% DDT, 1% carbaryl, 5% fenithrothion, 1% Trichlorophan and 1% parathionmethyl gave better control of the jassid, *Empoasca devastans* (D.) on okra. Phosphin 24.E.C applied at 10ml /5 litres of water; Aldrex 40 applied at 11mls/5litres of water; Gadona 24 E.C at 20ml/5litres of water have been used successfully against okra pest. (Hill, 1987). Metcalf (1991) reported that insect pest of okra such as *Heliothis armigera* (Hub.); *Anthonomus grandis* Boh. and *Aphis gossypii* Glov. could be controlled effectively using 10% DDT. applied at 10 – 15 15kg/ha plus BHC containing 3% X – isomer. Tindal (1965) also reported that the use of DDT, BHC or malathion could effectively control leaf feeding beetles and weevils in okra when applied in an effectient manner. Udzu (1993) also reported from his survey on chemical insecticides used in okra production in the Assin manpong and Tema in the Central and Greater Accra Regions of Ghana respectively that the farmers use insecticide like Cymbush, Dimethoate, Karate and Furadan to control okra insect pests on their farms. Also from his work on the control of insect pest of okra at Legon, he recommended perfekthion at 10ml/litre of water applied using knapsack sprayer as more effective and efficient in controlling insect pest of okra than Furadan at 2g/plant. The perfekthion treated plants had the lowest number of damaged leaves, flower and fruit drops, and produced heavier and many undamaged fruits. Pesticide use has therefore been the main method for controlling pests of vegetables including okra.

The heavy reliance on synthetic insecticides for the control of insect pests in okra is likely to create problems such as environmental pollution and insecticide resistance in most of the insect pests. It is therefore about time to try other control measures that would be environmental and user friendly.

2.4.2. Use of botanical insecticides

Limonoids are bitter tetranortriterpenes found predominantly in plants belonging to the families Miliaceae and Rutaceae (Champagne, *et al.*, 1989), which account for the plants' insecticidal activity. The major compound in neem is *azadirachtin* and it is known to have adverse effects on more than 200 insect species (Butterworth and Morgan, 1971). Neem seed extracts have exhibited antifeedant activity against several insect orders, including Orthoptera (Attri, 1975), Coleoptera (Sarademma *et al.*, 1977), Lepidoptera (Warthen *et al.*, 1978) and Diptera (Kareem *et al.*, 1974). The compound responsible for these activities is *azadirachtin*, a terpenoid that Butterworth and Morgan (1971) isolated from neem seed (Sanaa, 1992). They reported that even at concentrations as low as 40 ug per litre of water, the compound prevented *Schistocerca gregaria* Forskal from feeding. Redknap (1991) reported of an antifeedant effect of aqueous neem seed extract against the flea beetles, *Podagrica sjostedti* and *P. uniformis*. Siddig (1981) also recorded similar effects of neem seed and leaf water extracts on *P. puncticollis*.

In the laboratory neem has demonstrated its potency against several insects. Arnason *et al.*, (1985) reported from laboratory tests of neem products on the corn borer (*Ostrinea nubilalis*) larvae that 10 ppm *azadirachtin* produced 100% mortality, 90% mortality at 1ppm and 0.1ppm showed no effect. However, the adults that later emerged had grossly altered sex ratios (more males than females) with the few females laying few eggs at later periods. Recent laboratory research on the desert locust indicated that neem oil causes 'solitarization' of gregarious locust nymphs. This is because after exposure to doses equal to 2.5 litres per hectare, the juveniles fail to form the massive, moving, marauding plagues that destroys crops and trees (Schmutterer and Freres, 1990). From a laboratory test on NeemAzal, a neem product of TRIFOLI, at 3% and 5% v/v concentrations against the cocoa capsid, *Sahlbergella singularis* (Hagl.), the 5% concentration proved very effective causing 95 % mortality compared to 90 % at 3 % concentration. Besides, the number of feeding lesions and exuviae (moulted skin) at both concentrations were much lower on the treated capsids than capsids in the control. This indicates

the chemical's inhibition on feeding and reproduction (Adu-Acheampong and Padi, 1999). Obeng-Ofori *et al.*, (1997) evaluating the effects of neem seed water extracts in the laboratory on the oviposition and development of fruit fly, *Ceratitidis capitata* (Wiedemann) infesting citrus at the Agricultural Research stations, Kade, reported that neem powder sprayed at 20%, 25% and 30% wt/vol. concentration significantly reduced oviposition and larval development.

Neem products have proved to be effective against insect pests of okra and other malvaceous plants. Patience (1994) compared aqueous extracts of neem seed with karate 2.5 E.C for the control of insect pests on okra at the Ashaiman Irrigation site. She reported that neem seed powder at 30 g/l of water although showed some control was not as effective as the karate 2.5 E.C in protecting the crop against insect pests, and therefore recommended an increase in the concentration of the neem extract. This observation was confirmed by Emosairue and Ukeh (1998) also working on water extract of neem seed powder in Nigeria and reported that at 50 g/l the aqueous extract was as effective as the synthetic insecticide, cymbush, in protecting okra against insect pests. Sackey (1999) reported from a field trial of aqueous neem seed extract on insect fauna of okra at the University farms, Legon, that the neem seed extracts at 50 g/l and 75 g/l were equally effective as the synthetic insecticide, actellic 25 EC., at 2 ml/l, in controlling the insect pests. He also recorded a better fruit yield of okra from the 50 g/l and 75 g/l neem treatments than the 100 g/l treatment and consequently recommended the 50 g/l as an alternative for okra insect pests control. Okra plants treated with a methanolic neem kernel extract at 1 % to 4 % concentrations reduced the damage caused by *P. uniformis* than the untreated plants (Adhikary, 1984). Dreyer (1986) confirmed the antifeedant effect of weekly applications of aqueous neemseed extract at 50 g/l against *P. uniformis*, and reported of similar effect against the occasional pest, *Sylepta derogata.*, and the onion thrips, *Thrips tabaci* (Freisewinkel, 1989). Taylor (1974) reported that Dipel (*Bacillus thuringensis* var *thuringensis* Berliner) applied at the rate of 0.56 – 1.12kg per hectare was a suitable alternative for the control of Lepidopterous larvae associated with okra grown for leaves and fruits while Irvine (1964) stated that early sowing of okra seeds would reduce the attack by the cotton stainer, *Dysdercus spp.* Schmutterer (1995) also reported in the Dominican Republic that water extracts of neem seed proved effective against *Aphis gossypii* on cucumber and okra, and against *Lipaphis erysimi* (Scop.) on cabbage as direct contact sprays. However, when applied in a systemic manner, neem has little effect on aphids because aphids feed only on the phloem tissues where neem materials least accumulate.

Various neem extracts are effective against over 200 insect species including many that are resistant to or inherently difficult to control with conventional insecticides. These include the sweet potato whitefly, green peach aphid, western floral thrips, diamond back moth and several leaf miners (Anon, 1992). Saxena (1990) reported that Neem cake after oil extraction successfully controlled brown plant hoppers and other pests of rice in the Phillippines. Similarly, five applications of a 25% neem oil emulsion sprayed with an ultra - low volume applicator protected rice against the increasing severe scourage caused by the plant hoppers.

Neem showed considerable potential for controlling pests of stored products with repellency being the primary importance. This is because jute sacks treated with neem oil or other neem extracts prevented pests particularly weevils (*Sitophilus* species.) and flour beetles (*Tribolium* species.) from penetrating for several months. (Anon, 1992). Zehrer (1984) also reported that Neem oil offered an extremely effective and cheap protection for stored beans, cowpeas and other legumes as it keeps them free from bruchid beetle infestation for at least six months, regardless of whether the beans were infected before treatment or not. NeemaAzal-T (a liquid formulation containing 5% *Azadiractin*) was found to be effective against *Sitophilus oryzae* in stored rice in Egypt especially when applied as bag surface treatment (EL - Lakwah and Abdel - Latif, 1998).

Neem seed extract when sprayed against the birch leaf miner, *Fenusa pusilla*, performed as well as the registered commercial pesticide, Diazinon. However, It was slow acting, and the insects continued to damage the trees before they died. When applied to the soil, neem compounds are absorbed by the roots and translocated to the crop's leaves so that leaf miners munching on the leaves get their moulting - hormone jammed, trapped fatally in their own juvenile skins (Anon, 1992). A commercial neem seed extract formulation (Margosan - O) produced 100 % kill at very low concentration 90.2 l/ha.) against the Gypsy moth, and after 25 days of application, larvae shrivelled, stopped feeding and died, (Anon, 1992).

A wide range of aqueous neem concentrations (5 - 50 g of seed powder per litre of water) have been quoted as being effective in reducing pest damage in vegetable field trials (Dreyer, 1987; Ruscoe, 1972; Asari and Nair, 1972; Cobbinah and Osei-Owusu, 1988). However, at 75 g/l, the

neem seed water extract significantly promoted vegetative growth in garden eggs than Karate and *Bacillus thuringiensis* (Biobit) preparations, and delayed flower initiation. (Ofosu-Budu, et. al., 1998). Afreh-Nuamah et al., (1993) reported from a field evaluation of two bio pesticides (Neem and Garlic seed water extracts) against the standard insecticide, (Karate 25EC - Lambdacyhathrin, a pyrethroid) on lepidopterous pest of egg plant in Ghana that Neem at 50 g/l (7 kg/ha) and the Karate treatments reduced fruit damage from 26.1 to 11.8 % and 26.1 to 10 %, respectively. They also indicated that among the three concentrations of neem seed water extract tested, (25 g/l, 50 g/l and 75 g/l), the performance of the 50 g/l was significantly similar to the Karate treatment during the major rainy season. However, in the minor season, the 75 g/l compared favourably well to the karate insecticide.

In onions, Fagoonee and Toory (1984) reported that 5 % aqueous extract of neem leaf gave effective control of the leaf miner, *Learis trifolii*, and that treated plots yielded four to six times higher than the control plots. Saxena and Batis (1982) indicated that egg-laying ability of *Amrasca devastans* on cotton treated with neem oil was significantly reduced. However in Taiwan, for reasons unknown, Klemm and Schmutterer (1993) and Schmutterer (1995) indicated that *Plutella xylostella* preferred neem treated cabbage to the untreated since very high numbers of eggs were laid on the treated than the untreated. In India, experiments have proved the repellent effects of aqueous neem seed extract (10 g/l) against *Empoasca spp.*, *Aphis gossypii* and *Epilachna* beetles on brinjal. Asari and Nair (1972) reported that neem performed better in post treatment counts showing immediate repellency. Consequently damage caused by the Colorado potato beetle, *Leptinotarsa decemlineata*, was significantly reduced by weekly application of ethanol extract of neem seeds (Reed and Reed, 1985). When exposed to sunlight, neem products degrade and lose their activity. Topically, the crude extract remains active for only eight days when exposed to the sun's ultra violet rays. Neem products although natural, can produce some deleterious effects. Jacobson (1989) reported that cabbage when treated with neem, produced medium sized heads whereas in tomato, growth and yield were reduced.

Tanzubil (1991) reported from Northern Ghana that aqueous extract of neem seeds or leaves reduced the incidence of *Megalurothrip sjostedti* infesting cowpeas and increased yields significantly. Eziah (1999) reported from a field trial on the evaluation of aqueous extracts of *Jatropha curcas* (40 g/l), *Jatropha* seed oil (4 ml/l), aqueous neem seed extract (75 g/l) and

cymethoate (2 ml/l) for the control of insect pests complex of aubergine that the plant products compared favourably with the synthetic insecticide in controlling most of the major insect pests (*Aphis gossypii*, *Selepa docilis* and *Urentius hystericellus*). Osterman (1992) also reported from a field trial that weekly applications of aqueous neem seed extract (50 g/l) drastically reduced the damage caused by *Heliothis amigera* to tomato compared to aqueous extract of neem leaf and neem powder. The treatment was also superior to deltamethrin, and increased marketable fruit yield considerably. Similarly, weekly applications of aqueous extract of neem seed (50 g/l) and 1.5% neem oil when compared with two different insecticide combinations against *Bemisia tabaci*, the two neem treatments kept the population levels of *B. tabaci* very low compared to the synthetic insecticide, (Sierra, 1992, and Schmutterer, 1993).

The extent of pest control achieved by any of the above methods would depend on the efficiency and efficacy of the product, its application (distribution) and coverage of the target. Consequently it is always important to choose a nozzle that would help achieve these objectives.

2.5. PRODUCT APPLICATION TECHNIQUES FOR INSECT PESTS MANAGEMENT

Nozzles are the means by which plant protection agents are applied to their targets and the success of any plant protection measure depends on the quality of the product, its distribution and coverage and correct timing of application (Basel, 1985, Norman, 1986).

2.5.1. Hydraulic Energy Nozzles

A nozzle is any device through which spray liquid is emitted, broken up into droplets and dispersed at least over a short distance, (Mathews, 1984). A hydraulic energy nozzle is that type in which pressure generated by liquid with sufficient velocity energy breaks a thin sheet of liquid into droplets of different sizes (Dent, 1990). Four different types of hydraulic energy nozzles have been identified (Mathews, 1984, and Anon, 1991).

(a) Polyjet, Flood or Impact nozzle: This is probably the most popular nozzle used with a knapsack sprayer. It produces a fan shaped spray pattern. There is usually more spray deposited at the edges of the fan (spray horns) with wider swath width.

(b) Cone Nozzles:

(i) Hollow Cone. In this, liquid is forced through a slot to impact a swirl to the spray cloud, which produces a hollow cone shape

(ii) Solid cone. This pattern is produced by passing the liquid centrally through the nozzle to fill the air core, giving a narrow display of spray.

(c) Variable cone nozzle: In this, the swirl chamber depth can be adjusted to produce sprays ranging from solid stream to a fine mist. It has two or more holes. Cone nozzles are used widely for spraying foliage because their droplets approach leaves from more directions than in the single plane produced by a flat fan or polyjet nozzles.

(d) Fan nozzles: In this, liquid is forced through an elliptical hole producing a fan jet with tapered edges. The random integration of the spray sheet from the nozzle produces a wide range of droplets spectrum. It is recommended for general applications particularly spraying flat surfaces such as the soil. Anon (1991) indicated that where a single cone nozzle was used and not a boom, the effective spray width was small and for convenience, operators frequently used flood or polyjet nozzle to obtain wider swath. However, this technique was not recommended for fungicide or insecticide applications where droplet size and distribution are critical.

