CONTROL OF CASHEW SUCKING BUGS *HELOPELTIS ANACARDII* AND *PSEUDOTHERAPTUS WAYI* BY MANIPULATING THE AFRICAN WEAVER ANTS (*OECOPHYLLA LONGINODA*) POPULATIONS IN CASHEW NUT TREES.

BY

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ABSTRACT

Five field experiments were conducted during the 2000/2001 season at ARI-Naliendele, Mtwara region in southern Tanzania. The general objective of the study was to establish optimum population levels of weaver ants that will give effective control of *Helopeltis anacardii* and *Pseudotheraptus wayi* in cashew nut trees. The experiments were also conducted to establish the bionomics of the population of the cashew pests *H. anacardii* and *P. wayi*, and the predator, *Oecophylla longinoda* in relation to the antagonistic ant, *Pheidole megacephala.* Assessment of shoot and nut damage, and associated yield were carried out to establish the effectiveness of the predator against the two pests. The study has shown that high levels of *O. longinoda* had significant effects in protecting cashew trees from attack by *H. anacardii* and *P. wayi* Manipulation of number of nests of *O. longinoda* confirmed that 30 and 40 nests can provide maximum protection of cashew trees. The protective effect of the biological agent led to reduction of damage levels in shoots and nuts due to reduced number of pests and increased nut yield/tree. When the performance of the biological agent at different nest levels was compared to chemical control using lamda cyhalothrin (5 %), the chemical was found to be less effective as compared to cashew trees subjected to 30 or more *O. longinoda* nests. The antagonistic ant, *P. megacephala*, to the biological agent *O. longinoda* was successfully suppressed by Amdro bait. Reduction in population of the competitor ant resulted to increased numbers of *O. longinoda* in the field, and increased predation activity against the pests. Significant variations ($P \leq 0.05$) of damage levels between trees subjected to weaver ants alone and those subjected to weaver ants in combination with Amdro bait were evident. Lowest damage levels were recorded in trees treated with Amdro bait in combination with weaver ants. It is concluded that weaver ants have a great potential for suppressing *H anacardii* and *P. wayi* to low uneconomic levels. However, for a successful establishment of weaver ants in the field, controlling of the antagonistic ants *P. megacephala* is essential.

DECLARATION

I, Waziri Ali Mwinyi, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and that it has not and is neither being concurrently submitted for a degree award in any other university.

Signature....Mwinyi.......................... Date....14-6-2002....................

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DEDICATION

To my parents Fatuma Mohamed and my late lovely father Masudi Mwinyi for sending me to school. To my wife Maua Mtwa, my children Mwanaheri, Rehema and Zuberi for their love, and endurance.

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
AC	Anacardium Cylon
a.i.	active ingredient
ANOVA	Analysis of Variance
ARI	Agricultural Research Institute
a.s.l.	above sea level
Aug.	August
AZA	Anacardium Zanzibar
CV	Coefficient of variation
D	Depth
Dec.	December
E	East
EC	Emulsifiable Concentrates
HD	Horizontal distance
Jan.	January
Jul.	July
Km	Kilometers
LR	Lower reading
M	Meters
M^2	Square meter
Mm	Millimeter

MSCA	Mass selection and character assessment
Nov.	November
Oct.	October
RCBD	Randomized Complete Block Design
R/H	Relative Humidity
S	South
S.E	Standard error
Sept.	September
TSRT	Tukey's Studentized Range Test
UR	Upper reading
U.S.A.	United States of America
V	Volume
VIT	Variety improvement trial
W	Width

CHAPTER ONE

INTRODUCTION

Cashew is the leading cash crop in southern regions of Tanzania. It is estimated that 280 000 households grow about 400 000 hectares of cashew in mono or mixed crop production systems (Annual Cashew Report. 1997). In Tanzania cashew ranks the third after coffee and cotton in generating foreign exchange earnings from agricultural exports (Kikoka *et al.*, 1997). In 1990. Tanzania obtained about 10.7 million US dollars from cashew nuts exports. Worldwide Tanzania is the fourth biggest cashew nut producer after India. Brazil and Mozambique (Annual Cashew Report, 1997).

The problem of insect pests in cashew nut production in Tanzania has increased recently as a result of application of sulphur dust and other organic fungicides to control powdery mildew. Increased use of fungicides results into formation of shoots attractive to sucking bugs such as *Helopeltis anacardii* and *Pseudotheraptus wayi* (Topper *et al.*, 1997). These pests were originally less important. but have now become a big threat to the cashew nut industry in the country.

Damage by cashew sucking bugs lowers yield and nut quality due to damage of the productive parts, the flowers. young shoots and nuts. It has been reported that out of

100 panicles attacked by adults and nymphs of *H. anacardii*, 65% die off completely and the remaining panicles suffer black lesions (Boma *et al.*, 1997). *Pseudotheraptus wayi* may cause up to 100% panicle die back (Topper *et al.*,1997).

Several methods are used to control cashew pests. These include cultural practices, chemicals and to a lesser extent biological control. However, cultural and chemical control methods have some limitations. It has been reported that clean weeding for example does not bring an immediate suppression of pests unless it is integrated with other cashew management practices (Stanthers, 1994). Pesticides are very expensive and are not affordable by many farmers. The chemical in current use in Tanzania is Lamba-Cyhalothrin (5% EC.), which costs up to 15,000/= per litre. In addition the motorized mist blower used for the application costs TShs 350,000/=. The use of chemicals could also lead to upsetting the relationship between the pests and their natural enemies, which may increase the pest problem (Valera, 1994). Casuli (1981) also identified other problems including: chemicals do not reach farmers timely, unavailability and expensive fuel to run motor blowers and lack of spare parts for the blowers. A sound alternative for the management of insects pests of cashew nuts is therefore the use of biological control agents. Bio- agents are safe to users, as well as to non-target organisms and are environmentally friendly.

The most promising natural enemy for *Helopeltis anacardii* and *Pseudotheraptus wayi* is the African weaver ant, *Oecophylla longinoda* (Stanthers, 1995). Studies on the use of *O. longinoda* as a biological agent in cashew nut have been conducted in Tanzania (Varela, 1997; Sijaona, 1999). However, the population level, which could give effective control of the pest has not been established. Therefore, the objective of this study is to establish the optimum population levels of weaver ants that will give effective control of *H. anacardii* and *P. wayi* in cashew nut trees.

Specific objectives:

1. To determine levels of damage by *H. anacardii*, and *P. wayi* when cashew nut trees are subjected to different densities of weaver ants population.
2. To assess damage in trees treated with lamda cyhalothrin to control *H. anacardii*, and *P. wayi*.
3. To assess population levels of *H. anacardii*, and *P. wayi* subjected to different densities of ants
4. To determine nut yield under different population densities of ants.

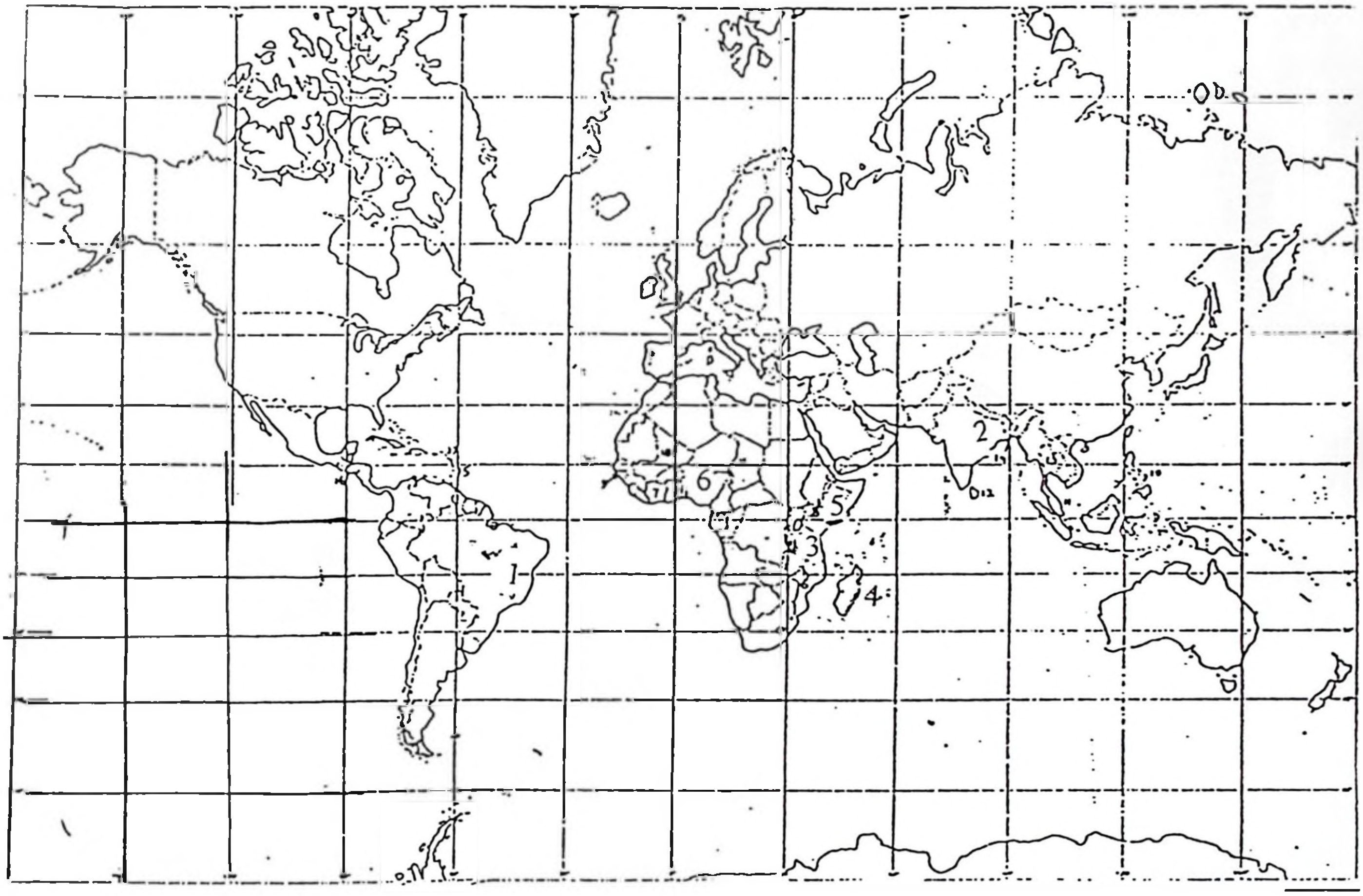
CHAPTER TWO

LITERATURE REVIEW

2.1 Cashew plant

2.1.1 Origin and Distribution

The cashew plant originated from Central and South America. From its center of origin it has now been widely distributed throughout the tropics. particularly in Africa and Asia (Axtell. 1992). It was one of the first fruit tree from the New World to be wildely distributed throughout the tropics by the early Portuguese and Spanish adventurers. The Portuguese introduced it to India from Brazil in the 16th century and it reached the East African coast and Malaya about the same time. It has become a popular tree crop in many tropical countries especially in the coastal areas (Purseglove. 1987). Major producing countries in the world include India. Brazil. Mozambique. Malaysia. Tanzania. Indonesia. Nigeria. Angola. Kenya and Thailand (Figure 1). In Tanzania. cashew is grown mostly in Tanga. Morogoro. Coast. Dar es Salaam. Lindi. Mbeya. (Kyela) and Ruvuma. (Tunduru) regions (Figure 2). However, the bulk of the crop comes from Mtwara region particularly in Newala district with a marked concentration on the Makonde plateau (Annual Cashew Report, 1999).



Key
1. Brazil
2.India
3.Tanzania
4.Madagascar
5.Kenya
6.Nigeria

Figure 1. Major cashew growing areas in the word (Source: Sijaona, 1997)

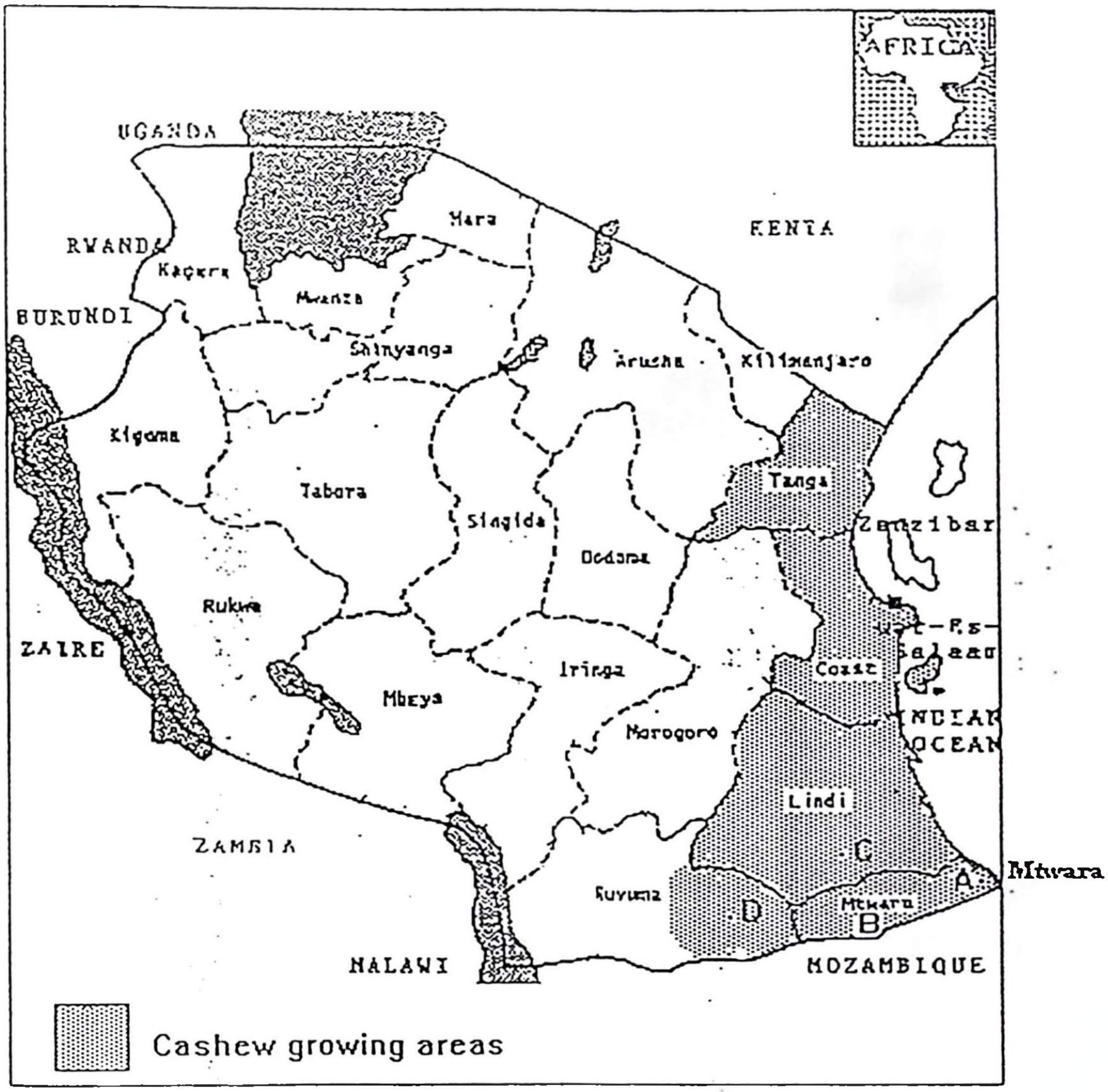


Figure 2. Map of Tanzania showing cashew-growing areas (Source: Sijaona 1997)

2.1.2 Ecology

The plant tolerates a wide range of conditions including drought and poor soils, but cannot withstand cold or frost (Axtell, 1992). The crop is best grown at an altitude of about 170m above sea level (a.s.l.) with well distributed rainfall ranging from 1000 - 2000 mm per year. Relative humidity (RH) between 40% - 50% is regarded as the most desirable range especially during flowering and fruit setting. High humidity over 70% promotes fungal infection whereas humidity less than 40% leads to withering of flowers and development of small nuts (Kumar and Udaga, 1996). Cashew is grown in almost all types of soils from sandy to laterite including wastelands of low fertility. It grows and yields best in well-drained red sandy loam's and light coastal sands. Heavy clay soils and poor drained soils are unsuitable for the crop (Axtell, 1992).

2.1.3 Flushing and Flowering.

Flowering and flushing vary in response to weather and genotype differences, but it usually extends over 3 - 4 months (Bigger, 1960; Wait and Jomeson, 1986). Flowering normally takes place after flushing at the end of the rainy season. The inflorescence is a panicle, and may either be conical pyramidal or irregular in shape. The time of the first appearance of the inflorescence to opening of the flowers is about 5 – 6 weeks (Ohler, 1979).

2.1. 4 Nut setting

The number of fruit that attain maturity is often low compared to the number of perfect flowers produced (Kasuga, 1991). Bigger (1960) obtained 55.5% fruit set of the perfect flowers whereas under open pollinated condition 38% fruit set was affected. The number of nuts that matured was only 17% out of the flowers that had set fruits. Ohler (1979) recorded a mean number of 4.8 nuts per panicle out of 128 trees observed. Pillai and Pillai (1975) dissected fruits from six trees to examine ovule development. Out of 85% of the fertilized fruits only 4% reached maturity. The remaining 81% shed away at various stages of development. High percentage of fruit dropping was reported to be due to several factors including genetical, physiological, nutritional, moisture stress, insects and diseases (Patnalk *et al*., 1985).

2.1.5 Production trends and problems

Generally cashew gained economic importance in Tanzania just after Second World War when 7,000 tonnes of raw nuts were exported to India (Annual Cashew Report, 1997). Ten years later cashew production increased three folds and in 1960 about 42,000 tonnes of raw nuts were exported. Production continued to increase and reached a maximum of 145,000 tonnes in 1973/74 season. Unexpectedly, from 1974/75 season, the production trend reversed and there was a continuous and drastic decline in cashew production to as low as 16,000 tonnes in 1986/87 (Figure 3).

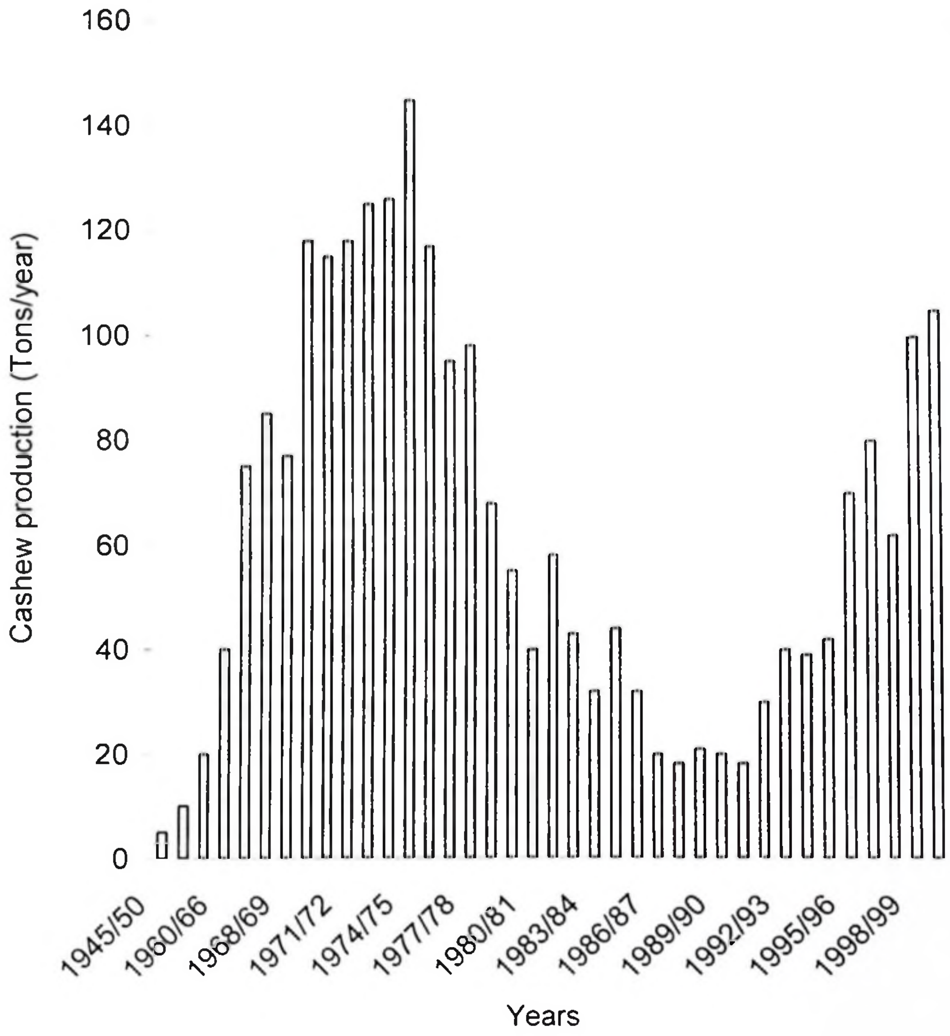


Figure 3. National cashew nut production from 1945 to 1999 ('000 Tons) (Source: Cashew nut Research Annual Report, 1999)

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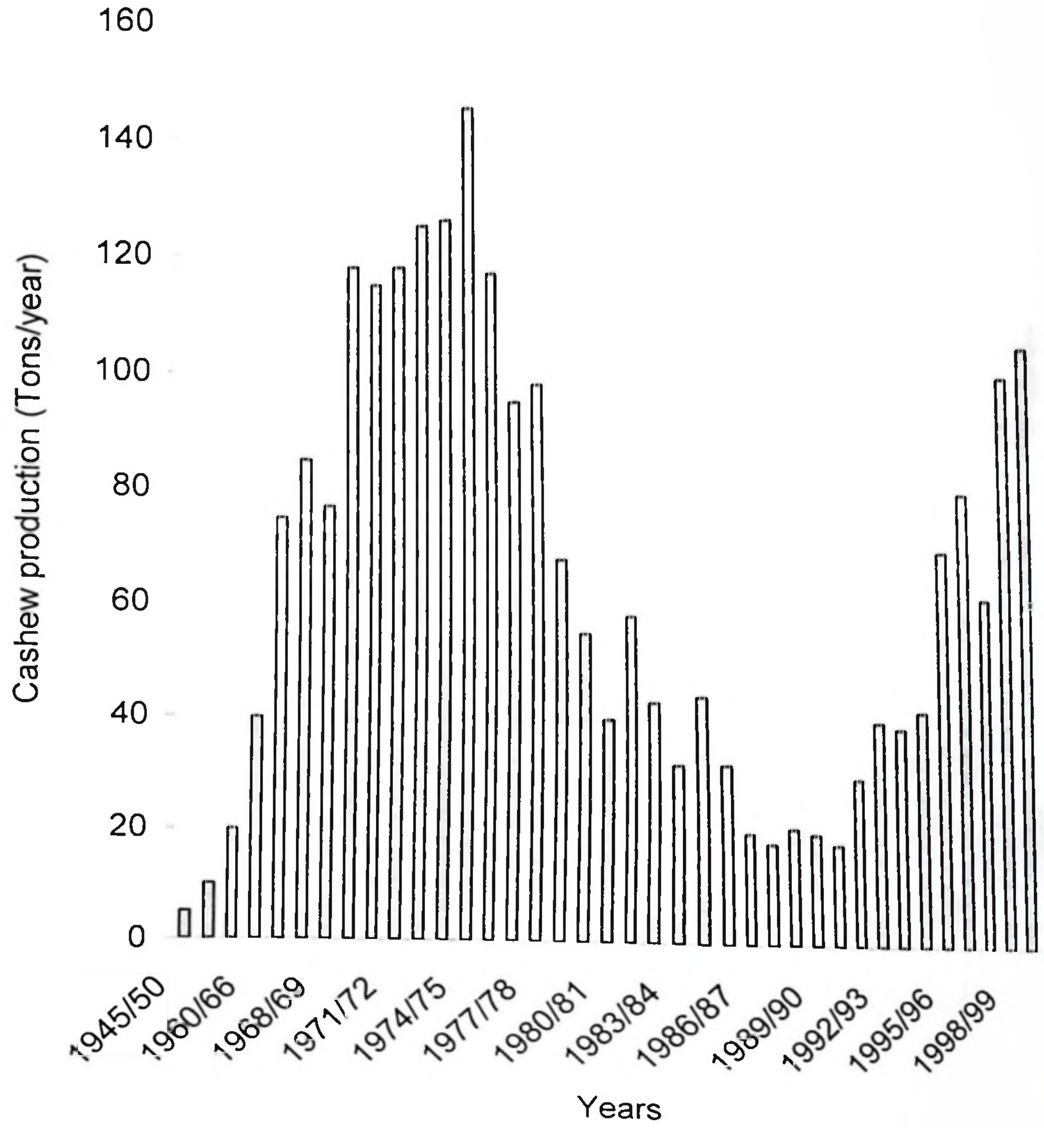

Figure 3. National cashew nut production from 1945 to 1999 ('000 Tons) (Source: Cashew nut Research Annual Report, 1999)

The decline in cashew production was consistent in all cashew-growing areas in the country, which resulted in a large loss of revenue for both growers and the government. Several reasons have been given for the decline in cashew production. They include abandonment of plantations due to forced resettlement in new areas, diseases, aging trees, poor husbandry, pest attack and low prices given to farmers (Kasuga, 1991). Pest problems played a major role in the decline of cashew production (Stefano, 1984).