2.5.2. Spray coverage and distribution

When sprays are applied at high volume (HV), the aim is to achieve complete coverage of the crop. However with discrete droplets, the pesticide applicator needs to know the droplets density required and the distribution of the droplets on the target. Microvariations in droplets have little or no effect on the control especially when systematic or translocate insecticides are used, hence control of mobile pest like jassids can be achieved without complete coverage but uniform coverage is required for the control of scale insects and leaf miners (Mathews, 1988).

2.5.3. Spray Application

Successful spraying depends on thorough coverage of the target with evenly distributed individual droplets, and for good biological efficiency, an application that would yield not less than 20 droplets per cm^2 on the target is recommended (Basel, 1985). According to Norman (1986) the technique by which plant protection agents are applied, are so important for successful

plant protection as the product itself, and as decisive as the timing of its application. Hence the success of any plant-protection measure depends on the quality of the product, its distribution and coverage, and correct timing.

Evaluating four different spray nozzles on a cowpea variety “Asontem” at the University of Ghana research station, Kade, Afreh–Nuamah (1991) reported that for each of the insecticides (Cymbush and Karate) the cone nozzle gave better spray coverage and distribution at all stages of the plant growth than the polyjet on the Technoma Knapsack sprayer. However, when the electrodyne sprayer was used, greater efficiency was achieved because of electrical charges it imparts to the spray droplets.

2.6. INTEGRATED CROP MANAGEMENT IN OKRA

The combination of the various chemical and soil amendment practices and cultural methods in managing okra varies from place to place in Ghana. This holistic approach, which aims at improving the performance and yield of the crop, helps to decrease pest populations to levels that would not cause economic damage and also enhances the vigour of the crop. In Ghana, at Asempaneye, a suburb of Kumasi in the Ashanti Region, okra farmers grow their crops in compost and sprayed neem seed extracts against insect pests. They gained over 200% increase in fruit yield and a corresponding higher fruit weight compared to those grown using conventional farmer practice (fertilizer application). Also in farms where integrated crop pest management practices were carried out (timing insecticide application, regular weed control and using methods that enhance plant nutrition), populations of natural enemies were far higher than that of insect pests (Antwi *et al.*, 1999). From a survey on integrated pest management (IPM) in some regions of Ghana, FAO (1997) reported that at Dawhenya irrigation project site in Greater Accra Region, vegetable growers use organic manure and fertilizers in an attempt to improve soil fertility and to increase yield. Such farmers carry out four pesticide applications in a cropping season to fight insect pest with the view to complementing the effects of the soil amendment practice to enhance yield in okra. However, at Ekoso in the Asamankese district of the Eastern Region, okra growers use chemical fertilizers to grow the crop. Besides, every year, different locations are used (crop rotation) for the crop with the view to evade nematode and insect pest attack. Pesticides such as Karate 2.5 EC and Cymbush are sprayed using knapsack sprayers to

control the most rampant insect pest *Prodagrica* spp. These practices help to increase the yield of okra.

At Kasoa in the Central Region, okra farmers intercropped okra with pepper, and maize. In the field, chemical fertilizers are applied at 2 weeks and 40 days after seedling emergence. To prevent the development of resistance to insecticides, the farmers use a mixture of Biobate and Karate to protect their crop and reap higher yields with less damage from insect pests.

At Akumadan in the Ashanti Region, okra farmers grow the crop using manures for fertilizing the crop and where funds are available, at flowering, side dressing is done with N.P.K. fertilizer in holes. Two insecticide products are mixed and used to protect the crop with 4 – 8 applications made in a season using knapsack sprayers. However, in Kumasi, the farmers use Dipel mixed with Karate and Dipel alone to control beetles and Lepidterous pests to obtain higher yields.

In the Near East, high rates of nematode infestation in okra is controlled using fumigants such as DD and 1,3 - dichloropropene applied a week before sowing of seeds. Weeds are controlled manually by hoeing four times at fortnight intervals and the farm irrigated to field capacity a week after (Lebeek and Lenteren, 1992). However, in Tunisia, okra farmers grow the crop using poultry manure with three irrigations in a week. These farmers also manage soil borne pathogenes that survive on debris in the soil, *Botris cinerea* and *Colletotrichum coccodes*, which account for over 32% fruit yield reduction by practicing crop rotation every two to three years (Davis, 1982).

In Western Nigeria, during the dry season, okra farmers manage their crop by regular watering to ensure good yields. Also since insect pests greatly reduce seed production, they are managed by prompt harvesting of the matured fruits 30 days after flowering. The fruits are then opened immediately in the sun to avoid attack by the larvae of *Heliothis armigera* on the soft ripe seed. Consequently, seed losses through dehiscence are also avoided (Ewete *et al.*, 1980). In the case of diseases, the yellow vein mosaic is a serious virus disease and often causes total crop failure. Okra farmers manage this situation by removing and burning affected plants, while those in the vicinity of such affected plants are supplied with additional fertilizer and watered regularly. For Fusarium wilt, the farmers uproot and burn affected plants, weed the farm and reduce water supply to the field (Oyolu, 1983).

CHAPTER THREE-EXPERIMENTAL WORK
STUDIES ON SOIL AMENDMENTS, AND NEEM PRODUCTS FOR THE
MANAGEMENT OF INSECT PESTS OF OKRA

3.0. INTRODUCTION

Insect pests and poor soil fertility have been the major constraints to successful okra production in Ghana. Potential farmers grow the crop by applying chemical fertilizers to promote yield increases. However, continual use of these fertilizers renders the soil unproductive due to excessive accumulation of salts (Davis, 1982). Resource poor farmers grow the crop without the application of any soil nutrient. Consequently, the tolerance of the crop to insect pests and diseases, as well as its yield becomes drastically reduced. Yield from fertilizer treated vegetables are often low unless the nutrients are replenished at the reproductive stage of the crop (Grimes and Clark, 1963), thus increasing the cost of production.

Compost is easy to prepare and hence comparatively cheap. It contains both major and minor nutrients and when applied to vegetables, they obtain a wide range of nutrients, which enable them to thrive and withstand attacks from diseases and insect pests (Hugues and Philippe, 1992) and thus increase their yields. This potential of compost to pest management has not been realised by most vegetable growers.

Aqueous neem seed extracts (ANSE) have been reported to control over 200 insect species including those that have been resistant to or inherently difficult to control with conventional insecticides (Schmutterer, 1995). Consequently when the effects of neem are complemented with agronomic practices that will enhance plant tolerance, the devastating effects of insect pests on okra could be reduced and yield drastically increased. It has therefore become necessary to investigate compost and neem products on the performance of okra.

3.1. MATERIALS AND METHODS

3.1.1. Collection of neem seeds, drying and storage

Ripe neem seeds were collected from neem trees at Klagon, Lashibi near Ashaiman. The seeds were depulped in water and dried on tarpaulin sheets in a shade for 14 days at room temperature (28 ± 2 °C). This was to prevent deterioration and germination of the seeds. The dried seeds were stored in sacks in a room and used when needed.

3.1.2. Preparation of aqueous neem seed extract

Neem seeds were milled for 5 minutes using a high - speed blender (Electodee, model 13452E, Volume - 750 ml.). The powdered seed was weighed and dissolved in sufficient water at the rate of 50 g/l for 24 hours to ensure adequate infusion. The mixture was sieved using a 0.5 mm sieve, the residue was discarded and the filtrate used for the spraying.

3.1.3. Other insecticides

Other insecticides used were dimethoate 40 EC and neemazal T/S. Dimethoate: O,O - dimethyl-S-methyl carbamoyl (methyl) phosphorodithioate, is an organophosphorus insecticide with systemic and contact action against a wide range of insects attacking various crops particularly sap sucking insects. It was applied at the manufacture's recommendation of 75 ml/ 15litres of water.

NeemAzal T/S on the other hand is an emulsifiable concentrate (EC) of Azadirachtin supplied by EID Parry and Trifolio - M- GmbH, Germany. It contains 10,000 ppm Azadirachtin and over 60 other limonoids. It has a wide range of activity (antifeedancy, repellency, oviposition deterrent, growth regulation etc.) against a broad spectrum of insect pests of crops. It was applied at the manufacture's recommended rate of 2 ml/litre of water (ie. 30 ml/15liters of water).

3.1.4. Site selection, Land preparation and sowing

The Ashaiman Irrigation site was chosen for the project since water for irrigation is readily available and Ashaiman is one of the major vegetable growing areas in the Greater Accra region of Ghana, supplying Tema and Accra with fresh vegetables. Most vegetable farmers in the area

also grow okra. The soil is clayey and an example of Akuse soil series, a Dystric Vertisol (FAO/UNESCO classification). The slope of the land is almost flat (Terrace land), drains slowly and floods easily. The texture is clay loam with the following properties: pH = 7.6, organic content = 1.18, total nitrogen = 0.09%, C/N ratio = 13.1, available P (ppm) = 18.1, CEC = 25.1, and changeable cations: Ca = 7.86, Mg = 5.22, K = 0.61, Na = 0.37 (Koei, 1997).

A land of 18 x 144 m was ploughed and harrowed to a fine tilth. The field was lined and pegged at 35 x 17.5 m per block. Four blocks were laid across the gradient of the land with 1m distance between adjacent blocks to offset any variation in soil moisture and fertility. Within a block, 28 small cells of size 2.7 x 3.6 m each were demarcated with a 1m distance between adjacent cells to prevent spray drift. Within each cell, lining and pegging was done at a spacing of 90 x 60 cm.

3.1.5. Treatments and their application, and experimental design

Owing to the clayey nature of the soil, the field was irrigated to field capacity and sowing was done the following day. The okra variety used was Labadi dwarf and this was sown at the rate of three seeds per hole. A split – plot design was used with NPK 15-15-15 fertilizer (20 g/plant), compost (500 g/plant), compost plus fertilizer (250 g/plant and 10 g/plant respectively) and no soil treatment (control) as main plots treatments. Insecticides namely – aqueous neem seed extract, (ANSE), Neemazal, and dimethoate as well as no spray (control) constitute the sub–plot treatments, and were applied using a Green cone hydraulic energy nozzle fitted on the PB- 16 knapsack sprayer. The compost was prepared from cocoa husk, poultry manure and rice husk, and was supplied by Dr. Ofosu - Budu of the University of Ghana Agricultural Research Station, Kade. Treatments were combined in a factorial manner per block.

One week after emergence, the compost treatment was applied around the base of the seedlings, and a week later the fertilizer was applied 5 cm from the stem of the seedlings to prevent scorching of their tender roots. The compost was immediately covered with soil to form ridges and furrows created for irrigation. Spraying was done on weekly schedule using the Green cone nozzle and the insecticides at their recommended dosages in turn. Seedlings were thinned two weeks after emergence to one plant per hill. All insecticide treatments were carried out using the knapsack sprayer (Model PB - 16 from Malaysia) with the water as a diluent. Each insecticide treatment was applied fortnightly from November 2000 through to February, 2001. Cultural

practices, weeding and irrigation, were done by local vegetable growers in Ashaiman who participated in the project. Weeding was done when necessary and the field irrigated at weekly intervals to field capacity. In each block, both main-plot and sub plot treatments were assigned randomly. Within a cell in each block, there were four rows of seven plants each, and the middle 2 rows were used as a sampling area, leaving a border row of one plant. Consequently, 10 plants were taken as reading units.

Farmers participated in the project because Ashaiman is one of the major vegetable growing areas in the Greater Accra region and the farmers in this area grow okra throughout the year using chemical fertilizers only. Also the farmers always use synthetic insecticides to protect their crops without any agronomic practices that could help manage their pest problems. Consequently, the farmers' participation was to indirectly influence their practices and to expose them to sustainable okra production practices.

3.1.6. Data collected.

Plant height was assessed fortnightly using a meter rule. Height was taken from the soil surface to the terminal bud and the average for each of the 10 plants was calculated for each cell (small plot, 2.7 x 3.6 m in a block). Plant girth was taken at 10 cm from the soil surface and the average recorded. Number of functional leaves was also counted for the 10 plants and the average recorded (Functional leaves are green leaves with less than 50 % area damaged). Insect damage to leaves was assessed by determining the proportion of leaf area damaged for the three topmost fully flexed leaves and then rated using a five-point scale (1 = no damage; 2 = 1 -20 % damage; 3 = 21 - 50 % damage; 4 = 51 - 75 % damage; 5 = > 75 % damage).

3.1.6.1. *Insects.*

The number and type of insects were assessed by sampling the insects using sweep net, and water traps (detergent, omo, in water solution) weekly. Sweeping was done at a rate of 1 sweep per step and 10 sweeps per cell in east - west direction. During sampling, 2 minutes was spent per reading unit in a cell and the number and kinds of insects found on a plant recorded. Sampling started from 6 am (0600. GMT), and ended 9am (0900. GMT). The immature stages found were cultured in the laboratory until the adults emerged. The water traps were arranged per cell and were inspected early mornings at weekly intervals, and the captured insects were sieved and

counted. The insects were soaked in 70% alcohol for 24 hours after which they were spread on tissue papers for another 24 hours to absorb the alcohol and then pinned. Insects caught were then identified by examining their features using identification keys under a stereo zoom binocular microscope (Zeiss, Stemi 1000).

Spraying started three weeks after emergence by which time pest damage was becoming pronounced.

3.1.6.2. *Fruit damage.*

The harvested fruits were separated into marketable and unmarketable portions and the percentage unmarketable fruit per treatment was calculated as

$$\frac{\text{No. of unmarketable fruits}}{\text{Total No. of fruits}} \times 100$$

The number of fruits bored by fruit borers was also recorded. Dry matter yield of fruit was determined by randomly selecting five fruits from each plot. The fruits were weighed, enclosed in a paper bag and dried in an oven to a constant temperature at 105 °C for 12 hours (Berrie *et al.*, 1987). The moisture content and the dry weight were recorded. The dry matter was calculated as mean fruit fresh weight - mean fruit moisture content.

3.1.6.3. *Fruit yield.*

At flowering, and post-flowering periods, the number of fruits dropped due to *D. Superstitiosus* attack was counted per treatment. Harvesting was done every other day (i.e. at 3 days interval) and fruit yield per treatment was determined by harvesting matured fruits (i.e. fruits produced 6 days after flower opening) (Ewete *et al.*, 1980) into well-labeled polybags. The polybags were taken to the laboratory, and by means of electronic scale, the average fruit weight was determined. Yield in tonnes per hectare (t/ha) of fruits obtained from each plot was calculated based on plot size, plant spacing and mean yield per plant. Other yield components such as number of fruits per plant per harvest, weight of marketable fruits as well as number of branches per plant were also recorded.

3.1.6.4. *Assessment of economic benefits.*

The economics of production was determined by assessing the costs associated with the use of the various nutrient sources. These were calculated by determining the cost of the soil nutrients on per - hectare basis. That due to pesticide application based on the cost of the pesticides was also determined. The total value of the harvested fruits was determined based on the prevailing price of ₵ 2000.00 per kilo. All costs of labour, land cultivation, maintenance of experimental site, seed were similar for all treatments and their values adjusted on per hectare basis from the research plots. Marginal cost and benefit were calculated as the difference between costs and benefits of treatments and their controls respectively.

3.1.7. **Data analysis.**

All count data on insect pests and yield indices were transformed by the square root transformation, that is $\sqrt{(x + 0.5)}$ to take care of zero figures before the variances were analysed. Where significant differences were observed, means were separated using the Least Significant Difference (LSD) test. Data in percentages were also transformed using the arc sine.

CHAPTER FOUR

4.0. RESULTS

4.1. INSECT FAUNA ENCOUNTERED ON OKRA AT ASHAIMAN.

The lists of insects encountered during the sampling period from the field work, are shown in Table 6. The insects fall within the orders Coleoptera, Heteroptera, Lepidoptera, Homoptera, Diptera, Orthoptera, Odonata, and Hymenoptera. Different stages attack various parts of the crop causing varying degrees of damage. The dominant order was Coleoptera followed by Heteroptera, and Diptera being the least. Among these, the major insect pests were classified based on the degree of their damage and their population levels. Those found included the cotton aphids, *Aphis gossypii* Glov., the cotton mealy bug, *Phenacoccus hirsutus* Green., white flies, *Bemisia tabaci* Genn., the flea beetle, *Podagrica uniformis* Jac., the cotton stainer, *Dysdercus supersticiosus* (F.). The beneficial insects were *Crematogaster* spp., *Brachyplatus* spp., the lady bird beetle, *Epilachna* spp., *Cheilomenes vicinia* Muls., *Cheilomenes lunata* F., *Odonata* spp., and *Rhinocoris rapax* (L.). Other insect pests found to cause little damage were considered to be minor pests.

Table 6. List of insects collected from okra plant during the sampling period at Ashaiman.

Insect	Order	Family	Activity
<i>Podagrica uniformis</i> Jac.	Coleoptera	Halticidae	Adult feeds on leaves
<i>Anthonomus grandis</i> Boh.	Coleoptera	Curculionidae	Adults feed on flower buds
<i>Sphaerocoris</i> spp.	Coleoptera	Scutelleridae	Feeds on leaves
<i>Epicauta abovittata</i> Gestro.	Coleoptera	Meloidae	Adults feed on leaves
<i>Colaspis flvida</i> Lefevre	Coleoptera	Chrysomelidae	Adults feed on leaves
<i>Mylabris</i> spp.	Coleoptera	Meloidae	Adults feed on leaves
<i>Coryna</i> spp.	Coleoptera	Meloidae	Adults feed on flower pollen
<i>Podagrica sjostedti</i> Jac.	Coleoptera	Halticidae	”
<i>Lagria cuprina</i> Thoms.	Coleoptera	Lagriidae	Feeds on flower buds
<i>Aspidomorpha</i> spp.	Coleoptera	Chysomelidae	Adults Feeds on leaves
<i>Pachnoda</i> spp.	Coleoptera	Cetoniidae	Adults Feeds on fruits
<i>Epilachna</i> spp.	Coleoptera	Coccinelidae	Feeds on leaves
<i>Brachyplatus</i> spp.	Coleoptera	Coccinelidae	”
<i>Cheilomenes vicinia</i> Muls.	Coleoptera	Coccinelidae	”
<i>Cheilomenes lunata</i> F.	Coleoptera	Coccinelidae	”
<i>Podagriac bowringi</i> Baly.	Coloeptera	Halticidae	Adults feed on leaves
<i>Lagria villosa</i> F.	Coloeptera	Lagriidae	Feed on flower buds
<i>Gasteroclisus rhomboidalis</i> Boh.	Coloeptera	Curculionidae	Feeds on flower buds
<i>Diopsis thoracica</i> Westw.	Diptera	Diopsidae	Larva feeds on flower

<i>Riptortus dentipes</i> Dall.	Hemiptera	Coreidae	Suck sap from fruits
<i>Dysdercus supersticiosus</i> (F.)	Heteroptera	Pyrrhocoridae	Adults and nymphs suck sap from fruits
<i>Aspavia brunnea</i> (Hust.)	Heteroptera	Pentatomidae	Suck sap from terminal buds
<i>Aspavia ingense</i> (F.)	Heteroptera	Pentatomidae	„
<i>Nezera viridula</i> (L.)	Heteroptera	Pentatomidae	„
<i>Chinavia acuta</i> (L.)	Heteroptera	Pentatomidae	Suck sap from terminal and flower buds
<i>Anoplecnemis curvipes</i> Fab.	Heteroptera	Coreidae	Suck sap from fruits
<i>Oxycaraenus</i> spp.	Heteroptera	Lygaeidae	Suck sap from flower buds
<i>Dysdercus fasciatus</i> Sign.	Heteroptera	Pyrrhocoridae	Suck sap from fruits
<i>Anthocoris</i> spp.	Heteroptera	Coreidae	Adults suck sap from fruits
<i>Acanthomia horrida</i> Germ.	Heteroptera	Coreidae	Suck sap from flower buds
<i>Calidea dregii</i> Germar.	Heteroptera	Pentatomidae	Suck sap from fruits and flower buds
<i>Graptostethus</i> spp.	Heteroptera	Pyrrhocoridae	Suck sap from fruits
<i>Acanthocoris</i> spp.	Heteroptera	Pentatomidae	„
<i>Rhinocoris rapax</i> (L.)	Heteroptera	Reduvidae	Feeds on other bugs and coleoptera
<i>Aphis gossypii</i> Glov.	Homoptera	Aphididae	Suck sap from under side of older leaves
<i>Phenacoccus hirsutus</i> Green.	Homoptera	Pseudococcidae	Suck sap from leaves and tender shoots
<i>Bemisia tabaci</i> (Genn.)	Homoptera	Aleyroidae	Suck sap from under side of older leaves
<i>Empoasca</i> spp.	Homoptera	Cicadellidae	Suck sap from under side of older leaves
<i>Crematogaster</i> spp.	Hymenoptera	Formicidae	Attend mealybugs and aphids
<i>Heliothis armigera</i> Hb.	Lepidoptera	Noctuidae	Larvae feed and bore into fruit
<i>Sylepta derogata</i> (F.)	Lepidoptera	Pyralidae	Larva rolls leaves and feed on leaf lamina
<i>Earias insulana</i> Boisd.	Lepidoptera	Noctuidae	Larva feeds on leaves
<i>Anomis flava</i> (F.)	Lepidoptera	Noctuidae	Larva feeds on leaves
<i>Selepa docilis</i> Butler	Lepidoptera	Noctuidae	Larva feeds on leaves
<i>Odonata</i> spp.	Odonata		Feeds on other insects
<i>Brachytrupes membranatus</i> Drury.	Orthoptera	Gryllidae	Feeds on leaves
<i>Atractomorpha acutipennis</i> Guerin.	Orthoptera	Pyrgomorphidae	„
<i>Zonocerus variagatus</i> (L.)	Orthoptera	Pyrgomorphidae	Feeds on leaves
<i>Trilophidia</i> spp.	Orthoptera	Acrididae	„
<i>Eulioptera reticulata</i> Pagge	Orthoptera	Gryllidae	Feeds on leaves
<i>Acisoma</i> spp.	Orthoptera	Gryllidae	Feeds on leaves
<i>Urenthis</i> spp.	Orthoptera	Gryllidae	Feeds on leaves

4.1.1. Effects of the various insecticide treatments on the major insect pests and beneficial insects observed on okra during the sampling period.

Table 7a shows the effect of the insecticide treatments on the major insect pests observed in the field during the experiment. The numbers of *Aphis gossypii* Glove. and *Bemisia tabaci* Genn. recorded were significantly ($P < 0.01$) higher under the dimethoate treatment compared to the neem treated plots, with *Sylepta derogata* (F.) being the least recorded insect (appendix 1). Under the neem products, the ANSE treatment recorded significantly ($P < 0.01$) lesser number of the major pests relative to the neemazal and the control treatments. However, the overall performance of the ANSE in the control of the major pests was not significantly ($P < 0.01$) different from that of the dimethoate.

Table 7a: Effects of the different insecticide treatments on the major insect pests

Insect pest	Mean (\pm) Number of Insects			
	ANSE	Neemazal	Dimethoate	Control
<i>Aphis gossypii</i> Glov.	25.80d \pm 1.2	106.20c \pm 0.9	135.03b \pm 1.3	168.10a \pm 1.1
<i>Bemisia tabaci</i> Genn.	34.28d \pm 0.6	108.35c \pm 1.1	139.03b \pm 0.6	167.53a \pm 0.8
<i>Empoasca</i> spp.	29.65c \pm 1.4	77.65b \pm 1.7	15.60d \pm 0.8	97.22a \pm 1.1
<i>Phenacoccus hirsutus</i> Green.	39.98c \pm 1.1	93.20b \pm 0.4	9.95d \pm 1.5	105.73a \pm 0.6
<i>Heliothis armigera</i> (Hb.)	26.50c \pm 2.0	60.85b \pm 0.8	8.45d \pm 0.2	89.43a \pm 0.2
<i>Dysdercus</i> spp.	8.73c \pm 1.6	31.08b \pm 1.5	14.35d \pm 1.1	43.25a \pm 0.8
<i>Anthonomus grandis</i> Boh.	29.45c \pm 0.4	65.75b \pm 0.2	11.00d \pm 1.4	90.78a \pm 0.4
<i>Sylepta derogata</i> (F.)	29.68c \pm 0.3	53.78b \pm 0.8	5.85d \pm 1.2	66.88a \pm 1.5
<i>Podagrica uniformis</i> Jac.	12.55c \pm 2.1	45.30b \pm 0.6	10.00c \pm 0.3	78.13a \pm 1.6
Mean	29.29c	71.35b	38.81c	100.78a

LSD = 10.02; Means followed by the same letter in a row are not significantly different ($P > 0.01$)

Table 7b shows the effect of the different insecticide treatments on the beneficial insects encountered during the experiment. The dimethoate treatment recorded significantly ($P < 0.01$) the least number of all the beneficial insects compared to the other treatments (appendix 2). The control (no spray), however, recorded significantly ($P < 0.01$) the highest number of each beneficial insect collected. Generally, the effects of the botanical insecticides, ANSE and neemazal, on the beneficial insects were not significantly ($P < 0.01$) different. However, they differed significantly from the synthetic insecticide, dimethoate.

Table 7b. Effects of the different insecticide treatments on the beneficial insects.

Beneficial insects	Mean (\pm) Number of Insects			
	ANSE	NeemAzal	Dimethoate	Control
<i>Cheilomenes vicina</i> Muls	16.75b \pm 1.3	12.70c \pm 1.4	1.43d \pm 0.2	39.68a \pm 0.5
<i>Cheilomenes lunatus</i> (F.)	30.35b \pm 0.5	34.13b \pm 0.6	0.78c \pm 0.1	46.93a \pm 1.1
<i>Rhinocoris</i> spp.	14.05c \pm 1.1	18.48b \pm 0.5	0.83d \pm 0.4	37.45a \pm 1.3
<i>Rhinocoris rapax</i> (L.)	21.43b \pm 1.8	32.55a \pm 0.8	0.98c \pm 0.1	32.60a \pm 0.5
<i>Coccinella</i> spp.	27.95b \pm 0.9	30.23b \pm 1.7	1.05c \pm 0.1	37.68a \pm 0.7
<i>Odonata</i> spp.	24.48b \pm 1.7	30.78a \pm 1.8	1.20c \pm 0.3	32.83a \pm 1.2
<i>Bachyplatus</i> spp.	24.68b \pm 0.3	25.65b \pm 0.2	1.13c \pm 0.1	32.13a \pm 0.4
Mean	22.81b	24.36b	1.05c	37.04a

LSD = 3.91. Means followed by the same letter in a row are not significantly different ($P > 0.01$)



Plate 1. *Dysdercus supersticiosus* (Major pest)



Plate 2. *Anthonomus grandis* (Major pest)



Plate 3. *Podagrica uniformis* (Major pest)



Plate 4. *Phenacoccus hirsutus* (Major pest)

4.1.2. Relative abundance of major pests and beneficial insects encountered at pre- and post- flowering growth stages of okra.

Tables 8a and 8b show a summary of major pests and beneficial insects encountered at pre- and post- flowering growth stages of okra under the various treatments. A week after seedling emergence, the cotton aphid, *Aphis gossypii* Glove. was the first to be observed on the compost treated plants and then on the sole fertilizer treated plants. Later they appeared in each of the soil amendment treatments irrespective of the insecticide applied. In the control, no soil amendment treatment, infested plants sprayed with any of the test insecticides showed no improvement in their stuntedness and distorted leaves except those treated with ANSE. The yields of such affected plants were virtually reduced to zero. During the 2nd and 3rd weeks after seedling emergence, *Podagrica uniformis* Jac. *Bemisia tabaci* Genn., *Empoasca* spp. and *Phenacoccus hirsutus* Germ. appeared and were randomly distributed in the field. Attack by these pests caused severe wilting of leaves particularly in the control (no soil treatment) plots where no pesticide was applied. However, the compost, and inorganic fertilizer treated plants appeared healthy with those grown in compost developing broader and greener leaves. After flowering, the infestation levels of the major pests were not much different from that at pre- flowering. Fruit damage and flower drop were also very low in the compost treated plants compared to those in the sole fertilizer and the control (no soil amendment) treatments. *Dysdercus supersticiosus* Fab. and *Heliothis armigera* (Hb.) were virtually absent at the pre- flowering stage and appeared only after flowering. The *D. supersticiosus* sucked sap from young and matured fruits and caused heavy fruit drop in plants grown without any soil amendment. However, its attack in the ANSE and dimethoate sprayed plots were quite low for each soil treatment.

Predators like the Coccinellid beetles and the *Cheilomenes* species were the first to be observed during the 2nd week after seedling emergence and they fed on the aphids at the underside of the leaves. These beneficial insects occurred abundantly on the compost treated plants compared to the other soil treatments. Other beneficial insects such as *Odonata* and *Rhinocoris* species appeared later after the 4th week, but *Rhinocoris rapax* in particular, appeared after fruit setting and were found feeding on the Pentatomid pests, *Aspavia* and *Nezera* species. The number of beneficial insects was quite low on the dimethoate treated plants irrespective of the soil treatment. Both insect pests and beneficial insects occurred abundantly on the compost treated plants than those in the sole fertilizer and the control plots. However, such compost treated plants

grew healthily, vigorously and produced succulent fruit and vegetative parts, and yielded higher. They were also less damaged particularly when sprayed with ANSE or dimethoate. Other insects listed in Table 6 were not considered serious pests of okra in Ghana due to the lesser damage they inflicted on the crop. Plate 5 shows one of the beneficial insects while plates 6 - 8 depict some of the minor insect pests encountered during the experiment.