2.2 Pests of cashew

Cashew is commonly attacked by various species of insects but only few of them are of economic importance (Topper *et al.*, 1997). They include *Selenothrips rubrocinctus* Giard (Thysanoptera Thripidae), *P.wayi* Brown (Heteroptera: Coreidae) *Helopeltis spp.* Miller; *Pseudaconidia trilobitifomis* Green (Homoptera: Diaspididae), Aphids (Homoptera: Aphidae) (Stefano, 1984) (Table 1). *H. anarcadii* Miller and *P. wayi* Brown (Heteroptera: Coreidae), are the most serious pests threatening the cashew nut industry in Tanzania (Boma *et al.*, 1997).

Table 1. Incidence of attack of cashew by the main phytophagous insect pest species.

	% Damage			
Insect	Leaves	Panicles	Nuts	Apples
Helopeltis ssp	20.0	8.8	4.0	-
Pseudotheraptus.wayi	2.9	12.0	0.9	-
Aphids	24.0	7.7	2.1	0.3
P.trilobitifomis	16.6	-	-	-
Mytilococi sp	1.2	-	-	-
Acrocercops sp	24.1	-	-	-
Gypomychus sp	7.6	-	-	-

Source: Italo – Tanzania Cashew Research Program Report (Phase II. 1982 – 84)

2.2.1 *Helopeltis anacardii* (Hemiptera: Miridae)

2.2.1.1 Biology and general characteristics

Ohler (1979) reported that the adult male bugs are about 4.5 mm long; the females 60 mm (Plate 1). Stanthers (1995) reported that mating could occur two days after the final molt. Adults may live for 14 - 21 days. The female lays 3 – 4 eggs per day. Hatching occurs between 1 – 4 weeks after oviposition. Nymphs commence feeding soon after emergence and continue throughout the five nymphal instars. They have very long legs and antennae. The color varies from brown. red to orange. The major diagnostic feature in both nymphs and adults is the pin-like procession. which rise vertically from the thorax. The adult bug is about 2 mm long (Sirasaka. 1998). *Helopeltis anacardii* like many other Miridae bugs is a poor flier. and is commonly seen on cashew trees during the cooler late afternoons and mornings.

Plate 1. Adult *Helopeltis* bug sucking on a tender leaf.

2 .2. 1. 2 Host range and pest status

All *Helopeltis spp.* are polyphagous on a range of crop plants including numerous weeds. The principal crops they attack include cashew. tea. mango. castor. sweet potato. pigeon peas. cocoa. cotton. guava and avocado (Sirasaka. 1998). Both nymphs and adults feed by pushing their tube like mouthparts into soft green tissues. Saliva is forced into the plant before feeding begins and is highly toxic to the cells. A dark water soaked mark first appears around the feeding puncture. which later turns into the characteristic lesion with a light brown center and black edge. Stem lesions tend to split longitudinally and finally become corky as callous formation occurs. Young shoots often die off completely (Plate 2). This results to stimulation of secondary branching which is also very susceptible to attack (Sirasaka. 1998). Attack on the floral shoots arrest fruit and nut formation (Stanthers. 1995). Severely damaged trees can look as if they have been burnt. The insects also feed on young nuts and apples, which results in the formation of elliptical shaped black marks on the developing nuts (Topper *et al.*. 1997). The damage symptoms are shown in Plates 3 and 4.

Plate 2. Shoot damage showing complete death of young growing shoot

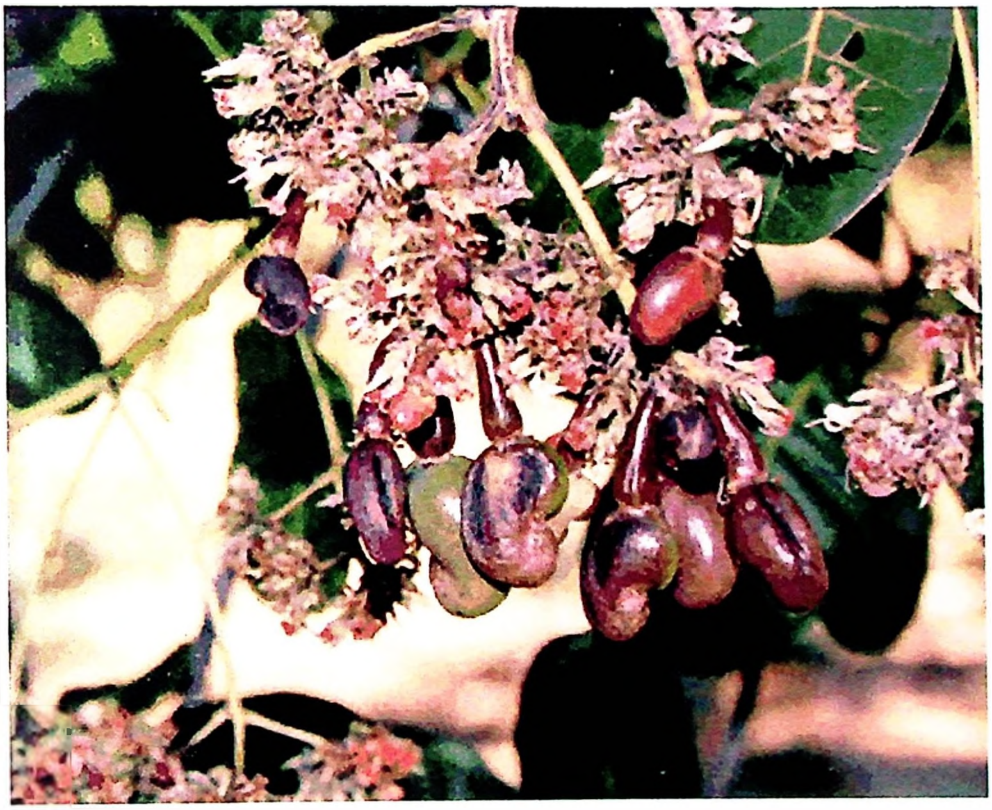

Plate 3: Pre-mature nut damage showing black lesions.

Plate 4: Nut damage showing black lesions on mature nuts, which results to loss of nut quality.

2.2.2 *Pseudotheraptus wayi* (Hemiptera: Coreidae)

2.2.2.1 Biology and general characteristics

Pseudotheraptus wayi is a small red/brown insect. The upper surface of the abdomen is red as the eyes and the three basal segments of antennae, while the fourth segment is brown (Plate 5). According to Lever (1969) the mature female lays 74 eggs in its lifetime. Ohler (1979) observed that the pre-oviposition period varies between 4 and 30 days but the first eggs are usually laid after 18 days. The life span of adults is often more than 60 days and the longest life recorded lasted 150 days (Adenya, 1974). This species has about 9 generations per year (Hill, 1975). Topper *et al.* (1997) reported that *P. wayi* eggs take between 9-16 days to hatch depending on the temperature. After hatching the nymph stage lasts for 17 days.

Plate 5: Adult *Pseudotheraptus* bug feeding by sucking on a tender leaf

2. 2. 2. 2 Host range and pest status

The coconut bug, *P. wayi*, is an important pest of cashew in East Africa (Mariau, 1969). It was first reported in South Africa in 1977 on mangoes and guavas, but it is known to attack many other crops like macadamia, avocado, and coconuts (Van Der Meulen, 1990). Both adults and nymphs cause damage in crops as they extract sap from the fruit with their piercing sucking mouthparts (Van Der Meulen, 1992). The attacked portion form hard internal knob just underneath the surface. This knob can be up to 10 mm in diameter when damage is inflicted at a young stage and normally comes off when the peel is removed. The fruit can also be malformed when infestation by adult coconut bug occurs at an early stage of fruit development, but internal fruit rot is seldom observed. Coconut damage can be distinguished from that caused by fruit flies which form star -like lesions on the outside of the peel. Each individual pest can cause approximately 200 punctures in it's life time (Lever, 1969).

2.3 Cashew pests population dynamics

Chung and Wood (1989) reported that population build up of *H. anacardii* and *P. wayi*, varies depending on various factors including availability of food and weather conditions particularly rainfall. Food sources like presence of new flushes, and young nuts were reported to contribute significantly to the survival of the sucking bugs. Tan (1974) reported that in June, there was lower damage since there was limited food supply. It has been established that there is a relationship between flushing and subsequent build up of the pest population (Boma *et al.*, 1995). Julia and Mariau (1978) reported that peak infestations of *P. wayi* occur at the end of the rainy season.

2.4 Control of cashew pests

Several methods of controlling *Helopeltis spp.* and *P. wayi* in cashew and other trees have been evaluated in several countries including Ivory Cost. Tanzania. Ghana. Malaysia. and India (Chen. 1962; Doucho. 1984: Julia and Mariau. 1978: Oswald and Rashidi. 1992). Generally. *H. anacardii* and *P. wayi* can be controlled by using cultural methods such as field sanitation. proper selection of good intercropping crops. chemical treatment, and biological control (Oswald and Rashidi. 1992).

2.4.1 Cultural control

Clean weeding is an important agricultural practice for controlling many cashew pests because weeds tend to harbor pests. Cutting grass was reported to reduce *H. anacardii* .(Italian Technical Report. 1981). Clean weeding also can reduce the risk of fire and may facilitate easy picking of nuts during harvesting. Intercropping with crops that carry the pest or planting close together should be avoided. It has been reported that coconut. pigeon peas. tea. avocado. castor. and cotton fields should not be established near a cashew field in order to avoid infestation of *P. wayi* and *H. anacardii* bugs (Sirasaka. 1998: Topper *et al.*. 1997).

2.4.2 Chemical control

The use of chemicals is still one of the most popular and effective method of controlling *H. anacardii* and *P. wayi* in cashew nuts. *Helopeltis anacardii* is effectively controlled by lindane (20% a.i.) at two application intervals (Italian Technical Report 1981). The first application is done during formation of young shoots and the second after 15 - 20 days, before flowering. Thiodan (35% a.i.) also is used to control the pest. *Pseudotheraptus wayi* was reported to be controlled by either Lindane (0.05 % a.i) or Dimethoate (0.05 %). Currently, however, it has been shown that *H. anacardii* and *P. wayi* can be controlled by lamda cyhalothrin (5% EC). (Boma *et al.*, 1995)

2.4.3 Biological control

It has been established that the African weaver ants *O. longinoda* are good natural enemies of both *H. anacardii* and *P. wayi* (Stanthers, 1995). Enhancement of this predator leads to a substantial amount of control resulting into increased nut yield and quality. One of the methods used to increase the number of trees colonized by *O. longinoda* involves connection of colonized to uncolonized cashew tree canopies using locally made grass ropes (Sijaona, 1999).

2. 4. 3. 1 *Oecophylla longinoda* (Hymenoptera: Formicidae):

The males and females are referred to as"kings" and "queens," respectively. The life span of the queen is 10 – 15 years (Metcalf and Flint., 1990; Mani, 1982). The population of a single colony varies considerably from a few thousands to over 500,000 individuals (Mani, 1982). However, Valera (1994) established that an individual colony has a population of up to a million workers. Generally the weaver ants belong to a large group of ants which are widely distributed and are very numerous in terms of numbers and species (Mathew, 1979). Metcalf and Flint (1990) reported that ants are the most abundant terrestrial animals. They have perhaps the most highly organized social life of all insects. Weaver ants are unique in the use of larval silk to fasten leaves together to form large bag like nests (Mathew, 1979). Dejean (1991) reported that the ants respond very quickly to increase in prey density, and have a great diversity of potential preys, and thus are very effective as a biological control agent.

2. 4. 3. 2 Social behaviour

In a colony of *Oecophylla longinoda*, there are two main groups, the major workers and minor workers. Major workers are very numerous, relatively big in size and are responsible for most works in the colony. The minor workers are small in size, few in numbers and play an auxiliary role in the colony. Major workers are reported to be very aggressive and when disturbed could rush out to attack and bite any intruder. When attacking they release formic acid from their poison glands (Stanthers, 1994). It was reported by Way (1954) that only one fertile queen is present in each colony. From laboratory studies, Holldobler and Wilson (1990) found that major workers feed the queen by regurgitating food into its mouth. Stanthers (1994) reported that the major workers from different colonies of *O. longinoda* are very antagonistic. Any worker venturing into the territory of another colony is grabbed and killed, or thrown away from the tree. Peng *et al.* (1999) also reported the antagonistic nature of *O. longinoda*, where boundary fighting occurred between *O. smaragdina* colonies in cashew trees.

2. 4. 3. 3 Diet and host range

The order Homoptera is widely distributed with many insect species found in different plant species. *O. longinoda* has a wide host range of plants to colonize (Stanthers, 1994). Weaver ants are found to colonize many other plants including mangoes, citrus, coconuts, cloves and cocoa. Weaver ants normally take their prey and transport them to their nests by using their mandibles. The weaver ants were found to be able to survive even in situation where the source of food is only from those insects under the order Homoptera (Way, 1954). This highlight the stability of food sources of *O. longinoda* during times when insect prey is low or unreliable.

2. 4. 3. 4 Distribution and effect of climate on weaver ants survival

The genus *Oecophylla* is found throughout the tropics. The green ants *O. smaragdina* have been found in Southern Asia, Northern Australia and in many tropical Western Pacific islands. *Oecophylla longinoda* in particular, is found in Africa in areas that have ever green trees and bush vegetation throughout the year. The green vegetation enable activities such as nests building and prey searching to continue efficiently (Plate 6) (Stanthers, 1994). Way (1954) noted that in inland areas of Kenya and Tanzania, particularly at higher altitudes, *O. longinoda* is uncommon or absent. Lokkers (1986) reported that temperature and rainfall influence the distribution of *O. smaragdina*. Low temperature was reported to inhibit larval development (Lokkers, 1986). *Oecophylla longinoda* essentially inhabits vegetation mainly found in the tropical areas with rainfall above 500 mm per year (Stanthers, 1995).

Brain (1983) reported that *Oecophylla* is very vulnerable to rain and wind. According to Sijaona (1997) a sharp drop of number of nests between January and May. occurred at Naliendele (Tanzania). which was thought to be due to high levels of wind gusts that destroyed some of the nests.

Topper *et al.* (1997) reported that heavy rainfall causes high mortality of nymphs. particularly the 1st and 2nd instars. In India. highly significant negative correlations were observed between meteorological factors like rainfall. relative humidity and minimum temperature and the population abundance of *H. antonii* (Pillai *et al.*. 1976).

Plate 6. Weaver ant's nest where workers are found foraging outside the nest

2.5.5 Parasites and predators of *Oecophylla longinoda*

It has been established that other ants. including *Pheidole spp.* are important predators of *O. longinoda* (Zerhusen & Rashidi. 1992). These ants were found catching weaver ants particularly those venturing around the trunk of cashew nut trees. In the dry season, when the population of *Pheidole spp.* increases. *O. longinoda* completely stopped ground foraging around trees where they were previously active and often a few ants could be seen loitering about 20 cm up the trunk (Stathers. 1994). Vanderplank (1960) reported many predators of *O. longinoda* in Tanzania including *Crematogaster spp.*. *Analolipes longipes* (Crazy ants). *Anaplolipes custodiens*. In southern Tanzania they were found to coexist in the trees with *O. longinoda* and pseudo – scorpion. *Hanenius spp.*. that hides in nests and cracks in barks.

2.5.6 Potential of the genus *Oecophylla* as a biological control agent

The earliest account of biological control of insect pests came from southern China. where in AD 304 nests of *O. smaragdina* were gathered. sold in the market and placed in citrus trees to combat insect pests including Lepidoptera larvae and *Rhynchoris humeralis* (Stanthers. 1994). The use of the genus *Oecophylla* in biological control has been reported widely (Cheng & Yang. 1987; Oswald & Rashidi. 1992; Varela. 1992; Sijaona. 1997). The genus *Oecophylla* was reported to control different pest species including *Helopeltis pernicialis* (Peng *et al.*. 1997). *Helopeltis antonii* in South India. *Pseudotheraptus devastans* in West Africa and *P. wayi* in East Africa (Way and Khoo. 1992). Others include *O. smaragdina*. the weevil *Pantorrhytes* spp.in the Solomon Islands and *O. longinoda* in Tanzania (Stapley, 1980; Varela; 1992; Sijaona, 1997).

The efficiency of *Oecophylla longinoda* as predators is explained by the stability of their large colonies, their aggressiveness, and their extensive foraging ability (Way *et al.*, 1992). Their main food sources are prey like the *Helopeltis* and *Pseudotheraptus* bugs and the honeydew they produce. Twenty-one different species of Homoptera bugs have been reported to provide a good source of food to *Oecophylla spp.* in Tanzania (Varela, 1992).

2.5.7 Colony establishment of the biological agent.

2.5.7.1 Establishment methods

Varela (1997) reported that *O. longinoda* could be established in new areas by using small colonies reared from fertile queen collected after swarming or by the transfer of nests during the period when reproductive forms are produced. It was argued that transfer of nests during this time could be a source of founder queen in an area where natural colonies do not exist. In Zanzibar, Oswald and Rashidi (1992) reported an increased colonisation of *O. longinoda* in coconut plots where continuous nests introduction was done. High mortality in the field was compensated by massive production of queens. However, no evidence was found for colony foundation by excision (Varela, 1997).

Sijaona (1996, 1997, 1998) introduced locally made ropes made of grass to enhance movements of predatory weaver ants in which colonised cashew trees were interconnected to uncolonised trees. The results further showed that there were large numbers of *O. longinoda* nests construction on interconnected trees as compared to non-interconnected trees.

2.5.7.2 Survival of colonies during time of establishment

Survival of colonies during time of establishment depends on several factors including adequate host plants, and transfer of nests early in the morning (Doucho, 1984). Sijaona (1998) also reported that care should be taken making sure that nests belonging to one colony are placed on one tree. This is important because *O. longinoda* colonies are antagonistic. Oswald and Rashidi (1992) reported that removal or suppression of competitive ants to *O. longinoda* is very important when establishing new ants colonies. It has been established that *Pheidole megacephala* is an important competitor of weaver ants (Seguni *et al*., 1997). This ant can be effectively controlled by use of hydramethylnon "Amdro" bait a slow acting stomach poison insecticide (Oswald and Rashidi, 1992).

Amdro consists of 0.88% hydramethylon dissolved in refined Soya oil and incorporated in maize bran (Harlan *et al*., 1981). The bait is attractive only to ants of the subfamily Myrmicidae (*Pheidole spp.*) and not those of the family Formicidae like *O. longinoda* (Samways, 1985). The bait was previously developed for control of fire ant, *Solenopsis invicta*, a domestic health pest in the U.S.A. (Harlan *et al*., 1981). It has now been used successfully against *P. megacephala* in coconut in Zanzibar and Tanzania mainland (Oswald.and Rashidi, 1992; Seguni, 1993). Varela (1994) reported that in Mtwara the best control is obtained when nests establishment is done between October and May. time when the weaver ants have reached the reproductive stage

2. 5.7. 3 Time taken for *Oecophylla longinoda* establishment

Principally. ants occur naturally in cashew trees throughout the year. but sometimes their numbers fluctuate depending on climatic factors. particularly rainfall (Brain. 1983). Sijaona (1997) noted that within two weeks *O. longinoda* were able to move from one tree to another across ropes and new nests were found in previously uncolonized trees.

2.5.7.4 Colony composition

Mani (1982) reported that an ant colony comprises of four groups of individuals:

1.Workers; which are sterile females comprising the smallest members of the colony.

2. Soldiers; which are peculiarly modified workers with enormous head and mandibles for crushing and fighting.

3. Fertile females; which are large and often with wings and well developed reproductive organs. and

4. The queen; which once fertilized during the nuptial swarming establishes the first nest and rears her first brood.

2.5.7.5 Colonisation and nests construction

Interconnecting the tree canopies by ropes facilitates colonization and nests construction of weaver ants (Boma *et al*.. 1995). This enables ants to move along aerial pathway to construct new nests: forage new territories. at the same time still able to return safely to the main colony (Sijaona. 1996). Ants were frequently found foraging on ground and trunks of trees indicating absence of high population of antagonistic ground foraging ants (Sijaona. 1996). This suggests that when *O. longinoda* has the opportunity of being the primary colonizer it provides a high level of protection against sucking bugs. It was further suggested that care has to be taken to insure that nests would not be tugged and damaged by the rope during strong gusts of wind (Topper *et al.*, 1997). Ropes should be put across and attached just behind a healthy flushing shoot of an uncolonized tree. However. it is important to make sure that the attached ropes originate only from one colony in order to avoid the antagonism behavior of ants (Sijaona. 1997). The rope interconnection is shown in Plate 7

Plate 7: Rope interconnection showing movement of weaver ants across the rope between two trees within a plot

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of study

The experiments were conducted at the Agricultural Research Institute (ARI)-Naliendele, Mtwara region, in southern Tanzania. The Institute is situated at an altitude of 113 m a.s.l., and is 13 km from Mtwara town along the Newala road (40° 11' E, 10° 21' S). The experiments were conducted at the variety improvement trial (VIT) block, which is two kilometers away from the center.

3.2 field survey and cashew clones selection

The trees for the experiment were selected out of five major cashew clones: *Anarcadium* cylon (AC_4 200, AC_{10}, AC_{28}), *Anacardium* zanzibar (AZA_{20} and AZA_{17}) identified at ARI Naliendele. These five basic clones contribute the bulk of grafted cashew plants, which have been distributed to farmers and are predominant in the polyclonal seed gardens. However, *Anarcadium* cylon (AC_4 200) clone was used in this experiment. Selection was done in order to obtain consistent data, as there are great variations among cashew clones. The clone AC_4 200 was produced after a mass selection and character assessment trial (MSCA) conducted at the center in the variety investigation trial (VIT). A total of 66, seven years old trees with roughly uniform vigour and growth were selected.

Before the layout of the experiment, the study site was surveyed to determine the presence and distribution of the insect pests, *H. anacardii* and *P. wayi*. Also the biological agent *O. longinoda* and its competitor ant, *P. megacephala*, were surveyed in all the trees. Forty trees were used for experiment I, 10 trees for experiment II and 16 trees for experiment III. The distribution of trees for each experiment was based on the number of treatments. Different ways were used to assess population levels depending on the type of insect. The populations of *H. anacardii* and *P. wayi* bugs were determined by walking around the tree and individually counting the insects. Counting of individual insects was possible in this case since the two species occur in very few numbers. The pests were counted when feeding on young growing shoots and nuts on the periphery area of tree branches. However, since *Oecophylla longinoda*, and *P. megacephala* occur in greater abundance, it was not possible to count individual insects, instead their populations were estimated using a special score index as a guide (Varela, 1992; and Sijaona, 1997). The following ranges were used:

0 = No ants

1 = Few ants (1 – 20)

2 = Some (21 – 50)

3 = Many (51 – 200)

4 = Abundant (200 - 500)

5 = Very abundant (> 500)

3.3 Field management and layout

The trial block with previously established cashew trees (spaced at 12 m x 12 m) was ploughed by a tractor. Weeding was done once during the whole period of the experiment. The trees were planted in a pure stand. Three experimental trials were laid out and the treatments were assigned to plots randomly. Trees were tagged with numbered plastic labels showing tree number, plots, and number of replications and treatments.

3.4 Effects of weaver ants population on *Helopeltis anarcadii* and *Pseudotheraptus wayi.*

3.4.1 Experimental design

The experiment was conducted using a Randomized Complete Block Design (RCBD). A total of 40 cashew trees were used for the experiment in 20 plots, each with two trees. The treatments were replicated four times with 10 trees/replicate. One row from each side was left as a guard row.

3.4.2 Treatments

Control – trees without weaver ants

Ten (10) nests of weaver ants

Twenty (20) nests of weaver ants

Thirty (30) nests of weaver ants

Forty (40) nests of weaver ants

3. 4. 3 Weaver ants collection, establishment and enhancement in the field.

Weaver ants were established in the field by nests transfer as recommended by Sijaona (1997). Each colony was put in a separate plastic bag. Nests transfer was done early in the morning and late in the evening. Before establishment. the weaver ants colonies were identified and separated. The identification was done by putting into contact two nests whereby similar colonies mixed. but different ones fought vigorously (Peng *et al.*, 1999). Relatively medium to large nests were selected. but small ones were rejected. Each plot of two trees was subjected to weaver ants population belonging to the same colony. Colonies were alternated within plots in such a way that adjacent plots contained different colonies. This was done purposely in order to limit movement of weaver ants from one treatment to another. Nests were distributed evenly on the tree canopy and tied with small piece of sisal twine close to freshly growing shoots. However. in order to enhance movement of weaver ants. two trees within the same plot were interconnected with ropes.

3. 4. 4 Maintenance of number of nests

Since weaver ants reproduce and construct new nests very fast. only the initial nests put in each treatment were considered. The assumption was that ants had an equal chance to multiply and increase in number from each treatment. Therefore. at any time more weaver ants may be expected from high treatment levels than those from low ones. Therefore. there was no regulation of number of nests at the later stage after establishment.

3. 4. 5 Assessment of damage level, pest population and yield

3. 4. 5. 1 Damaged and undamaged shoots

The number of newly flushed damaged and undamaged shoots was counted and recorded from each tree canopy. A quadrat of $1m^2$ was used for the sampling. All shoots within the quadrat of $1m^2$ were counted on weekly basis. The counts were made on each of the four sides of the tree canopy (North. West. South. and East).