Plate 5. *Rhinocoris rapax* (Beneficial insect)



Plate 6. *Aspavia brunnae* (Minor pest)



Plate 7. *Anoplocnemis curvupis* (Minor pest)



Plate 8. Larva of *Earias insulana* (Minor pest)

Table 10a. Incidence of major insect pests encountered on okra under the various treatments at pre- and post- flowering growth stages

Major insect pests	Compost								Compost + Fertilizer							
	Dimethoate		ANSE		Neemazal		Control		Dimethoate		ANSE		Neemazal		Control	
	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST
<i>Aphis gossypii</i> Glove.	***	***	++	+	***	***	***	***	***	***	++	++	***	***	***	***
<i>Podagrica uniformis</i> Jac.	+	+	+	++	**	**	**	**	+	+	++	+	**	**	**	**
<i>Sylepta derogata</i> (F.)	+	+	++	++	*	*	**	**	+	+	++	++	*	*	**	**
<i>Dysdercus supersticiosus</i> (F.)	NIL	++	NIL	++	NIL	**	NIL	**	NIL	++	NIL	++	NIL	**	NIL	**
<i>Phenacoccus hirsutus</i> Green.	++	++	+	++	*	*	**	**	++	++	+	+	*	**	**	**
<i>Heliothis armigera</i> (Hb.)	NIL	++	NIL	++	NIL	*	NIL	*	NIL	++	NIL	++	NIL	*	NIL	*
<i>Bermisia tabaci</i> Genn.	***	***	*	*	***	***	***	***	***	***	*	*	***	***	***	***
<i>Empoasca</i> spp.	++	+	++	++	**	**	**	**	*	*	++	++	**	**	**	**
<i>Anthonomus grandis</i> Boh.	+	++	++	++	*	*	**	**	+	++	++	+	**	**	**	**

Major insect pests	Fertilizer								Control							
	Dimethoate		ANSE		Neemazal		Control		Dimethoate		ANSE		Neemazal		Control	
	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST
<i>Aphis gossypii</i> Glove.	***	***	++	+	***	***	***	***	**	**	++	++	**	**	**	**
<i>Podagrica uniformis</i> Jac.	+	+	+	++	**	**	**	**	+	+	+	+	*	*	*	*
<i>Sylepta derogata</i> (F.)	+	NIL	++	++	*	*	*	*	+	NIL	++	++	*	*	*	*
<i>Dysdercus supersticiosus</i> (F.)	NIL	++	NIL	++	NIL	**	NIL	**	NIL	+	NIL	+	NIL	*	NIL	++
<i>Phenacoccus hirsutus</i> Green.	+	+	+	+	**	*	**	**	+	+	+	+	*	*	**	**
<i>Heliothis armigera</i> (Hb.)	NIL	++	NIL	++	NIL	*	NIL	**	NIL	+	NIL	+	NIL	*	NIL	*
<i>Bermisia tabaci</i> Genn.	***	***	++	++	***	***	***	***	**	**	++	++	**	**	**	**
<i>Empoasca</i> spp.	+	+	++	++	*	*	**	**	++	++	++	++	*	*	**	**
<i>Anthonomus grandis</i> Boh.	+	+	++	+	*	*	**	**	+	+	+	+	++	++	++	*

Incidence key :

*** : Very high infestation (80 or more insects/ sampling)

** : High infestation (50 - 79 insects/ sampling)

* : Medium infestation (30- 49 insects/ sampling)

++ : Low infestation (29 - 10 insects/ sampling)

+ : Very low infestation (1 - 9 insects/ sampling)

NIL : Not encountered

Table 10b. Incidence of beneficial insects encountered on okra under the various treatments at pre- and post- flowering growth stages

Beneficial insects	Compost								Compost + Fertilizer							
	Dimethoate		ANSE		Neemazal		Control		Dimethoate		ANSE		Neemazal		Control	
	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST
<i>Coccinella</i> spp.	NIL	+	**	*	*	*	**	**	NIL	NIL	**	**	**	**	*	**
<i>Brachylplatys testudionigra</i> D.	+	+	*	*	*	++	*	*	NIL	NIL	*	*	*	*	*	**
<i>Cheilomenes vicina</i> Muls.	+	+	**	**	**	*	**	**	+	NIL	**	**	**	**	**	**
<i>Cheilomenes lunata</i> (F.)	+	+	**	**	**	**	**	**	NIL	+	**	**	**	**	**	**
<i>Rhinocoris rapax</i> (L.)	NIL	+	NIL	*	NIL	*	NIL	**	NIL	+	NIL	**	NIL	**	NIL	**
<i>Rhinocoris</i> spp.	+	+	++	*	*	*	**	**	+	+	**	**	**	**	**	**
<i>Odonata</i> spp.	+	+	++	++	*	*	*	*	+	+	*	*	*	*	*	*

Beneficial insects	Fertilizer								Control							
	Dimethoate		ANSE		Neemazal		Control		Dimethoate		ANSE		Neemazal		Control	
	PRE	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST	PRE-	POST
<i>Coccinella</i> spp.	NIL	NIL	*	**	**	*	**	**	NIL	NIL	*	*	*	*	*	*
<i>Brachylplatys testudionigra</i> D.	NIL	+	*	*	*	++	*	*	NIL	NIL	++	++	++	*	++	++
<i>Cheilomenes vicina</i> Muls.	+	+	**	**	**	**	**	**	+	+	*	*	*	*	++	++
<i>Cheilomenes lunata</i> (F.)	+	+	**	**	**	*	**	**	+	+	*	*	*	*	*	++
<i>Rhinocoris rapax</i> (L.)	NIL	+	NIL	*	NIL	**	NIL	**	NIL	+	NIL	++	NIL	*	NIL	++
<i>Rhinocoris</i> spp.	+	+	**	**	**	**	**	**	+	+	*	*	*	*	++	++
<i>Odonata</i> spp.	+	NIL	++	*	*	++	++	*	+	NIL	++	++	++	++	+	+

Incidence key :

*** : Very high infestation (80 or more insects/ sampling)

** : High infestation (50 - 79 insects/ sampling)

* : Medium infestation (30- 49 insects/ sampling)

++ : Low infestation (29 - 10 insects/ sampling)

+ : Very low infestation (1 - 9 insects/ sampling)

NIL : Not encountered

4.2. EFFECTS OF THE DIFFERENT TREATMENTS ON GROWTH AND YIELD INDICES.

4.2.1. Leaf damage

Table 9 shows the percentage leaf area damage caused by various phytophagous insect pests per treatment. For the soil treatments, the untreated control plants had their leaves significantly ($P < 0.05$) damaged than the treated (appendix 3). However, leaf damage between the treated soils was not significant different ($P > 0.05$). Significant differences, however, occurred between the insecticide treatments. The untreated control (no spray) plants were significantly ($P < 0.05$) heavily damaged compared to the treated plants. Significant interaction also occurred between the soil and insecticide treatments.

Table 9. Effect of the different treatments on leaf damage in okra plant (%)

Soil treatment (S T)	Mean (\pm SE) Percentage leaf damage				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	11.3 \pm 0.51	18.8 \pm 0.22	10.0 \pm 0.31	32.3 \pm 0.36	17.8
Fertilizer (NPK)	15.0 \pm 0.38	20.0 \pm 0.19	10.0 \pm 0.41	32.8 \pm 0.47	19.4
Compost + Fertilizer	13.8 \pm 0.18	22.5 \pm 0.35	10.0 \pm 0.39	31.8 \pm 0.37	19.2
Control	12.5 \pm 0.41	22.5 \pm 0.29	11.3 \pm 0.48	39.6 \pm 0.39	20.3
Mean	13.1	20.9	10.6	32.2	

LSD ($P = 0.05$) ; Soil treatment (ST) = (2.4)NS ; Insecticides** = 2.2;

ST X insecticide* = 4.2 ; NS = Not significant .

ANSE = Aqueous neem seed extract.

* = significant at $P < 0.05$; ** = significant at $P < 0.01$

4.2.2. Plant height and girth.

The height and girth of plants are shown (Tables 10 and 11). For the soil treatments, the compost treatments, produced the tallest and vigorous plants at flowering, and were not significantly ($P > 0.05$) different. They, however, differed significantly from the control, which produced the shortest plants at flowering. All the insecticide treatments were not significantly ($P > 0.05$)

different from each other but were significantly ($P < 0.01$) different from the control (no spray) (appendix 4). The aqueous neem seed extract (ANSE) produced the tallest plants. However, significant interactions occurred between the soil and insecticide treatments. The compost + fertilizer treated plants when sprayed with dimethoate, produced the tallest plants at flowering while the control (no soil treatment) plants which is also not protected (no insecticide spray) produced the shortest and less vigorous plants.

With the plant girth, highly significant differences occurred among the soil treatments. Girth of sole compost and compost + fertilizer treated plants were not significantly ($P > 0.05$) different. These treatments produced the healthiest and thickest plants while the control (no soil treatment) produced the weakest and thinnest plants (5.00). All the treated soils were significantly ($P < 0.01$) different from the control (appendix 5). Significant differences also occurred among the insecticides. The dimethoate treated plants produced the largest girth (5.75) compared to the control (no spray). Interactions between soil and insecticide treatments produced thicker and healthier plants. The compost + fertilizer treated plants when treated with dimethoate produced the thickest plants while the unsprayed control (no soil treatment) produced the thinnest plants

Table 10. Effect of the different treatments on height of okra plant at flowering (cm).

Soil treatment (S T)	Mean (\pm SE) Plant height at flowering				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	59.74 \pm 0.45	60.59 \pm 0.19	59.14 \pm 0.34	56.38 \pm 0.40	58.96
Fertilizer (NPK)	56.65 \pm 0.38	52.51 \pm 0.31	51.69 \pm 0.33	51.28 \pm 0.25	53.03
Compost + Fertilizer	62.94 \pm 0.47	60.66 \pm 0.41	63.59 \pm 0.27	60.06 \pm 0.14	61.81
Control	54.45 \pm 0.22	54.75 \pm 0.37	55.70 \pm 0.31	49.96 \pm 0.34	53.72
Mean	58.44	57.13	57.53	54.42	

LSD ($P = 0.05$) ; Soil treatment** (ST) = 2.94; Insecticides** = 1.32;
 ST X insecticide* = 3.55; NS = Not significant.
 ANSE = Aqueous neem seed extract.

* = significant at $P < 0.05$; ** = significant at $P < 0.01$

Table 11. Effect of the different treatments on girth development in okra plant (cm)

Soil treatment (S T)	Mean (\pm SE) ANSE	Girth of plant NeemAzal	Dimethoate	Control	Mean
Compost	5.74 \pm 0.25	5.78 \pm 0.28	5.92 \pm 0.74	5.98 \pm 0.84	5.86
Fertilizer (NPK)	5.49 \pm 0.69	4.90 \pm 0.88	5.34 \pm 0.68	5.43 \pm 0.54	5.29
Compost + Fertilizer	6.12 \pm 0.95	6.00 \pm 0.35	6.47 \pm 0.55	5.81 \pm 0.81	6.10
Control	5.06 \pm 0.65	5.37 \pm 0.46	5.27 \pm 0.48	4.93 \pm 0.65	5.00
Mean \pm SE	5.53	5.51	5.75	5.54	

LSD (P = 0.05); Soil treatment** (ST) = 0.24; Insecticides* = 0.17

ST X insecticide** = 0.36; NS = Not significant

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.0

4.2.3. Production of branches and functional leaves.

The number of branches and functional leaves produced per treatment, and their interactions are shown (Tables 12 and 13). Highly significant (P < 0.01) difference occurred within individual soil, and insecticide, treatments. Considering the soil treatments, the compost treated plants produced significantly higher number of branches, while the control produced the least number of branches. Among the insecticides, the untreated control (no spray) plots also significantly produced the highest number of branches (appendix 6). Plants sprayed with neemazal produced the least number of branches. Interaction between soil and insecticide treatments produced significantly (P < 0.05) lower number of branches compared to the untreated control. Plants on the control (no soil treatment) plots when sprayed with dimethoate produced the least number of branches while the unsprayed compost + fertilizer treated plants produced the highest number of branches.

Considering functional leaves, highly significant (P < 0.01) differences occurred among the soil treatments (appendix 7). The compost treated plants produced the highest number of functional leaves. Significant differences also occurred among the insecticide treatments. The ANSE

protected plants produced the highest number of functional leaves but were not significantly ($P > 0.01$) different from those sprayed with dimethoate. Significant differences, however, occurred in the soil - insecticide interactions. The compost treated plants when sprayed with dimethoate produced high numbers of functional leaves relative to plants in the unsprayed control (no soil treatment) treatment.

Table 12. Effect of treatments on number of branches produced in okra.

Soil treatment (S T)	Mean (\pm SE) Number of branches produced				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	15.16 \pm 0.56	11.84 \pm 0.73	15.60 \pm 0.21	18.55 \pm 0.15	15.29
Fertilizer (NPK)	12.25 \pm 0.59	11.56 \pm 0.35	14.28 \pm 0.26	14.35 \pm 0.73	13.11
Compost + Fertilizer	14.31 \pm 0.11	12.94 \pm 0.98	15.05 \pm 0.15	18.71 \pm 0.57	15.50
Control	6.44 \pm 0.78	8.11 \pm 0.78	6.10 \pm 0.25	6.38 \pm 0.35	6.76
Mean	12.04	11.11	13.01	14.50	

LSD ($P = 0.05$); Soil treatment** (ST) = 1.28; Insecticides** = 0.76;
ST X Insecticide** = 1.74 ;

NS = Not significant. ANSE = Aqueous neem seed extract
* = significant at $P < 0.05$; ** = significant at $P < 0.01$

Table 13. Effect of treatments on number of functional leaves produced in okra.

Soil treatment (S T)	Mean (\pm SE) Number of functional leaves produced				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	18.33 \pm 0.25	12.50 \pm 0.22	16.99 \pm 0.26	11.56 \pm 0.29	14.84
Fertilizer (NPK)	13.89 \pm 0.35	11.65 \pm 0.31	13.45 \pm 0.22	10.23 \pm 0.34	12.30
Compost + Fertilizer	18.46 \pm 0.14	11.86 \pm 0.15	18.78 \pm 0.17	12.19 \pm 0.21	15.32
Control	10.21 \pm 0.27	9.25 \pm 0.19	10.59 \pm 0.16	6.50 \pm 0.13	9.14
Mean	15.22	11.32	14.95	10.12	

LSD ($P = 0.05$); Soil treatment** (ST) = 2.42; Insecticides**=1.17;. ST X insecticide* = 3.00; NS = Not significant. ANSE = Aqueous neem seed extract

* = significant at $P < 0.05$; ** = significant at $P < 0.01$

4.2.4. Fruit damage

Tables 14 and 15 show the number of insect bored fruits and the fruits dropped due to insect pests per treatment respectively. Highly significant differences occurred among the soil amendment treatments. The compost treatments produced significantly ($P < 0.05$) higher numbers of bored fruits than the other soil treatments (appendix 8). Significant differences were also observed among the insecticide treatments. The control (no spray) produced the highest number of bored fruits while the aqueous neem seed extract (ANSE) produced the least bored fruits (8.88).

The number of fruits dropped also showed significant differences among the soil treatments. The compost treated plants significantly ($P < 0.01$) reduced the number of fruit drop than the other soil treatments (appendix 9). The highest number of fruits dropped was in the plots of the unsprayed plants (control) while the dimethoate treatment significantly ($P < 0.05$) had the number of fruit dropped reduced. There was also significant difference between treatment interactions ($P > 0.05$) in the number of fruits dropped. The highest number of fruit drop was recorded within the control (no soil treatment) - control (no spray) interaction, whilst the least number of fruit drop was achieved in compost treated plants sprayed with ANSE (Table 15).

Table 14. Effect of treatments on number of bored fruits on okra plant.

Soil treatment (S T)	Mean (\pm SE) Number of bored fruits				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	9.00 \pm 0.23	10.25 \pm 0.25	9.50 \pm 0.65	27.12 \pm 0.89	13.97
Fertilizer (NPK)	7.62 \pm 0.56	10.38 \pm 0.36	7.87 \pm 0.66	28.75 \pm 0.98	13.66
Compost + Fertilizer	10.13 \pm 0.84	15.38 \pm 0.14	9.88 \pm 0.74	34.50 \pm 0.36	17.47
Control	8.75 \pm 0.86	11.88 \pm 0.74	12.13 \pm 0.54	10.88 \pm 0.81	10.91
Mean	8.88	11.97	9.85	25.31	

LSD ($P = 0.05$); Soil treatment** (ST) = 1.48; Insecticides** = 2.14; ST X insecticide = NS; NS = Not significant. ANSE = Aqueous neem seed extract.

* = significant at $P < 0.05$; ** = significant at $P < 0.01$

Table 15. Effect of treatments on number of fruits dropped in okra.

Soil treatment (S T)	Mean (\pm SE) Number of fruits dropped				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	6.62 \pm 0.63	12.50 \pm 0.45	10.38 \pm 0.87	24.37 \pm 0.93	13.47
Fertilizer (NPK)	11.38 \pm 0.85	13.13 0.24	10.500.79	23.87 0.23	17.34
Compost + Fertilizer	9.88 \pm 0.66	17.00 \pm 0.35	11.38 \pm 0.81	31.12 \pm 0.94	14.72
Control	18.00 \pm 0.11	30.75 \pm 0.69	16.25 \pm 0.44	47.38 \pm 0.36	28.09
Mean	11.47	18.34	12.13	31.69	

LSD (P =0.05); Soil treatment** (ST) = 2.73; Insecticides** = 2.58;
ST X insecticide** = 5.06; NS = Not significant.

ANSE = Aqueous neem seed extract.

* = significant at P < 0.05; ** = significant at P < 0.01

4.2.5. Percentage unmarketable fruits

High significant (P < 0.01) differences were observed among the insecticide treatments. The no insecticide treated plants produced the highest percentage of unmarketable fruits, but that for the dimethoate and aqueous neem seed extract treatments were not significantly different (P > 0.01). Interactions between soil and insecticide treatments produced vigorous plants and significantly (P < 0.05) reduced the percentage of unmarketable fruits produced (appendix 10). However, the control (no soil treatment) plants when sprayed with dimethoate produced the least unmarketable fruits. Irrespective of the soil treatment, dimethoate and ANSE application produced the least unmarketable fruits (Table 16).

Table 16. Effect of treatments on unmarketable fruits produced in okra (%)

Soil treatment (ST)	Mean (\pm SE) Percentage unmarketable fruits				Mean
	ANSE	NeemAzal	Dimethoate	Control	
Compost	10.22 \pm 0.39	26.41 \pm 0.77	12.81 \pm 0.73	32.95 \pm 0.44	20.60
Fertilizer (NPK)	15.21 \pm 0.95	24.66 \pm 0.66	10.64 \pm 0.33	31.89 \pm 0.22	20.60
Compost + Fertilizer	9.15 \pm 0.22	20.99 \pm 0.36	10.66 \pm 1.52	30.80 \pm 0.54	17.90
Control	9.47 \pm 0.29	25.17 \pm 1.22	7.15 \pm 0.31	34.28 \pm 0.25	19.02
Mean	11.02	24.31	10.32	32.48	

LSD (P = 0.05); Soil treatment (ST) = (2.69) NS; Insecticides** = 2.09;

ST X insecticide* = 4.23; NS = Not significant

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.01

4.2.6. Fruit dry matter yield and fresh fruit yield.

The fruit dry matter and fresh fruit yields per treatment, and that due to treatment interactions are shown in Tables 17 and 18. The soil, and insecticide treatments showed highly significant (P < 0.01) differences (appendix 11). For the soil treatments, compost treated plants produced significantly (P < 0.01) higher fruit dry matter compared to the other soil treatments whilst with the insecticide treatments, dimethoate produced the highest dry matter and neemazal, the least. Treatment interactions also showed significant differences. Compost treated plants when sprayed with dimethoate or ANSE produced significantly higher fruit dry matter than those plants in unsprayed - no soil treated plots.

High significant differences in fresh fruit yield were observed among the soil, and insecticide treatments (appendix 1). Among the soil treatments, the compost treated plants produced larger number of fresh fruits, but fresh fruit yield for the fertilizer alone, and the compost + fertilizer treatments were not significantly (P < 0.05) different. Among the insecticide treatments, plants sprayed with dimethoate produced the highest number of fresh fruit. The aqueous neem seed

outyielded the control. Interaction between soil and insecticide treatments showed significant differences in fruit yield. Compost treated plants when sprayed with dimethoate or ANSE produced higher number of fresh fruits than the unsprayed plants grown in compost.

Table 17. Effect of treatments on fruit dry matter yield in okra (g).

Soil treatment (S T)	Mean (\pm SE) Dry matter yield				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	4.51 \pm 0.68	4.17 \pm 0.87	4.89 \pm 0.49	4.45 \pm 0.85	4.51
Fertilizer (NPK)	3.20 \pm 0.69	3.13 \pm 0.72	3.41 \pm 0.69	3.72 \pm 0.57	3.37
Compost + Fertilizer	3.96 \pm 0.28	3.95 \pm 0.39	4.37 \pm 0.53	3.99 \pm 0.51	4.07
Control	1.90 \pm 0.57	2.08 \pm 0.99	2.24 \pm 0.83	1.67 \pm 0.31	1.97
Mean	3.39	3.33	3.73	3.46	

LSD (P = 0.05); Soil treatment** (ST) = 0.26; Insecticides** = 0.18; ST X insecticide* = 0.39; NS = Not significant .

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.01

Table 18. Effect of treatments on fruit yield in okra (t/ha).

Soil treatment (S T)	Mean (\pm SE) Fruit yield				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	2.07 \pm 0.25	1.84 \pm 0.67	3.60 \pm 0.39	0.53 \pm 0.27	2.01
Fertilizer (NPK)	1.64 \pm 0.87	1.40 \pm 1.87	2.45 \pm 0.29	0.38 \pm 0.73	1.47
Compost + Fertilizer	2.17 \pm 0.97	1.47 \pm 0.91	3.04 \pm 0.68	0.42 \pm 0.77	1.78
Control	0.73 \pm 0.83	0.57 \pm 0.45	1.41 \pm 1.91	0.09 \pm 0.88	0.70
Mean	1.65	1.32	2.63	0.35	

LSD (P = 0.05) ; Soil treatment** (ST) = 0.12; Insecticides** = 0.15

ST X insecticide** = 0.28 NS = Not significant

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.01

4.2.7. Number of fruits produced per plant at harvest and weight of marketable fruits.

Tables 19 and 20 respectively show the number of fruits per plant at a harvest and weight of marketable fruits for each treatment. Significant differences occurred among the soil, and insecticide treatments. Under the soil treatments, the compost treated plants produced significantly ($P < 0.05$) higher number of fruits per plant at a harvest (appendix 13). Among the insecticide treatments, dimethoate treated plants produced the highest number of fruit per plant. The number of fruits from the neemazal treatment was not significantly different from the control ($P > 0.05$). Significant interactions occurred between soil and insecticide treatments. The compost treated plants when sprayed with dimethoate produced the highest number of fruits but were not significantly ($P < 0.05$) different from those sprayed with ANSE.

Significant differences in marketable fruit weights were observed for both the soil treatments, and the insecticide treatments (appendix 14). Among the soil treatments, the compost treated plants produced the heaviest marketable fruits and were significantly ($P > 0.01$) different from those produced by the sole fertilizer and the untreated control. Similarly, the dimethoate treated plants produced significantly ($P < 0.01$) heavier marketable fruits than the neem products. However, between the neem products, ANSE sprayed plants produced significantly heavier fruits than those treated with neemazal. No significant interactions occurred between the soil and insecticide treatments.

Table 19. Effect of treatments on number of fruit produced per plant at harvest in okra.

Soil treatment (ST)	Mean (\pm SE) Number of fruits produced per plant at harvest				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	3.84 \pm 0.24	3.05 \pm 0.58	5.06 \pm 0.57	3.41 \pm 0.69	3.84
Fertilizer (NPK)	3.21 \pm 1.25	2.95 \pm 0.28	3.21 \pm 0.22	2.11 \pm 0.28	2.87
Compost + Fertilizer	3.84 \pm 0.58	3.16 \pm 0.84	4.90 \pm 0.29	3.11 \pm 1.23	3.75
Control	2.11 \pm 1.23	2.00 \pm 1.50	2.99 \pm 1.29	1.31 \pm 1.39	2.10
Mean	3.25	2.79	4.04	2.48	

LSD (P = 0.05) ; Soil treatment** (ST) = 0.46; Insecticides** = 0.32;

ST X insecticide* = 0.69; NS = Not significant

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.01

Table 20. Effect of treatments on weight of marketable fruits produced in okra(g).

Soil treatment (ST)	Mean (\pm SE) Weight of marketable fruits				
	ANSE	NeemAzal	Dimethoate	Control	Mean
Compost	31.59 \pm 1.38	28.62 \pm 1.47	35.26 \pm 1.69	28.60 \pm 0.97	31.02
Fertilizer (NPK)	29.91 \pm 0.58	28.19 \pm 0.86	33.45 \pm 8.39	26.74 \pm 1.68	29.57
Compost + Fertilizer	30.20 \pm 1.69	30.51 \pm 1.82	33.14 \pm 1.37	29.29 \pm 1.59	30.78
Control	24.73 \pm 1.36	22.11 \pm 1.97	25.36 \pm 1.38	20.40 \pm 0.87	23.15
Mean	29.10	27.36	31.80	26.26	

LSD (P = 0.05) ; Soil treatment** (ST) = 1.30; Insecticides** = 1.34;

ST X insecticide = NS; NS = Not significant

ANSE = Aqueous neem seed extract

* = significant at P < 0.05; ** = significant at P < 0.01

4.3. ECONOMICS OF PRODUCTION

4.3.1. Cost of production.

Table 21 shows the cost and their proportions for the various operations involved in producing okra in Ashaiman. The synthetic insecticides recorded the highest cost followed by land preparation with labour applying sole compost and sole fertilizer being the lowest. In terms of proportion of individual activities on cost of production, the synthetic insecticides form the highest percentage followed by land preparation.

Table 21. Cost of the various operations in okra production (ha)

Activities	Cost (¢)	Percentage cost
A) Land preparation (ploughing)	670,000.00	12.99
Seed and sowing	388,888.89	7.43
B) Insecticides		
- neem seed, 30kg used ,340kg/ha at ¢15000/30kg	170,000.00	3.25
- neemazal, 0.5lit used, 14.9lit/ha at ¢70,000/lit.	1,043,000.00	19.92
- dimethoate, 1lit used, 14.9lit/ha at ¢55,000.00/lit	819,500.00	15.62
C) Soil treatments		
-Compost (500g/plant), 16.67t/ha at ¢30,000.00/ton	500,100.00	9.55
Fertilizer (NPK-15-15-15), (10g/plant) 334kg/ha at ¢60,000/50kg	400,800.00	7.65
-compost + fertilizer (250g compost+ 10g fertilizer /plant)	450,450.00	8.60
D) Labour		
-hand weeding	350,000.00	6.68
-compost application at ¢20,000.00/1800m ²	111,111.00	2.12
-fertilizer „ „ „	111,111.00	2.12
-fertilizer +compost application	222,222.00	4.24

4.3.2. Cost benefit ratio and its monetary aspects.

This ratio shows a quicker assessment of the returns on an investment and hence indicates the viability of the investment. The cost - benefit ratio was determined as the ratio of cost incurred due to the combined effect of each soil – insecticide treatment to the benefit (revenue) realised from such combined treatments. Tables 22 a and 22 b show the cost - potential benefit ratio and their monetary terms, respectively. The cost - potential benefit ratio was lowest for the application of dimethoate on plants grown in compost (0.41) than the application of neem products. Between the neem products, application of aqueous neem seed extract on compost + fertilizer treated plants was 0.51, and on compost alone treated plants, 0.52. The control again had the highest ratio (7.83). No statistical analysis was performed. In monetary terms the application of neemazal on compost + fertilizer treated plants incurred the highest cost (¢3,124,561.11). However, dimethoate when applied on compost treated plants had the highest monetary benefit (¢7,200,000.00) and between the neem products, the application of ANSE on compost treated plants yielded the highest benefit.