3. 4. 5. 2 Damaged and undamaged nuts

Damaged and undamaged nuts were counted within a quadrat of $1m^2$ in four sides of the tree canopy and recorded accordingly.

3. 4. 5. 3 Number of *Helopeltis anacardii* and *Pseudotheraptus wayi*

The number of nymphs and adults was counted at intervals of one week. Counting was done by observing around the whole tree canopy. Counting was done early in the morning and late in the evening to avoid the hot sunny days as the pests tend to hide away.

3. 4. 5. 4 Yield

The yield. measured by nut weight. was determined. Nuts from each tree were picked and weighed separately using a Mettler electronic balance.

3.5 Control of antagonistic ants to *Oecophylla longinoda*.

3.5.1 Experimental Design

The entire trial field was mapped and surveyed for ants abundance before the experiment. The experiment was conducted in a Randomized Complete Block Design. Ten trees were used for the experiment, each tree representing a plot. The treatments were replicated five times.

3.5.2 Treatments

Untreated control

Amdro bait application

Amdro bait was applied at a rate of 4 g per tree. The application was done by sprinkling the bait uniformly around each cashew tree trunk. Application was done during the morning when the weather was calm and cool. Sunny days and damp soils were avoided. Damp soils have been reported to cause chemical degradation through photolysis and hydrolysis (Stanthers, 1995).

3. 5. 3 Assesment of *O. longinoda* and *P. megacephala* population

The population of the weaver ants *O. longinoda* was assessed by counting them when they were moving on the tree trunk and on the ground. Counting was done within a band of 1m of tree trunk from the ground, as well as 1m band around the base of the tree trunk. *Pheiodole megacephala* ants were attracted by placing a small piece of tissue paper soaked in sugar solution at the base of the tree trunk for 40 minutes before the insect population was estimated. For both, *O. longinoda* and

P. megacephala, population size was estimated by the score method previously described (Varela, 1992; and Sijaona, 1997).

3.6 Comparative effects of different nests levels with and without Amdro bait application

3.6.1. Experimental design

The experiment was conducted in a Randomized Complete Bock Design. Fourty trees were used, each representing one plot. The treatments were replicated four times.

3.6.2 Treatments

The treatments consisted of ten, twenty, thirty, and fourty nests alone. In the control, there were neither nests nor Amdro applied.

3.6.3. Assessment of damage level, pest population and yield

3.6.3.1 Damaged and undamaged shoots

The number of damaged and undamaged shoots was counted and recorded from a quadrat of $1m^2$ on all the four sides of the tree canopy.

3.6.3.2. Number of *Helopeltis anacardii* and *Pseudotheraptus wayi*

Counting of the pests was made around the tree canopy and recorded.

3.6.3.3 Yield

The yield was determined by weighing the picked nuts on an electronic balance

3. 7 Assessment of the commonly practised method for control of *Helopeltis anacardii* and *Pseudotheraptus wayi.*

3. 7. 1. Experimental design

The experiment contained 8 plots each with two trees, making a total of 16 trees. The treatments were replicated in four blocks. A Randomized Complete Block Design (RCBD) was used.

3.7.2. Treatments

Un sprayed - control

Trees sprayed with lamda cyhalothrin (5 %)

Lamda cyhalothrin (5 %), a synthetic pyrethroid, was used at a rate of 5g a.i per tree as a foliar spray. Spraying was done by a motorized mist blower early in the morning. The chemical was sprayed two times at an interval of three months. The spraying was carried out in July and September.

3.7.3 Counting and population assessment of *H. anacardii* and *P.wayi*

Physical counting of individual insects was used when assessing population levels of the cashew sucking bugs *H. anacardii* and *P. wayi.* Counting of the pests was done by moving around the tree canopy. This is due to the fact that most of the pests are concentrated on new flushing shoots and young developing nuts as their main source of food. Care was taken to make sure that there was minimum disturbance of the insects. Total pest number per tree was taken and recorded.

3.8. Comparison of the control efficiency of lamda cyhalothrin (5 %) and the biological agent, *O. longinoda* at different nests levels.

Four nest levels ten, twenty thirty, and fourty were used and compared with the control (no nests) and lamda cyhalothrin (5 %) treated trees.

3.8.1 Population assessment of the pests, *H. anacardii* and *P. wayi*

The pests were counted from the outer branches of the tree canopy. Total number of pests per tree was taken and recorded.

3.8.2. Assessment of damage level

Assessment of damage level of shoots and nuts was done as described under sections 3.4. 5. 1 and 3.4.5.2.

3.8.2. Assessment of *H. anacardii* and *P. wayi*

The same assessment procedure applied under 3.7.3 was used. Pests from individual tree were counted and recorded.

3.8.3 Yield

The nuts collected from each tree were weighed and recorded.

3. 9 Data analysis

Before analysis, percentage shoot damage, nut damage and number of pests were subjected to square root transformation using the formula $(X + 0.5)^{1/2}$, where X = is the original data, 0.5 is a constant (Gomez and Gomez, 1983). The yield data were subjected to logarithm transformation. The data were then subjected to one way Analysis of variance (ANOVA). Means were separated using Tukey's studentized range test (TSRT). Results were ranked and compared accordingly. The following statistical model was used:

$Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}$

Where: Y_{ij} = response.

τ_i = Treatment effect

μ = General mean.

β_j = Block effect.

ε_{ij} = Random error effect or experimental error

CHAPTER FOUR

RESULTS

4. 1 Field survey

4.2.1 Distribution of the ants, *O. longinoda* and *P. megacephala.*

Table 2 shows the distribution of *O. longinoda* and *P. megacephala* in the surveyed cashew field. *Oecophylla longinoda* were found in few numbers as their population falls under 1 score index which represents a population ranging between 1 - 20 pests/ tree, while *P. megacephala* occurred in high population levels with score index 3, representing a population between 51 - 200 per tree.

4.2.2 Distribution of the cashew sucking bugs *H. anacardii* and *P. Wayi*

Most of the trees in the experimental area were colonized by *H. anacardi* and *P. wayi.* The colonization varied between trees. Many cashew trees were colonized by *H. anacardii*, while *Pseudotheraptus wayi* occurred at a low population level. (Table 3).

Table 2. Distribution of *O. longinoda* and *P. megacephala* ants in the cashew trees.

Insect	Total trees surveyed	Total trees occupied	% of trees occupied	Total No. of nests	Average no. of nests (Total nests/ Total trees)	Score index	Score index status
O. longinoda	66	18	27.3	410	6	1 (1 - 20 pests/tree)	Few
P. megacephala	66	60	90.1	NA	NA	3 (51 - 200 pests/tree)	Many

Key. NA. Not Applicable

Table 3. Distribution of *H. anacardii* and *P. wayi* in cashew trees.

Pest	Total trees surveyed	Total No. of trees occupied	% of trees occupied	Total pests	Mean no of pests per tree (Total trees/ total pests)
H anacardii	66	46	69.7	1460	22
P. wayi	66	51	77.3	740	11

Table 4. Percentage damage, pest populations size and yield of trees with different numbers of *O. longinoda* nests.

No. of nests	% Shoot damage	% Nut damage	*H. anacardii* (pests /tree)	*P. wayi* (pests/ tree)	Yield (Kg./tree)
0	48.65^{a}	63.25^{a}	22.24^{a}	14.81^{a}	18.00^{a}
10	41.90^{b}	51.65^{b}	18.72^{b}	12.49^{b}	18.20^{a}
20	39.90^{b}	41.50^{c}	16.45^{c}	11.23^{c}	19.20^{a}
30	33.70c	33.90^{c}	14.16^{d}	9.44^{d}	20.85^{b}
40	29.65^{c}	25.40^{d}	12.75^{e}	8.50^{e}	22.30^{c}
Mean	38.76	38.26	16.86	11.29	15.25
S.e ±	0.98	1.78	0.26	0.17	0.29
CV (%)	5.03	8.27	3.03	2.94	2.93

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

4.3 Effects of weaver ants population on the control of *Helopeltis anacardii* and *Pseudotheraptus wayi*

4.3.1 Shoot damage

There was a significant difference ($P \leq 0.05$) in shoot damage between the control and all levels of weaver ants nests (Table 4). The percentage shoot damage decreased with increasing number of nests. The control had the highest percentage shoot damage followed in decreasing order by trees subjected to 10. 20. 30 and 40 nests. Shoot damage in trees with 10 and 20 nests didn't differ significantly. ($P \leq 0.05$). The same was also observed in trees with 30 and 40 nests.

4.3.2 Nut damage

Nut damage was significantly different ($P \leq 0.05$) between the control and trees colonized by weavers ants (Table 4). However. nuts damage in trees with 10 and 20 nests didn't differ significantly ($P \leq 0.05$). Nut damage in trees treated with 40 nests differed significantly from other treatments.

4.3.3 Population of *Helopeltis anacardii*

Results in Table 4 also show that the population of *Helopeltis anacardii* in the control trees was significantly ($P \leq 0.05$) higher than in trees subjected to different levels of weaver ants. *Helopeltis anacardii* population was significantly different between treatments.

4.3.4 Population of *Pseudotheraptus wayi*

The population of *Pseudotheraptus wayi* was kept significantly low ($P \leq 0.05$) when cashew trees were colonized by weaver ants. The population of *P. wayi* in the control was significantly different from the remaining four levels of weaver ants nests (Table 4). Pest population density for both *H. anacardii and P. wayi* showed great variation across months.

4.3.5 Yield

There was a significant difference in yield ($P \leq 0.05$) between the control plots and the trees occupied with 30 and 40 nests (Table 4.). The yield in trees subjected to 10 and 20 nests didn't differ significantly. A higher yield was obtained from trees with large numbers of weaver ant nests than in trees with a smaller number of nests.

4.3 6 Relative abundance of *Helopeltis anacardii* and *Pseudotheraptus wayi* in cashew nut trees.

Figure 4. shows the relative abundance of *Helopeltis anacardii* and *Pseudotheraptus wayi* in cashew nut trees. *H. anacardii* were more abundant in cashew trees than *Pseudotheraptus wayi*

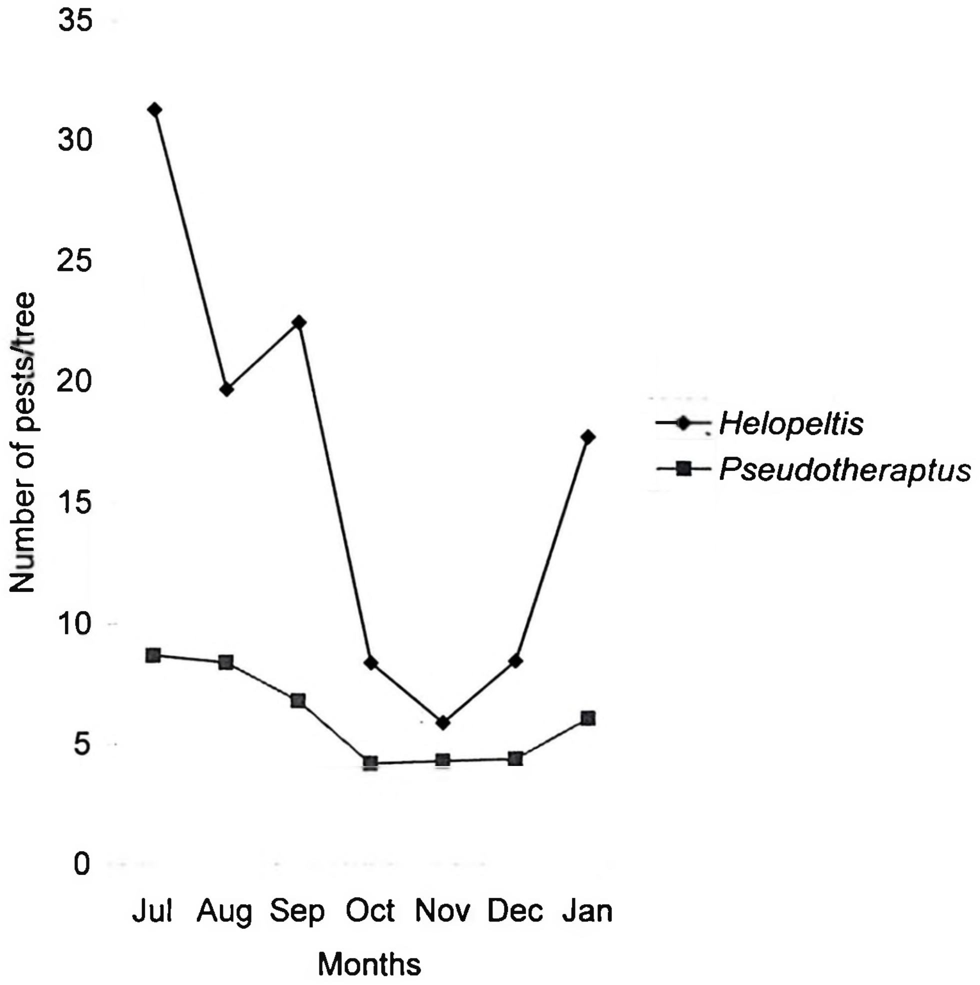

Figure 4. Relative abundance of *Helopeltis anacardii* and *Pseudotheraptus wayi* in cashew nut trees.