Table 22 a. Cost- benefit ratio for soil- insecticide treatments

Soil treatments	ANSE	Neemazal	Dimethoate	Control-no spray
Compost	0.52	0.83	0.41	1.91
Fertilizer	0.63	10.5	0.56	2.53
Compost + fertilizer	0.51	1.06	0.48	2.48
Control	1.08	2.15	0.79	7.83

Table 22 b. Cost and benefit for soil - insecticide treatments on okra (¢)

Soil treatments	ANSE	Neemazal	Dimethoate	Control- (no spray)
Compost	2,190,100.00 * (4,140,000.00)	3,063,099.89* 3,680,000.00	3,539,599.89* (7,200,000.00)	2,020,099.89* (1,060,000.00)
Fertilizer	2,090,799.89* (3,280,000.00)	2,963,799.89* (2,940,000.00)	2,740,300.00* (4,900,000.00)	1,920,799.89* (760,000.00)
Compost + fertilizer	2,251,561.11* (4,340,000.00)	3,124,561.11* (2,998,000.00)	2,901,061.11* (6,080,000.00)	2,081,561.11* (840,000.00)
control	1,578,888.89* (1,460,000.00)	2,451,888.89* (1,140,000.00)	1,559,058.89* (2,228,388.89)	1,408,888.89* (180,000.00)

NB; *=cost of production; () = cash benefit from sales

1kg fresh fruit weight of okra =¢ 2000.00

4.3.3. Marginal cost and benefit due to soil, and insecticide treatments.

Marginal cost is the additional cost incurred over the cost of the control treatment for adopting a particular treatment. Marginal benefit, however, is the additional benefit (revenue) gained over the control treatment for adopting a particular treatment. The marginal cost and benefits associated with the use of the soil and insecticide treatments are shown in Tables 23 a and 23 b respectively. Among the soil treatments, the use of compost yielded the highest benefit with a marginal cost of ¢ 611,211.00 while the control yielded the least benefit. The neemazal treatment yielded the highest marginal cost for the insecticide treatment. In terms of benefit, the dimethoate treatment yielded the highest, and between the neem products, application of ANSE yielded a higher benefit compared to the neemazal treatment.

Table 23a. Marginal cost and benefit for soil treatments (¢)

	Compost	Fertilizer	Compos+fertilizer	Control - no soil treatment
Cost	611,211.00	511,911.00	450,450	0.00
Cash benefit	880,000.00	580,000.00	660,000.00	180,000.00

Table 23b. Marginal cost and benefit for insecticides used (¢)

	ANSE	Neemazal	Dimethoate	Control-no spray
Cost	170,000.00	1,043,000.00	819,500	0.00
Cash benefit	1,280,000.00	960,000.00	2,640,000.00	180,000.00

4.3.4. Marginal cost and benefit due to the combined effect of the different treatments.

The marginal cost and benefit derived from the application of insecticides on okra is shown (Table 24). The application of dimethoate on compost treated plants yielded the highest benefit (¢6,759,000.00) while the unsprayed plant (control) grown in untreated soil (control) yielded the least benefit (¢180,000.00). Between the neem products, the highest benefit (¢5,209,000.00) was obtained for applying ANSE on compost treated plants. For marginal cost, the highest cost, (¢1,146,795.00) was incurred for applying neemazal on plants grown in compost with a corresponding benefit of (¢4,693,000.00). However, among the neem products, the least benefit was obtained from the use of neemazal in protecting the crop.

Table 24. Marginal cost and benefit due to the combined effects of the various treatments on okra production .

Soil treatments	Aqueous neem seed extract (ANSE)	NeemAzal	Dimethoae
Compost	814,856.*	1,146,795.*	1,065,798.*
	4,927,000.**	4,693,000.**	6,759,000.**
Fertilizer	775,459.*	1,102,532.*	1,026,402.*
	3,606,000.**	3,107,000.**	5,209,000.**
Fertilizer + compost	780,856.09*	1,112,048.*	1,025,435.*
	5,209,000.**	3,277,000.**	6,063,000.**
Control	291,159.*	6,287,15.*	542,102.*
	1,443,000.**	1,3170,00.**	2,923,000.**

NB: * = Marginal cost; **= marginal benefit

CHAPTER FIVE

5.0. DISCUSSION

5.1. INSECTS ENCOUNTERED ON OKRA DURING THE SAMPLING PERIOD: THEIR INCIDENCE AND DAMAGE

The insects encountered fell into seven orders belonging to twenty-three families and forty-four genera. Coleoptera dominated the order probably because both larvae and adults attack various parts of the crop right from the roots through the leaves to the fruit (Hill, 1987). Only one Diptera (*Diopsis thoracica* Westw.) was observed, hence the least order encountered. *Aphis gossypii* Glov. was the first to be observed three weeks after sowing followed by the whitefly, *Bemisia tabaci* Genn. and then the cotton mealy bug, *Phenacoccus hirsutus* Green. which appeared simultaneously with green leaf hopper, *Empoasca* spp. Other insects were also randomly distributed in the various treatments. However, some insects including *A. gossypii*, *P. hirsutus*, *B. tabaci* and *Empoasca* spp. attacked the crop and inflicted serious damage on it. In severe attacks, the leaves became chlorotic and resulted in mass leaf shed especially where a complex of these pests occurred on plants in the control (no soil amendment). In the compost treated plots, okra plants suffered relatively less damage from these sucking pests particularly when sprayed with Dimethoate or ANSE. However, in the sole fertilizer treatment, attack by the mealy bugs was quite high even in the presence of the insecticide sprays. This indicates the role of micronutrients inherent in compost on plants vigour and yield.

The green leaf hoppers, *Empoasca* spp. also sucked sap from underside of older leaves but in the evenings were found on the upper surface of the leaves. Severe infestation also resulted in the shedding of the leaves. Just before flower bud formation, the Pentatomids, *Nezera viridula* (L.), *Chinavia acuta* (L.) and *Aspavia* spp. began to increase and peaked at flower opening. They sucked from the terminal shoots and flower buds causing stunted growth, wilting and shedding of flower buds. Grasshoppers, *Acisoma* and *Urothemis* spp. were very abundant during the pre - flowering stage but their numbers reduced at flowering. They fed on the leaves. Attacks by the pentatomids caused relatively less damage. However, their damage to plants growing in the control (no soil amendment) plots was appreciable unlike those growing in compost due to poor nourishment. Under the compost soil amendment, okra sprayed with ANSE suffered relatively less damage from the pentatomids and grasshoppers than those sprayed with Dimethoate. This

probably could be due to the fact that with the systemic activity of the dimethoate, the damage would be caused before the insect is killed (Mathews, 1988).

At flower opening, *Coryna* and *Diopsis* species occurred in their numbers with the adult *Coryna* spp. feeding on pollen grains, destroying the stigma and the flower petals. The larva of the *Diopsis* was often seen feeding inside the opened flower particularly at the base of the stigma. The cotton bud weevil, *Anthonomus grandis* and the cotton dust bug *Oxycaraenus* spp. were found on the terminal shoot around the flower buds. They both suck from the base of the flower buds to cause severe flower bud shedding. Other insects also started to visit the field either to prey on other insects or to feed on the crop. Among these were *A. acutipennis* Guerin, *A. hornida* Germ. Synonym *C. shadabi* Dolling and *Lagria villosa* which fed on the flower buds. Also important predators like *Rhinocoris rapax* (L) and other *Rhinocoris* spp., *Odonata* spp. and Coccinelid beetles increased particularly in the botanical and control (no spray) treatments. The *Rhinocoris* spp. fed on the leafhoppers and other insects while the Coccinelids, particularly the ladybird beetle, fed on the aphids at the terminal buds and under leaf surface. The compost and fertilizer treated plants hosted many natural enemies such as *Odonata* spp., *Rhinocoris* bugs and Coccinelid beetles than the control probably due to the higher insect pest infestations as a result of their attractiveness. The flower feeding pests, *Coryna*, *Diopsis* and *Oxycaraenus* species heavily infested the compost treated plants, which could be due to their vigorous growth and flower production. However, such plants suffered relatively lesser flower drop particularly in areas where ANSE or Dimethoate sprays were applied. This could also be due to the complementary effects of better nourishment from the compost on the efficacy of these insecticides.

Shortly after fruit setting, the fruit suckers and borers also increased particularly, *A. curvipes* Fab., *Anthocoris* spp. and *Graptostethus* spp. sucking sap from the fruits. Most importantly is the *Dysdercus* spp. This attacked the young fruit, injected toxic saliva into it and caused it to wither and shed pre-maturely. *Calidea dregii* Germa. also appeared during the middle of fruit production and sucked sap from the fruits. *Pachnoda* spp. and *Riptortus dentipes* Dall. were also observed biting and sucking respectively from the fruits. *Pachnoda* spp., *R. dentipes* and have been reported as minor pests of okra in the Sudan (Schmutterer, 1969), and East Africa (Hill, 1987). However, this is the first record of these insects as okra pests in Ghana.

5.2. EFFECTS OF THE DIFFERENT INSECTICIDE TREATMENTS ON THE MAJOR INSECT PESTS AND BENEFICIAL INSECTS.

The major insect pests were those whose number totalled up to over 40 per visit in the control and caused serious damage to the crop. These are cotton aphid, *A. gossypii* Glov., blister beetle, *P. uniformis*, Jac., the cotton stainer, *Dysdercus* spp. the green leaf hopper, *Empoasca* spp. the cotton boll weevil, *A. grandis*, the whitefly, *B. tabaci*, and the cotton mealy bug, *P. hirsutus* Green. The nature of their damage is indicated. *P. uniformis* has already been documented as a key pest of okra in Ghana (Asante, 1978, Obeng Ofori, 1982, Critchley, 1997 and Sackey, 1999). Its number increased gradually with growth of the plant due to its ability to exploit other growth phases compared to other species that feed only entirely on the leaf (Asante, 1978). It fed on both the leaves and fruits causing serious reduction in yield. This could be attributed to reduction in the photosynthetic area of the crop culminating in total yield loss. Kaaya (1990) reported that adults of *P. uniformis* feeds on the leaf lamina of okra, leaving open holes thereby reducing the photosynthetic area of the leaf and consequently causing 90% yield loss in okra in Tanzania. The low numbers recorded under dimethoate treatment could be due to the systemic action of the compound. However, between the neem products, the relatively low numbers in the ANSE (Aqueous neem seed extract) could be due to its antifeedant effect. Redknap (1991) reported of antifeedant effect of ANSE against *P. uniformis* and *P. sjostedti*.

5.2.1. *Aphis gossypii* Glover.

This insect has been reported as a major pest of okra but elsewhere as a minor pest (Messiaen, 1992). However, in Ghana, it is a pest of okra of considerable importance (Asante, 1978; Sinnadurai, 1992; Critchley, 1997). Due to its sap sucking habit, it deprives the crop of its needed assimilates for proper growth and development. Kaaya (1990) reported that the feeding activity of the cotton aphid, results in leaf curl downwards and stunted growth with a 40% yield reduction during high infestation. Critchley (1997) also reported that *A. gossypii* sucks sap from young leaves and buds of okra and transmits diseases that reduce the efficiency of the leaves. Although no statistical analysis was performed on the relative abundance, the neem products were effective in reducing the aphids infestation particularly the ANSE probably due to its repellent effects. Schmutterer (1995) reported that ANSE proved effective against *A. gossypii* on cucumber and

okra in field studies. However, the high infestation observed in the dimethoate treatment could be due to resistance developed by the insect against the insecticide (Owusu, in-press).

5.2.2. *Dysdercus* species. This insect was previously not considered a major pest in Ghana (Asante, 1978), however, Critchley, (1997) recorded *D. supersticiosus* as a major pest in Ghana. It sucks sap from the developing fruits which turn yellow, shrivels and fall on the ground. This could be due to toxic saliva injected into the fruit. However, in older fruits, their feeding activity caused reduction in seed viability (Kaaya, 1990; Critchley, 1997). The low numbers of *Dysdercus* spp. observed on ANSE compared to the neemazal treatment could be due to its high repellent effect. Gracia *et al.*, (1989) reported *N. viridula*, *Dysdercus* spp. and *Helopelthis antonii* as economically important insect species that are very sensitive to neem products particularly the Aqueous extracts. The comparable performance of ANSE and dimethoate in the control of this pest indicates the repellent effects of ANSE being at par with the toxicity of the synthetic insecticide, dimethoate. This confirms the findings of Osterman (1992).

5.2.3. *Heliothis armigera* (Hb.) synonym *Helicoverpa armigera* (Hb.)

In Sudan, this insect was also recorded as a minor pest of okra (Schmutterer, 1969), but in Tanzania, Kaaya (1990) reported *H. armigera* as a major pest of okra causing as much as 90% yield loss. In Ghana, Critchley (1997) reported of *H. armigera* caterpillars as being important pest of okra. It is the caterpillar that caused serious damage to flower buds and fruits by boring into and feeding on the content, to reduce the quality of the fruits. Young fruits when attacked drop prematurely. The least number associated with dimethoate treatment could be attributed to its systemic effect that killed the caterpillars as they ingest parts of the treated plant. However, between the neem products the lower infestation of the pest in the ANSE compared to neemazal could be due to its antifeedant effect. Schmutterer (1995), reported that neem kernel suspension and emulsion from emulsifiable concentrate (EC) when fed to 8 - and 13 - day old larvae of *H. armigera* lowered their weight significantly. Osterman (1992) also reported from field trials that weekly application of ANSE (50 g/l) drastically reduced *H. armigera* damage to tomato considerably compared to deltamethrin.

5.2.4. *Empoasca* spp.

This insect as a major pest of okra has been confirmed in various places: Sudan, - schmitterer 1969; India - Butani and Verma, 1976; Tropical Africa and Southeast Asia - Gracia *et al.*, 1989; Ghana - Critchley, 1997 and Asante, 1978. They suck sap from the underside of older leaves to cause phytotoxaemia (hopper burn). In severe attacks plants become stunted, unable to produce flowers, and fruits yield decreases resulting in 100% crop loss (Uthemasamy, 1985). The lowest numbers encountered in the dimethoate treatment could be due to the systemic activity of the insecticide that might have killed them. Between the neem products the comparatively lower numbers associated with the ANSE compared to neemazal could be due to its high repellency. Sexena and Batis (1982) reported that oviposition by the brown plant hopper, *Amrasca devastans* on cotton treated with neem oil was significantly reduced. Asari and Nair (1972) demonstrated the repellent effect of ANSE (10 g/l) against *Empoasca* spp., *A. gossypii* and *Epilachna* beetles on brinjal

5.2.5. *Phenacoccus hirsutus* Green

P. hirsutus was also recorded as a serious pest of okra (Hill, 1987). It sucked sap from the underside of leaves and in severe infestation, the leaves turn yellow and were shed after the insects had moved to colonize the terminal shoot. Leaves of affected plants became more contorted and reduced in size. The systemic action of dimethoate was responsible for the lowest numbers of the pest in this treatment. However, the lower numbers in the ANSE could be due to its high repellency compared to that of neemazal. Aqueous neem seed extracts have been reported to be effective against a wide range of insect pests of both field crops and vegetables from various parts of Ghana including the diamond black moth, mealy bugs, pod and flower borers, and aphids (Adzaho, 1987; Kottoh, 1997; and Afreh - Nuamah *et al.*, 1998).