4. 4. Control of the antagonistic ant.

4.4.1 Population of *Pheidole megacephala*

The effect of Amdro bait on *P. megacephala* population level is shown in Figure 5. Amdro bait application resulted to a significant reduction ($P \leq 0.05$) of *P. megacephala* population. *Pheidole megacephala* occurred at higher population levels in the control than in the treatments with Amdro.

4.4.2. Population of *Oecophylla longinoda*

The population of *O. longinoda* in Amdro treated and in the control trees is shown in Figure 6. Application of Amdro bait resulted to a significant ($P \leq 0.05$) increase in numbers of *O. longinoda*. The highest population of weaver ants was recorded in trees applied with Amdro bait. Lowest numbers of weaver ants were observed in the control.

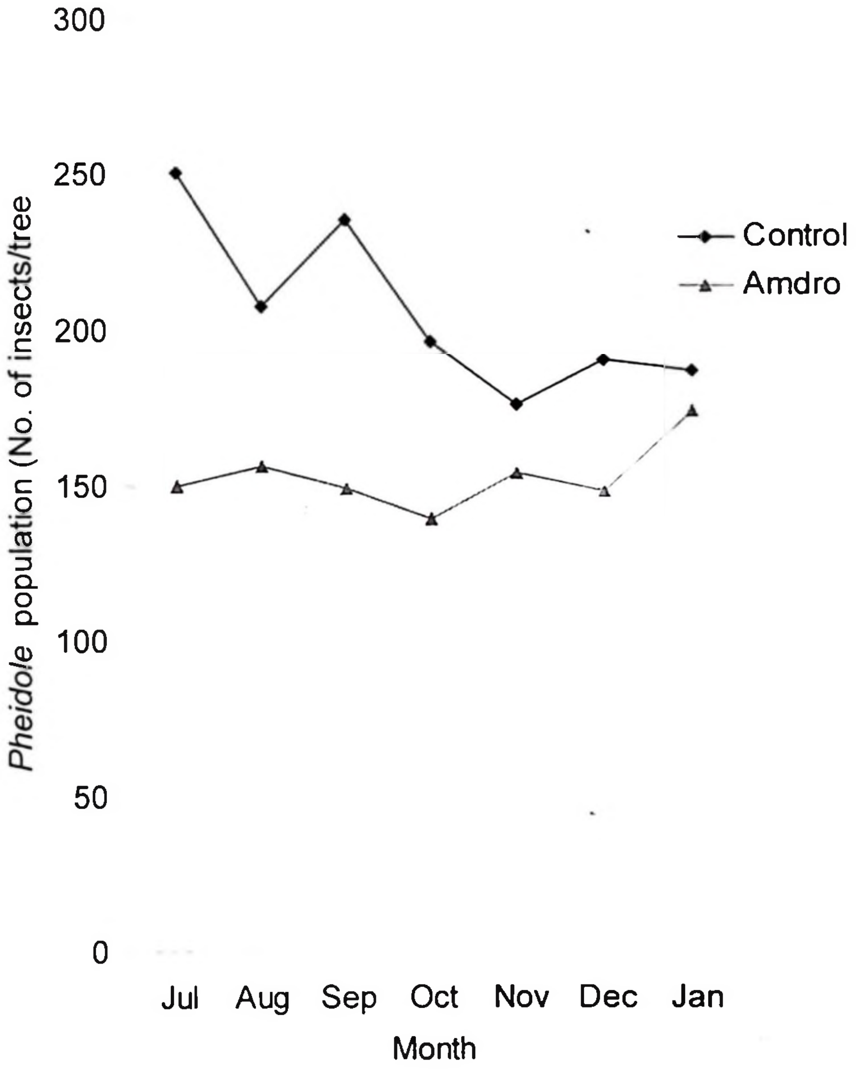

Figure 5. Monthly population levels of *P. magacephala*, in control and when the ants were treated with Amdro bait.

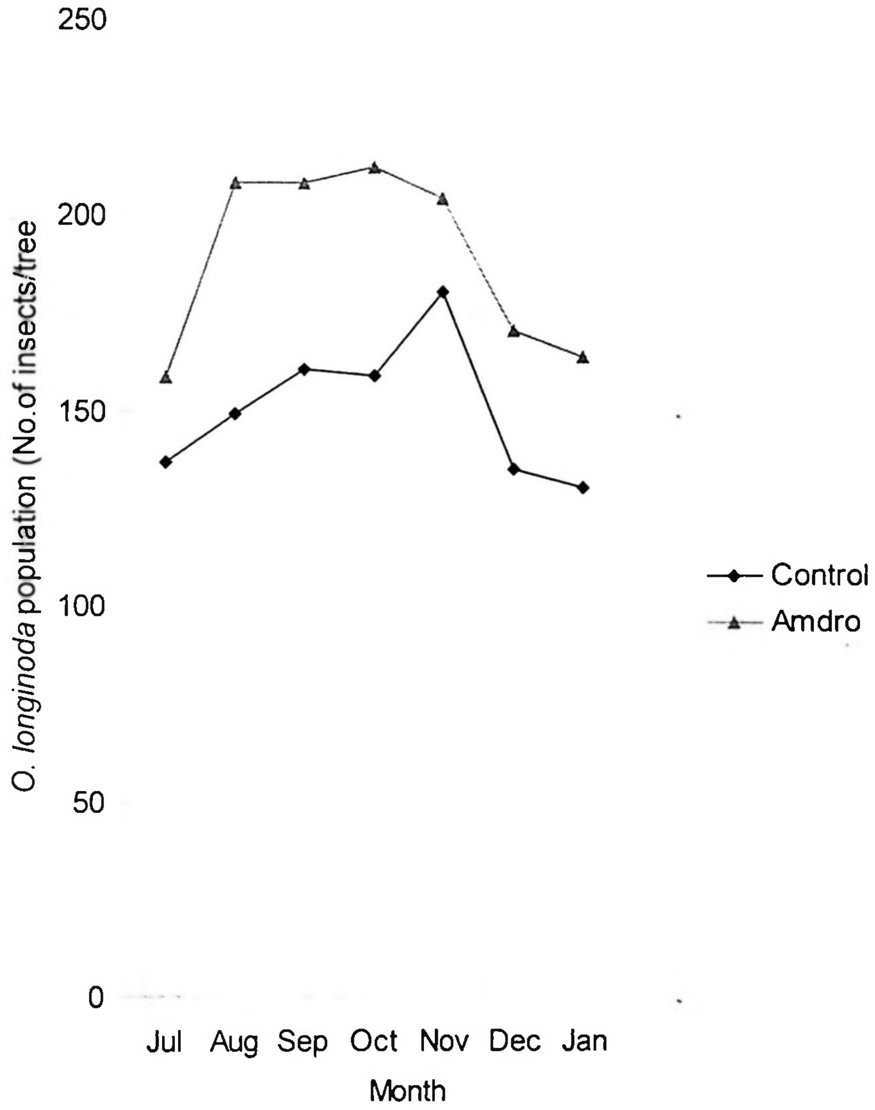

Figure 6. Monthly population levels of *O. longinoda* in control and when the competitor ant, *P. megacephala*, was controlled by Amdro bait.

4.4.3 Population of *Helopeltis anacardii*

Figure 7 shows the population levels of *H. anacardii* in control and Amdro treated plots. The *Helopeltis* population in the control was significantly higher ($P \leq 0.05$) than in trees with the Amdro treatment.

4. 4. 4 Population of *Pseudotheraptus wayi*

The population of *P. wayi* was also significantly ($P \leq 0.05$) higher in the control than in cashew trees treated with the bait (Figure 8).

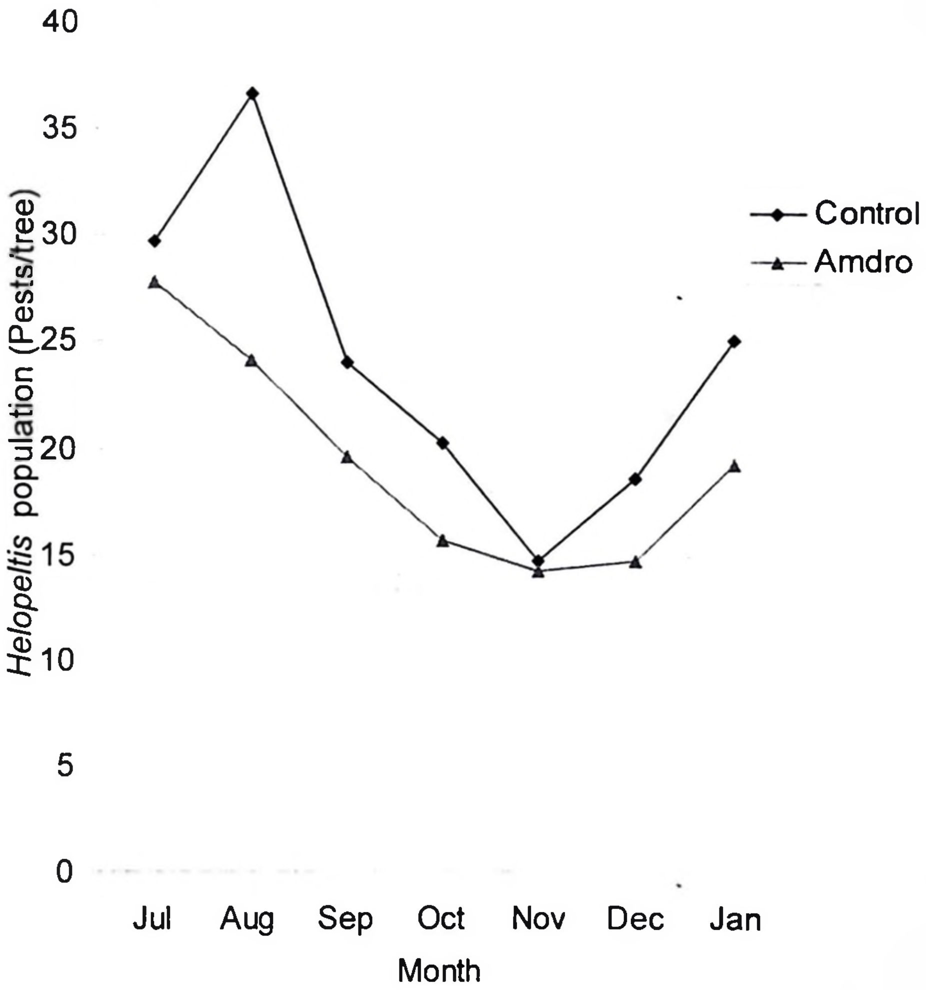

Figure 7. Population level of *H. anacardii* in control and after controlling the competitor ant, *P. megacephala*