5.2.6. *Anthonomus grandis* Green. This insect has been reported as a major pest of okra and cotton, feeding at base of flower buds in okra which are shed (Hill, 1987). It was found feeding in the crown of the crop at the base of flower buds and caused mass flower drop in heavy infestation. This activity of the insect results in heavy yield loss. The lowest numbers encountered in the dimethoate treatment could be due to its systemic action, which poisoned the pest and thus lowered their population levels. In the case of the ANSE, the lower numbers of the pest could be due to its high repellency compared to the neemazal. Aqueous neem extract when

applied at weekly intervals have been proved to be effective against insect pests of okra and other Malvaceous plants than the formulated neem product, neemAzal -T (Adhikary, 1984).

5.2.7. *Bemisia tabaci* Genn.

This insect was documented as a major pest of okra in the Sudan (Schmutterer, 1969). However, in Ghana, the insect has been documented as a minor pest of okra (Asante, 1978; Critchley, 1997). However, in this study, *B. tabaci* was one of the most abundant insect species encountered. They sucked sap from the underside of older leaves and caused the affected leaves to be distorted, curl upward and chlorotic in heavy infestation. The high numbers associated with the dimethoate treatment and the untreated control is an indication of the insect's resistance to the synthetic insecticide unlike the neem products. Various neem extracts have affected over 200 insect species including many that are resistant to, or inherently difficult to control with conventional insecticides (Schmutterer and Freres, 1990).

5.2.8. *Sylepta derogata* (F.)

This insect has been recorded as a major pest of okra in Ghana (Tindal, 1965; Asante, 1978; Critchley, 1997). The larvae feed on the leaf lamina by rolling the leaf and then feed with the rolled leaf. Affected leaves became curled and druppy. The defoliation of the plant caused serious reduction in the photosynthetic ability of the plant resulting in heavy yield loss (Hill, 1987). The low numbers of this insect observed in the dimethoate treatment compared to the neem products could be assigned to the systemic activity of the dimethoate which makes the compound more toxic to the pest (Hill, 1987). The relatively low numbers in the ANSE compared to the neemazal treatment confirms the higher antifeedant effect of the ANSE compared to the formulated neem products, neemazol and neemik, (Osterman, 1992).

The similarity in the performance of ANSE and dimethoate treatments in the control of the major insect pests could be due also to the repellent effect of the ANSE being at par with the toxicity of the synthetic insecticide (Schmutterer, 1995).

5.3. MINOR INSECT PESTS

These are insect pests that attacked the crop and caused comparatively less damage, and relatively few numbers were encountered during sampling. They included *Anoplocnemis curvipes*, *Calidea* spp. *Pachnoda* spp. *Earias insulana* and *Oxycaraemus* spp. among others. Schmutterer (1969) documented a host of insects attacking okra in the Sudan as minor pest except *B. tabaci*. However in Ghana the pest status of *B. tabaci* okra is controversial. Asante (1978) and Critchley (1997) have recorded it as a minor pest of okra. *Pachnoda* attacked by biting the fruit. Affected fruits produced a lot of foams and eventually rots completely.

5.4. BENEFICIAL INSECTS

These were found attacking some insect pests of the crop. They included *Cheilomenes vicinia* Muls. *C. lunata* F. and *Odonata* spp. (Table 7b). Asante (1978) reported of *C. lunata* F. and *C. vicinia* Muls. as insects whose occurrence were correlated to the presence of aphids on the leaves of okra and were always seen feeding on the aphids at the underside of the leaves. The high numbers of the beneficial insects in the control and the neem treated plots compared to the dimethoate treated plot suggested that the botanical insecticides were less harmful to them. Hill (1987) reported that predators and parasites are not affected by systemic insecticides unless they come into contact with the chemical during spraying of the crop or ingest a prey that is contaminated with the chemical. Neem products have also been reported to be less harmful to beneficial insects and environmentally friendly (Sackey, 1999; Eziah, 1999). The significantly higher number of the beneficial insects recorded in the control plots compared to those sprayed with the insecticides could be assigned to the fact that the unsprayed plots provided a congenial environment which enhanced proliferation of the insect pests and the predators.

5.5. RELATIVE ABUNDANCE OF MAJOR PESTS AND BENEFICIAL INSECTS UNDER THE VARIOUS TREATMENTS AT DIFFERENT GROWTH STAGES

Aphids gossypii, *Empoasca* spp. *Podagrica uniformis* and *Phenacoccus hirsutus* among others (Table 8a) as major pests of okra in Ghana have been established (Asante, 1978; Obeng- Ofori, 1982; Critchley, 1997). Also the efficacy of ANSE against aphids unlike the synthetic insecticide, dimethoate, confirms the findings of Afreh- Nuamah *et al.*, (1998). The healthy and vigorous growth associated with compost treated plants irrespective of the abundance of the

major pests could be due to better nourishment they derived from the compost and thus compensated for damage readily. According to George (1988), compost contains micronutrients that enhance nutrition in plants and promotes good health and yield. This also accounts for the lower fruit damage observed in the compost treated plants. The virtual absence of *D. supersticiosus* and *H. armigera* at the pre- flowering stage suggested these insects to be pests of okra fruit and flower buds (Critchley, 1997; Udzu, 1993). The lower fruit drop caused by *D. supersticiosus* in plants treated with dimethoate or ANSE for each soil treatment could be assigned to the repellent effect of ANSE which is at par with the toxicity of the synthetic insecticide. The better performance of the compost treated plants at the different growth stages when protected with Dimethoate or ANSE, unlike the other soil treatments could be attributed to the complementary effects of the insecticidal activity of these products on the nutritional efficiency of the compost.

The predatory activity of the Coccinelid beetles and the *Cheilomenes* species on aphids has been established (Asante, 1978; Schmutterer, 1969). The high incidence of the Coccinelid beetles on the compost treated plants indicates the heavy infestation of such plants by the aphids due to their vigorous growth and succulency. The low numbers of the beneficial insects associated with the dimethoate treatment (Table 8b) could be due to the toxicity of the synthetic product to these insects. Neem products have been proved to be harmless to beneficial insects and environmentally friendly (Sackey, 1999; Udzu, 1993). The abundance of the beneficial insects on the compost treated plants could again be attributed to the high pest infestation on such plants as a result of their vigorous growth, thus becoming attractive to the insect pests (Cooke, 1982).

5.6. EFFECTS OF THE DIFFERENT TREATMENTS ON GROWTH AND YIELD INDICES

5.6 .1. Vegetative growth

From the field studies, significant interactions occurred between soil and insecticide treatments. This accounted for the healthier and vigorous growth of the crop in some of the treatments. The compost treated plants when sprayed with any of the test insecticides produced healthier, taller, and more vigorous plants at flowering than the sole fertilizer and the control. Such plants although hosted higher populations of insect pest suffered the least damage. This could be due to the plants receiving enough of micronutrients coupled with the insecticidal activities of the test

insecticides in protecting the crop against pest damage. According to George (1988) compost contains high amount of trace elements not found in mineral fertilizers consequently when applied to crops they respond better in yield and other growth properties. The insignificant difference observed in the development of the crop's height between dimethoate and ANSE treated plants could be due to the efficacy of the ANSE, which may be at par with the synthetic insecticide in protecting the crop against sucking pests. Dreyer and Hellpap (1991) reported that cotton aphids, *A. gossypii* was controlled well on okra by four weekly applications of 50g/l ANSE and 2% neem oil, the effect being at par with that of the synthetic carbamate, butocarboxim.

As regards girth development, treatment interactions were significant. This indicates that the combined effects of both treatments enhanced girth development in okra. Okra plants grown in compost responded well to both major and minor nutrients, grew thicker, more vigorous and succulent stems even in the presence of higher pest populations. They also suffered less damage when sprayed with dimethoate. This observation could be attributed in part to the systemic activity of dimethoate which limited the uptake of assimilates by phytophagous insect pests, and hence enhanced growth and development of the plant. Kumar (1984) reported that systemic insecticides after absorption into the plant are translocated to various parts where they function as stomach poison, killing insect pests that feed on them, hence effective against chewing insect pest. Schmutterer (1995) reported that neem is not systemic in okra (bhendi) and hence has little effect on aphids, jassids, and whiteflies, which are phloem feeders even when applied in a systemic manner (into the soil).

For branch production in okra, treatment interactions were again significant. This could be due to the complementary effects of insecticide treatments on the soil amendment practices, which culminated in profuse branching. The better performance of the compost treated plants when sprayed with any of the test insecticide compared to the sole fertilizer and the control treatments could be assigned again to the effects of minor nutrients contained in compost that might have promoted growth through increase in plant metabolism. Those plants branched profusely as a result of better nourishment derived from the compost, showed vigorous growth and sustained vegetable yield. Flaig *et al.*, (1977) reported that humic substances (high molecular weight organic compound) effect changes in the environment of the roots and enhanced better crop

growth while the lower molecular weight compounds bring about increased plant metabolism. Among the neem products the superior performance of ANSE over neemazal could be due to its repellent effects. Siddig (1981) also reported that weekly applications of ANSE reduced the incidence of most adult insect pests of okra and hence limited the extent of their damage.

With functional leaves production, the significant interaction between the soil and insecticide treatments could be attributed to better nourishment provided by the soil treatment coupled with the efficacy of the test insecticides, in protecting the crop. Thus resulting in healthy and better leaf production. Okra grown in the compost when sprayed with either dimethoate or ANSE showed vigorous growth produced broader, less damaged and greener leaves than those in the sole fertilizer and control treatments. Such plants also hosted more insect pests but showed sustained growth and yield. Hugues and Philippe (1992) reported that vigorous plants are well fed and are able to replace the sap sucked by sapsuckers, and strong enough to develop new shoots and leaves. Both ANSE at 20g/l and ANLE (aqueous neem leaf extract) at 40 /l sprayed five times on beans (*Phaseolus vulgaris*) was a strong repellents to adults of the chrysomelid beetle, *Ootheca bennigseni* 24hours after application and reduced leaf damage well (Hongo and Karel, 1986). The effects of dimethoate and ANSE on the production of functional leaves are not significantly different due to repellent effects of ANSE, which may be at par with the effects of dimethoate.

For the indices of plant health and vigour studied, plant height, girth, functional leaves and branching, the compost treated plants performed better than the other soil amendments. Consequently such compost treated plants grew healthier, vigorously and more succulently, and produced greener leaves than those in the sole fertilizer and the control treatments.

5.6.2. Insect pests damage

5.6.2.1. Leaf damage

The significant interaction observed between the treatments for leaf damage could be due to increase vigour induced by the soil treatments, which complements the insecticidal effects of the test insecticides, and ultimately reduced leaf damage drastically. Plants treated with compost when superimposed with dimethoate or ANSE application experienced least leaf damage compared to the sole fertilizer treatment. Such plants also grew vigorously, produced broader,

greener and succulent (turgid) leaves with low pest population. Serwy (1998) reported that agricultural practices that enhance plant nutrition are effective and save methods for insect pest control because such effects indirectly encourage natural enemies or increase plant tolerance. According to Metcalf (1991), some systemic insecticides when absorbed accumulate in the vascular system of plants and kill phloem-feeding insects. The superiority of ANSE over the commercial neem formulation, neemazal, could be due to its high repellent and antifeedant effects. ANSE have been noted to exhibit antifeedant activity against several insect orders including Orthoptera (Attri, 1975), Lepidoptera (Warthen, 1978), Coleoptera (Saradamma *et al.*, 1977) and Diptera (Kareem *et al.*, 1974). Also in India experiments have proved the repellent effects of aqueous neem seed extract (20g/l) against *Empoasca* spp. *A. gossypii* and *Epilachna* beetles on brinjal (Schmutterer, 1995).

5.6.2.2. *Bored fruits and fruits dropped in okra.*

With the bored fruits, no significant interaction occurred between the treatments. However, the significantly high number of bored fruits which occurred on the compost treated plants relative to those grown in the sole fertilizer and control treatments could be due to the fact that the compost treated plants were better nourished, produced more fruits, and therefore became more attractive to the fruit boring pests. This confirms observations made by Lewis *et al.*, (1980). Cooke (1982) and Lebeek and Lenteren (1992) in the contrary indicated that well nourished plants, through balanced fertilization, become more tolerant to pests and diseases attack, and increase in yield. The low numbers of bored fruits in the control (no soil amendment) was due to poor nourishment, resulting in fewer fruits thus making such plants less attractive to fruit the boring pests. The better comparison of ANSE with the dimethoate treatment for the number of bored fruits could be attributed to a high repellent effect of the ANSE. Karel (1989) confirmed the repellent effect of neem products applied five times at weekly intervals against *Ootheca bennigseni* and reported that ANSE at 20g/l was most effective and at par with the synthetic organophosphorous compound, dimethoate.

The significant interaction between soil and insecticide treatments accounted for the lower fruit drop encountered in the compost treated plants particularly when sprayed with either dimethoate or ANSE. This observation could be due to the complementary effects of insecticidal efficacy on

the efficiency of minor nutrients in enhancing the plants tolerance to fruit suckers. Okra grown in compost showed increase in vigour, growth and succulency. They also experienced less fruit drop even in the presence of high infestations of fruit borers and suckers, and during the harmattan period. Davis (1982) reported that compost contribute in a major way in the diversity of soil organics and organisms that are critical to humus formation and to soil and plant health. There is no significant difference between dimethoate and the ANSE treatment in their effects on reducing fruit drop. However, the superior performance of neemazal over the control (no spray) confirms the results of Srivastava and Parmar (1985). Thakre *et al.*, (1983) reported that, four weekly applications of 50g/l ANSE significantly reduced the podfly, *Melanogromyza obtuse* in pigeon pea and was at par with two fortnightly applications of dimethoate.