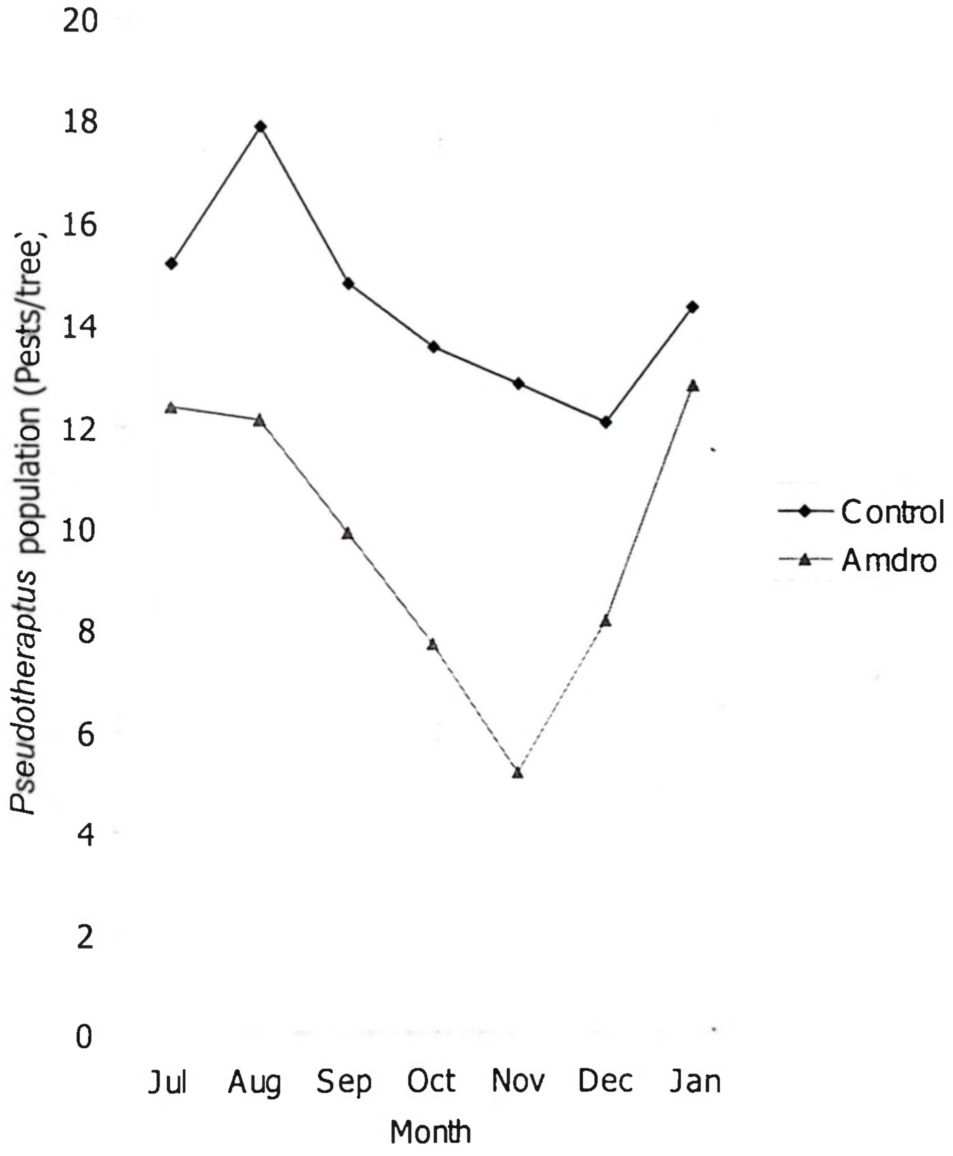

Figure 8. Population levels of *P. wayi* in control and after suppressing the competitor ant, *P. megacephala*, by Amdro bait.

4.4.5.Shoot damage

Figure 9 shows percentage shoot damage in cashew trees when the antagonistic ant *P. megacephala* was suppressed by Amdro bait. Suppression of *P. megacephala* ants, which hinders population build up of *O. longinoda*, resulted to a significant ($P \leq 0.05$) reduction in shoot damage in all months. The control had the highest shoot damage compared to trees treated with Amdro bait. In Amdro treated trees, percentage shoot damage remained low in each month. However variations in damage within months were noted both in the control and in Amdro treated tress.

4 4.6 Nut damage

Percentage nut damage when *O. longinoda* population was enhanced by controlling the antagonistic ant, *P. megacephala*, is shown in Figure 10. Nut damage in the control trees was significantly ($P \leq 0.05$) higher than in Amdro treated cashew plots. The control trees had the highest overall nut damage compared to trees treated with Amdro. Both the control and Amdro treated trees have shown similar trend of damage. This is due to nature of nut setting pattern, normally nut setting starts in August and up in December depending on clone. Peak nut production is reached on October.

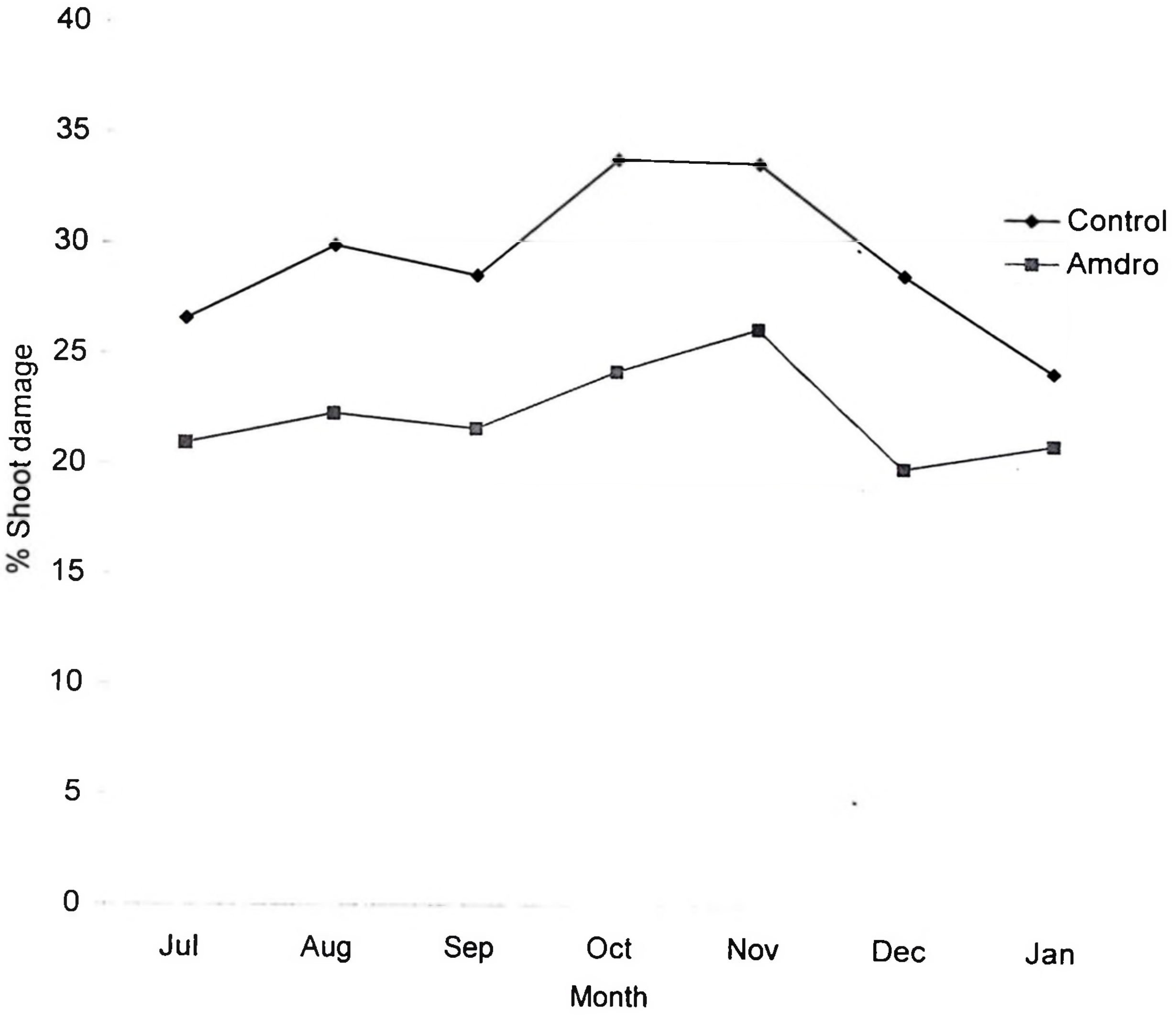

Figure 9. Monthly percentage shoot damage in control and after the competitor ant *P. megacephala* was suppressed by Amdro bait.

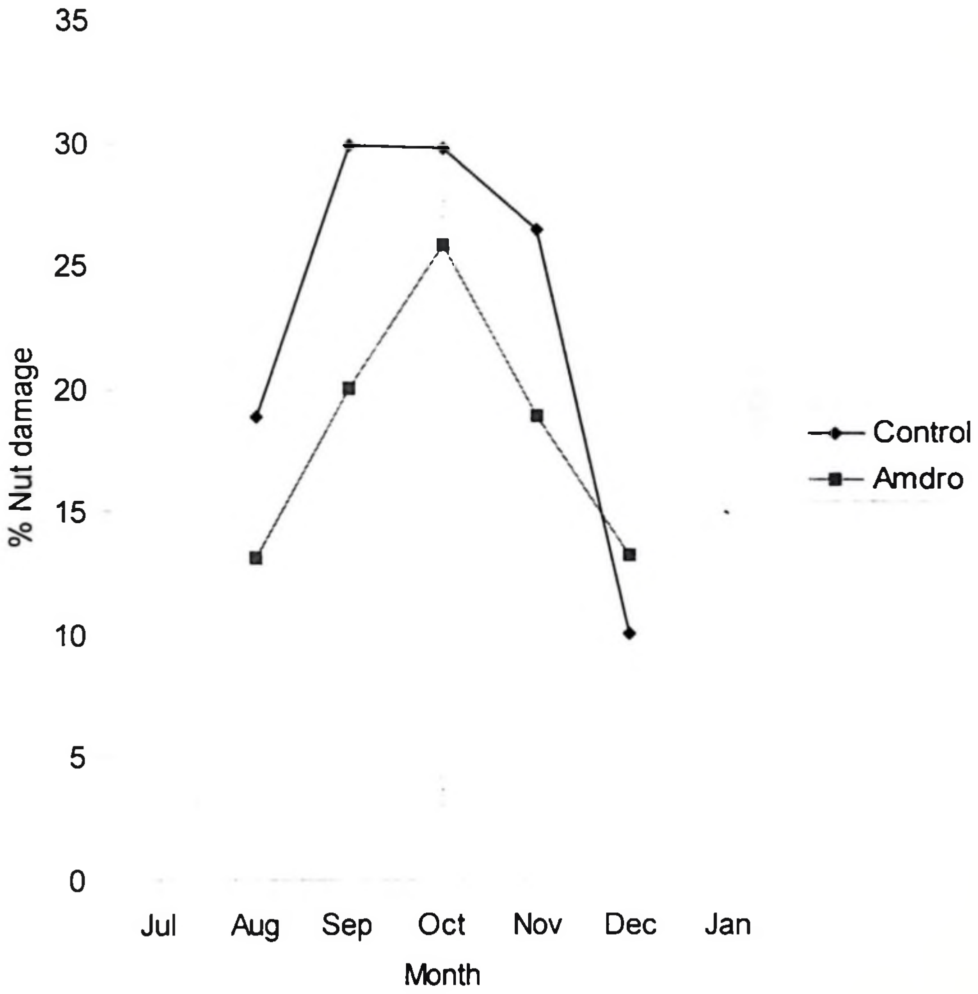

Figure 10. Nut damage after suppressing the competitor ant, *P. megacephala* by Amdro bait

4.7 Yield

The yield of cashew nuts after partial control of the competitor ant, *P. megacephala* is shown in Figure 11. The results show that, suppression of the competitor ant resulted to a significant (P ≤ 0. 05) increase in yield. Highest yield was obtained from trees treated with the bait.

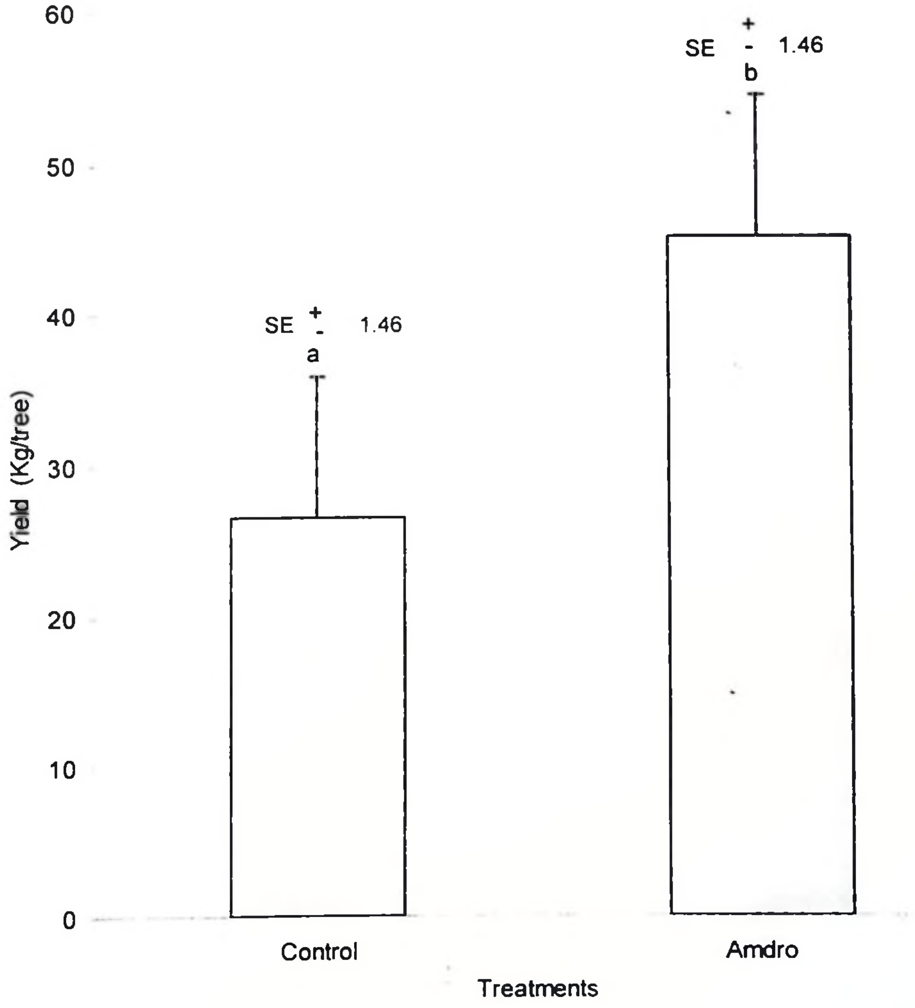

Figure 11. Cashew nut yields when *P. magacephala* ant was treated with Amdro bait.