5.6.3. Yield

5.6.3.1. *Fruit dry matter yield*

The significant interactive effects of the soil and insecticide treatments were responsible for the best performance of the sprayed compost treated plants in increasing dry matter yield in the fruit. This observation could again be due to the complementary effects of the insecticide treatments in protecting the compost treated crop against insect pests unlike the untreated control. Such okra plants grown in compost were nourished well, and yielded higher dry matter than those in the sole fertilizer treatment. They also had better recovery ability even under high pest pressure when protected with insecticidal sprays like dimethoate or ANSE. Afreh - Nuamah *et al.*, (1998) reported that ANSE applied at 50-70 g/l provided good protection against garden egg insect pests and increased dry matter content significantly. Dalzell *et al.*, (1987) also reported of higher dry matter yields in tomato from compost plus fertilizer combined application, and better juice from sugarcane. The highest performance of dimethoate over the neem products in terms fruit dry matter yield could be assigned to it's systemic activity which prevented extraction of assimilates from the plant by insect pests. The Superiority of ANSE over the neemazal treatment could be due to it's repellent effect which confirm the findings of Chitra *et al.*, (1992)

5.6.3.2. *Fruit yield and number of fruits produced at harvest*

With regard to fruit yield, significant interactions occurred between the treatments under investigation and this accounted for the better fruit yield recorded from the compost treated plants unlike the fertilizer alone and the control plants. When such plants were protected with

insecticides, they grew vigorously and profusely, and yielded bigger fruits. Although pest incidence was high, the fruit yields of such plants were not significantly reduced. Compost contains some nitrogen, phosphorous and potassium, and nitrogen being the motor of plant growth usually cause plants to develop dark green leaves and grew vigorously. However if unbalanced, excess nitrogen would result in greater pest attack decrease quality of produce and yield (Anon, 2000).

For the number of fruits produced per plant at harvest, the compost treated plants out yielded the sole fertilizer treatment, which in turn significantly out yielded the control especially when sprayed with dimethoate or ANSE. This could be due to the effects of micronutrients present in compost, which conferred vigour and tolerance on the crop to complement the insecticidal effect of these test compounds. Also such plants had better performance such as succulency, and higher fruit yield per plant although insect pest population was high. Flaig *et al.*, (1997) reported that phenolic compounds found in compost are responsible for efficient yield increases. The better performance of dimethoate over neem products for fruit yield per plant could be due to its systemic activity thereby decreasing the loss of assimilates to insect pests. Between the neem products, ANSE differed significantly from the neemazal treatment for the fruit yield per plant probably due to its higher repellency. Ambekar *et al.*, (1991) reported from a field trial involving seven synthetic and three botanical products on insect pests of wheat that all the treatments were more effective in reducing insect pests infestation than the control. However the synthetic insecticides were more effective than the botanicals.

5.6.4. Marketable fruits

No significant interactions occurred between the treatments for marketable fruit weight. However, the compost treated plants produced significantly heavier marketable fruits than the sole fertilizer and the untreated control plants. This could be attributed to the effects of compost on plant metabolism, which increased the plant tolerance to insect pests attack. Cooke (1982) reported that the merit of compost application is that such farming practices produced good yields through increasing plants tolerance to insect pest and diseases attack. Plants grown in compost although produced heavier fruits, they hosted high insect pest populations. The superior performance of dimethoate over the neem products in the protection of the crop against

herbivorous insects pests so as to improve accumulation assimilates confirms the findings of (Hill, 1987; Blandrin *et al.*, 1998).

For unmarketable fruits, plants grown in compost when protected with either ANSE or dimethoate showed marked reduction in fruit damage as such plants grew healthier and were more turgid than those in the sole fertilizer treatment. This observation could also be assigned to the complementary effects of insecticidal efficacy on the nutritional efficiency of the compost. Significant differences also occurred among the insecticide treatments. However, dimethoate and ANSE applicatons are at par in protecting the crop against insect pest damage which proves the repellent and antifeedant activities of neem being at par with the systemic activity of dimethoate (Chitra *et al.*, 1992).

5.6.5. Economics of production

5.6 .5.1. *Cost benefit ratio due to the combined effects of soil and insecticide treatments.*

The studies revealed that the application of ANSE on compost treated plants yielded a benefit of 100% over the cost of production compared to the untreated control (no soil treatment). The sole fertilizer treatment yielded 67 %. The dimethoate treated plants also yielded just above 100 %. Although no statistical analysis was performed, this benefit could be attributed to the higher plant tolerance induced by the combined effects of the micronutrients in compost coupled with the protection offered by the insecticide treatment. The plants were therefore able to withstand attacks by insect pests, grew and developed in a congenial atmosphere (Hill, 1987; Kumar, 1984). The higher benefit derived from growing plants in the various soil amendment practices unlike the control (no soil amendment) and protecting them with the various insecticides, could be attributed to the fact that the crop, okra, responded well to the various soil nutrients (Norman, 1992; Sinnadurai, 1992). The monetary aspect of the cost benefit ratio reflected in monetary value the actual gains due to the combined effects of the soil and insecticide treatments.

5.6 .5.2. *Marginal benefit due to soil, and insecticide use alone*

The added benefit derived from the use of compost was higher but similar to that of compost plus fertilizer (about ₵200,000.00 over the untreated control) unlike the sole fertilizer treatment (₵98, 000). However, each of the soil treatments resulted in some benefit except the untreated control. This reflected the tolerance induced in the plant by the various soil treatments, with the

compost being the best (George, 1988). The additional benefit due to the use of insecticides in protecting the crop against insect pests was higher for ANSE and dimethoate treatments (at least one million cedis above the additional cost). The neemazal resulted in a break even. However, the higher returns from each insecticide treatment over the control indicated that the crop, okra, cannot be successfully grown without any form of crop protection. This is because several insect pests attack the crop at every stage of its growth (Asante, 1978; Obeng - Ofori, 1982; Critchley, 1997).

It is therefore more economical to apply compost than fertilizer. Further more fertilizer should not be added to compost. This would reduce the cost of production and increase the returns on investment to vegetable farmers.

5.6.5.3. Marginal cost and benefit due to the combined use of the different treatments

The highest additional benefit gained from the application of dimethoate on the compost treated plants could be attributed to the systemic activity of the compound which protected the crop more efficiently against pest damage after its absorption (Hill, 1987; Mathews, 1988). Similarly, the greater benefit associated with the application of ANSE on compost and compost plus fertilizer treated plants than the use of neemazal indicates the higher repellent effects of ANSE against insect pests compared to the formulated neem product (Schmutterer, 1995; Osterman, 1992).

CHAPTER SIX

6.0. SUMMARY.

From the field work, the dominant insect pest order that attacked the crop from seedling to fruiting stage was Coleoptera. However, Nine major insect pests were found attacking the crop among which Homoptera was dominant. With the minor insect pests, *Pachnoda* spp., *Riptortus dentipes* and *Calidea* spp. were found to be newly recorded insect pests of the crop in Ghana although they have been recorded elsewhere. Seven beneficial insects were also found with Coleoptera being the dominant order. Such insects were less affected by the neem products.

There were significant interactions between the treatments for all the parameters investigated ($P < 0,05$) except for bored fruits and marketable fruit weight. Compost treated plants when sprayed with Dimethoate or ANSE suffered lesser leaf damage than those grown in sole fertilizer. In addition, the compost treated plants when sprayed with ANSE or Dimethoate compared very well in the production of taller, vigorous and healthier plants, and sustained vegetative growth than plants on the sole fertilizer treatment. All the soil amendment practices produced taller, healthier and more vigorous plants than the control (no soil amendment).

Compost, and fertilizer treated plants recorded significantly less bored fruits and fruit dropped. However, when such plants were sprayed with ANSE or Dimethoate, the level of fruit damage was drastically reduced compared to the untreated control. In the case of the neem products, ANSE performed far better than the commercial preparation, and was biologically efficient in protecting okra against insect pest damage.

Fruit dry matter and fruit yield parameters were higher in the compost treated plants than in the sole fertilizer and control treatments. Plants under such soil amendments compared well when sprayed with Dimethoate or ANSE than the control (no soil amendment).

CONCLUSIONS AND RECOMMENDATIONS

From the above results, the following conclusions can be made: -

- (1) Compost promotes vigour, faster growth and sustains vegetative yield in okra. Consequently where the crop is grown purposely for its leaves, sole compost (500g/plant) or in combination with chemical fertilizers where compost is limited (at 250g compost +10g fertilizer) is recommended.
- (2) Compost when applied to okra promotes higher metabolic activities and increases the plants ability to withstand insect pests and diseases attack, and to produce substantial fruit yield. For sustainable production of the crop, sole compost must be applied.
- (3) The synthetic insecticide, Dimethoate, and the botanical, ANSE, are comparable in managing insect pests of okra. However, the ANSE is environmentally and applicator friendly, less costly and safer to natural enemies. Consequently for sustainable and economic production of the crop, insect pests should be managed with ANSE (50g/litre of water).
- (4) Okra is very vulnerable to insect pests attack with about 52 insect pests belonging to 7 orders recorded on the crop in Ashaiman. Consequently for its sustainable production, selective and efficient pesticide application must complement the effects of good soil amendment practices to enhance vigour and yield of the crop.
- (5) In terms of economic benefit, the ANSE compared favourably well with Dimethoate and resulted in 100% returns over the cost of production when applied on okra grown in compost. Okra grown without any form of protection resulted in total loss. Marginal benefit due to the application of compost was well above ₵500,000.00/ha while the benefit due to complementary effects of pesticide application was in excess of ₵1,000,000.00/ha
- (6) Application of ANSE (50g/l) on plants grown in compost (500g/plant) was more cost effective and biologically efficient and hence must be recommended as a package for sustainable okra production.

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APPENDICES

1) ANOVA for effects of insecticides on major insect pests

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	1446.16	482.05	9.45	
Pests	8	123285.52	15410.69	302.05	<.001
Insecticide	3	121521.40	40507.13	793.94	<.001
Pests.Insecticide	24	59676.29	2486.51	48.74	<.001
Residual	105	5357.11	51.02		
Total	143	311286.48			

2) ANOVA for effects of insecticides on beneficial insects

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	90.071	30.024	3.89	
Pests	6	1281.566	213.594	27.71	<.001
Insecticide	3	19164.272	6388.091	828.59	<.001
Pests.Insecticide	18	1735.958	96.442	12.51	<.001
Residual	81	624.477	7.710		
Total	111	22896.344			

3). Analysis of variance (ANOVA) for Percentage leaf area damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	15.938	5.312	4.37	
Soil treatment	3	10.313	3.437	2.83	0.099
Residual (a)	9	10.938	1.215	0.64	
Chemical	3	902.813	300.938	159.03	<.001
Soil treatment.Chemical	9	14.063	1.562	0.83	0.597
Residual (b)	36	68.125	1.892	0.91	
Total	127	1192.188			

4). ANOVA for Plant Height at flowering

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	1503.608	501.203	18.61	
Soil treatment	3	1711.344	570.448	21.18	<.001
Residual (a)	9	242.355	26.928	3.95	
Chemical	3	287.510	95.837	14.05	<.001
Soil treatment.Chemical	9	165.735	18.415	2.70	0.016
Residual (b)	36	245.514	6.820	0.69	
Total	127	4896.327			

5). ANOVA for Plant Girth Girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	9.7475	3.2492	17.52	
Soil treatment	3	18.3886	6.1295	33.05	<.001
Residual (a)	9	1.6690	0.1854	1.69	
Chemical	3	1.2183	0.4061	3.70	0.020
Soil treatment.Chemical	9	4.7444	0.5272	4.80	<.001
Residual (b)	36	3.9551	0.1099	1.01	
Total	127	48.5297			

6). ANOVA for Number of functional leaves

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	611.994	203.998	11.16	
Soil treatment	3	773.002	257.667	14.09	<.001
Residual (a)	9	164.539	18.282	3.45	
Chemical	3	634.854	211.618	39.91	<.001
Soil treatment.Chemical	9	127.959	14.218	2.68	0.017
Residual (b)	36	190.882	5.302	1.96	
Total	127	2685.020			

7). ANOVA for Number of branches

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	37.713	12.571	2.48	
Soil treatment	3	1650.127	550.042	108.30	<.001
Residual (a)	9	45.711	5.079	2.28	
Chemical	3	208.009	69.336	31.10	<.001
Soil treatment.Chemical	9	205.968	22.885	10.26	<.001
Residual (b)	36	80.269	2.230	1.68	
Total	127	2331.643			

8). ANOVA for number of bored fruits

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	159.187	53.063	7.74	
Soil treatment	3	434.125	144.708	21.11	<.001
Residual (a)	9	61.688	6.854	0.39	
Chemical	3	10881.938	3627.313	204.24	<.001
Soil treatment.Chemical	9	157.687	17.521	0.99	0.468
Residual (b)	36	639.375	17.760	2.35	
Total	127	13054.000			

9). ANOVA for number of Fruit dropped

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	1743.06	581.02	24.98	
Soil treatment	3	4254.50	1418.17	60.98	<.001
Residual (a)	9	209.31	23.26	0.90	
Chemical	3	8447.31	2815.77	108.84	<.001
Soil treatment.Chemical	9	1105.31	122.81	4.75	<.001
Residual (b)	36	931.37	25.87	1.82	
Total	127	17932.88			

10). ANOVA for percentage Unmarketable fruits

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	457.143	152.381	6.75	
Soil treatment	3	166.658	55.553	2.46	0.129
Residual (a)	9	203.030	22.559	1.33	
Chemical	3	11132.661	3710.887	218.86	<.001
Soil treatment.Chemical	9	341.508	37.945	2.24	0.042
Residual (b)	36	610.386	16.955	.99	
Total	127	13246.567			

11). ANOVA for Fruit Dry Matter yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.72031	0.24010	1.13	
Soil treatment	3	117.89038	39.29679	184.79	<.001
Residual (a)	9	1.91391	0.21266	1.62	
Chemical	3	2.93518	0.97839	7.46	<.001
Soil treatment.Chemical	9	3.25564	0.36174	2.76	0.015
Residual (b)	36	4.71928	0.13109	2.09	
Total	127	135.89570			

12). ANOVA for Yield in tonnes per hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	0.94598	0.31533	7.09	
Soil treatment	3	31.37031	10.45677	235.14	<.001
Residual (a)	9	0.40023	0.04447	0.52	
Chemical	3	84.51193	28.17064	326.31	<.001
Soil treatment.Chemical	9	7.87888	0.87543	10.14	<.001
Residual (b)	36	3.10792	0.08633	1.52	
Total	127	140.46861			

13). ANOVA for Number of fruits per plant at harvest

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	2.7853	0.9284	1.42	
Soil treatment	3	55.5984	18.5328	28.34	<.001
Residual (a)	9	5.8859	0.6540	1.63	
Chemical	3	45.6753	15.2251	38.00	<.001
Soil treatment.Chemical	9	13.9959	1.5551	3.88	0.002
Residual (b)	36	14.4238	0.4007	2.22	
Total	127	159.3547			

14). ANOVA for Marketable fruit weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps	3	81.668	27.223	5.13	
Soil treatment	3	1319.627	439.876	82.88	<.001
Residual (a)	9	47.767	5.307	0.75	
Chemical	3	560.690	186.897	26.58	<.001
Soil treatment.Chemical	9	72.676	8.075	1.15	0.356
Residual (b)	36	253.098	7.030	1.45	
Total	127	2734.116			