4.5 Efficiency of weaver ants nests with and without Amdro bait application.

4.5.1. Population of *Helopeltis anacardii*

Results in Figure 12 show that combination of 30 and 40 nests with Amdro bait application performed better in reducing pests than the trees colonized with the same number of nests without Amdro bait treatment. Pests' population from this combination was significantly ($P \leq 0.05$) higher than the other remaining treatments. High pests population was found in trees which were not treated with the bait'

4.5.2. Population of *Pseudotheraptus wayi*

The population of *P. wayi* remained significantly low ($P \leq 0.05$) nd in trees treated with Amdro together with weaver ants at 40 nests. In addition all the four nests levels 10,20,30, and 40 in trees which were not treated with Amdro had significantly highest *Pseudotheraptus* population (Figure 13).

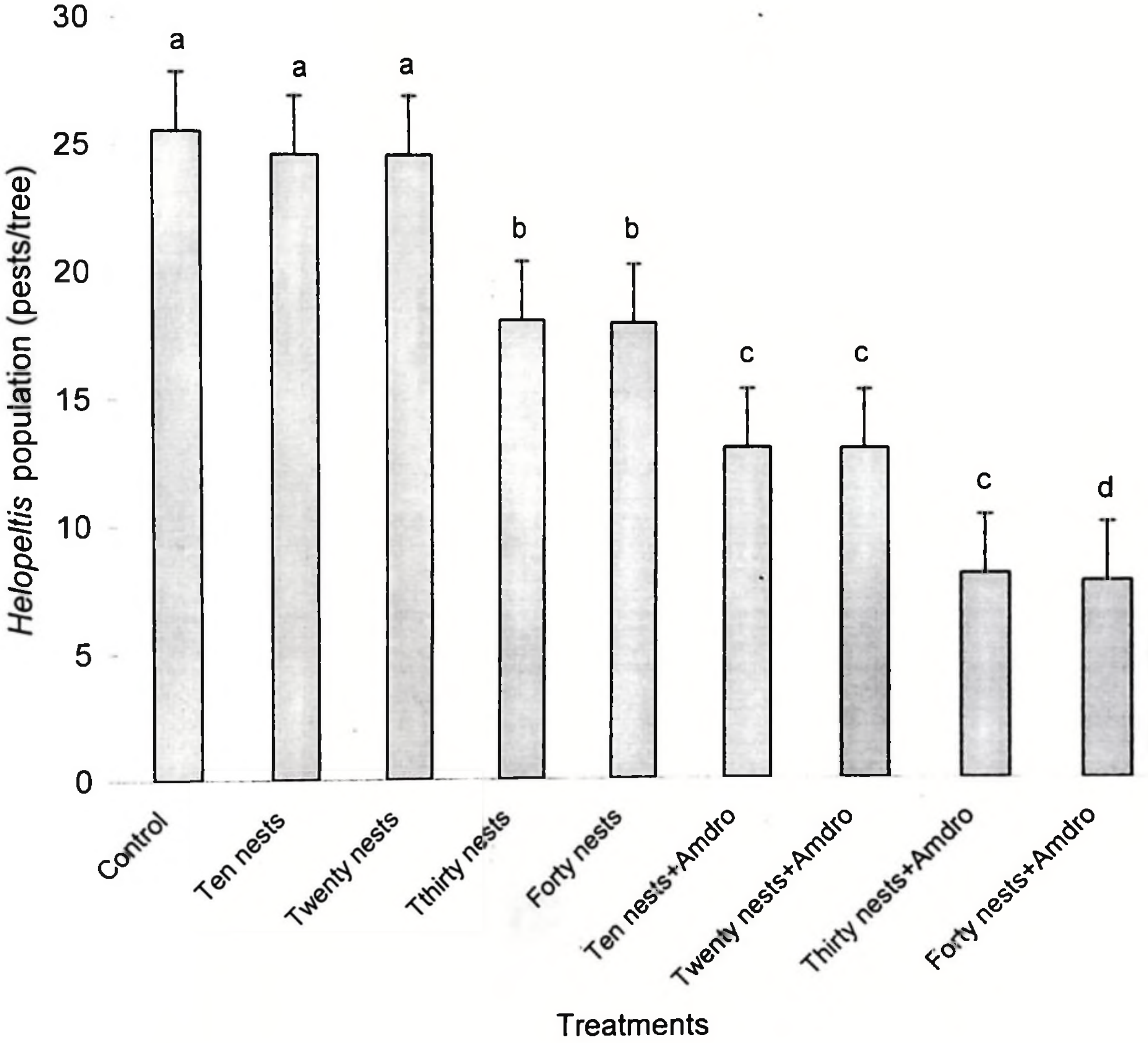

Figure 12. *Helopeltis* population in cashew trees colonized by weaver ant nests alone and a combination of nests and Amdro bait.

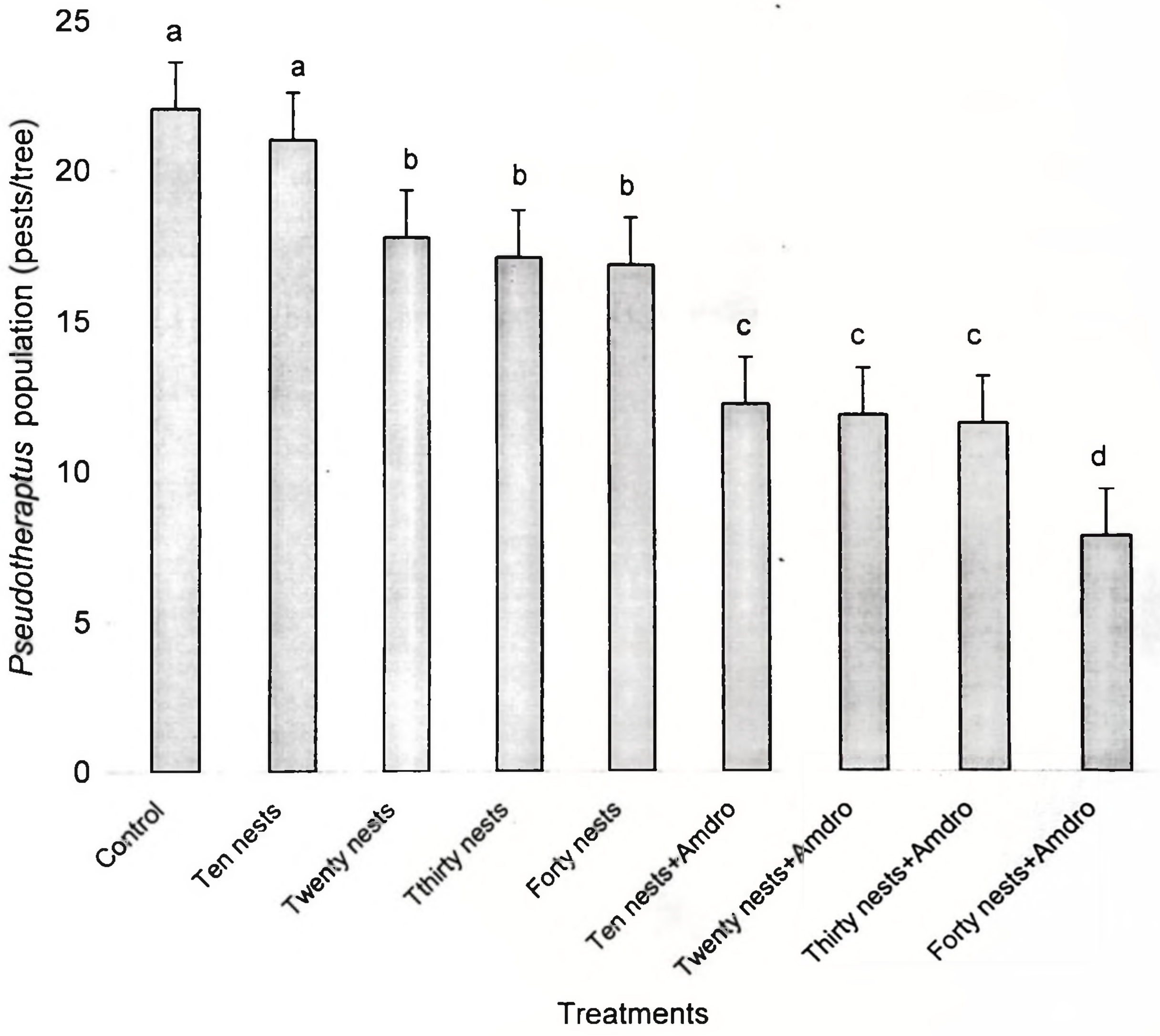

Figure 13. *Pseudotheraptus* population in cashew trees colonized by weaver ant nests alone and a combination of nests and Amdro bait.

4.5.3 Shoot damage

There was a significant difference ($P \leq 0.05$) in shoot damage between cashew trees with nests alone and those with the same number of nests in combination with Amdro bait. Lower damage level was recorded in trees treated with a combination of nests and Amdro bait than nests alone (Fig.14). A similar trend was observed for nut damage (Fig. 15).

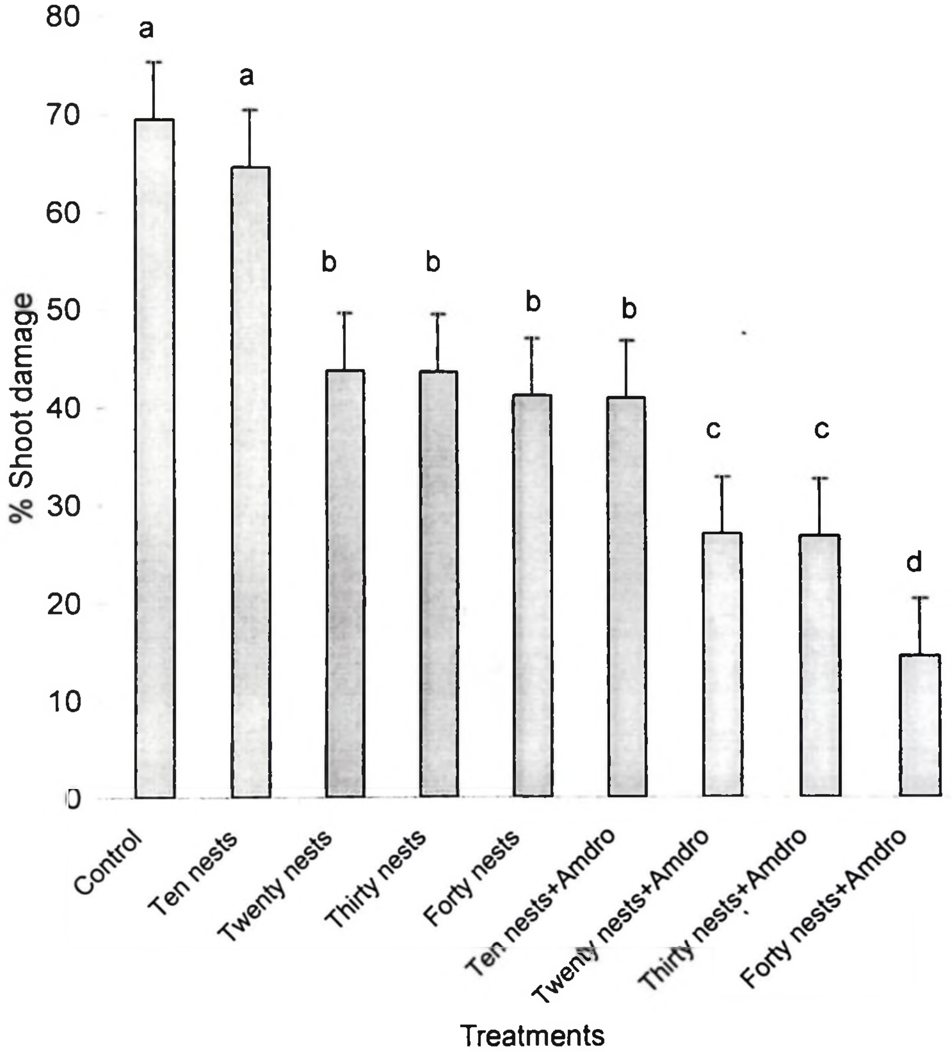

Figure 14. Percentage shoots damage in cashew trees colonized by weaver ant nests alone and a combination of nests and Amdro bait.

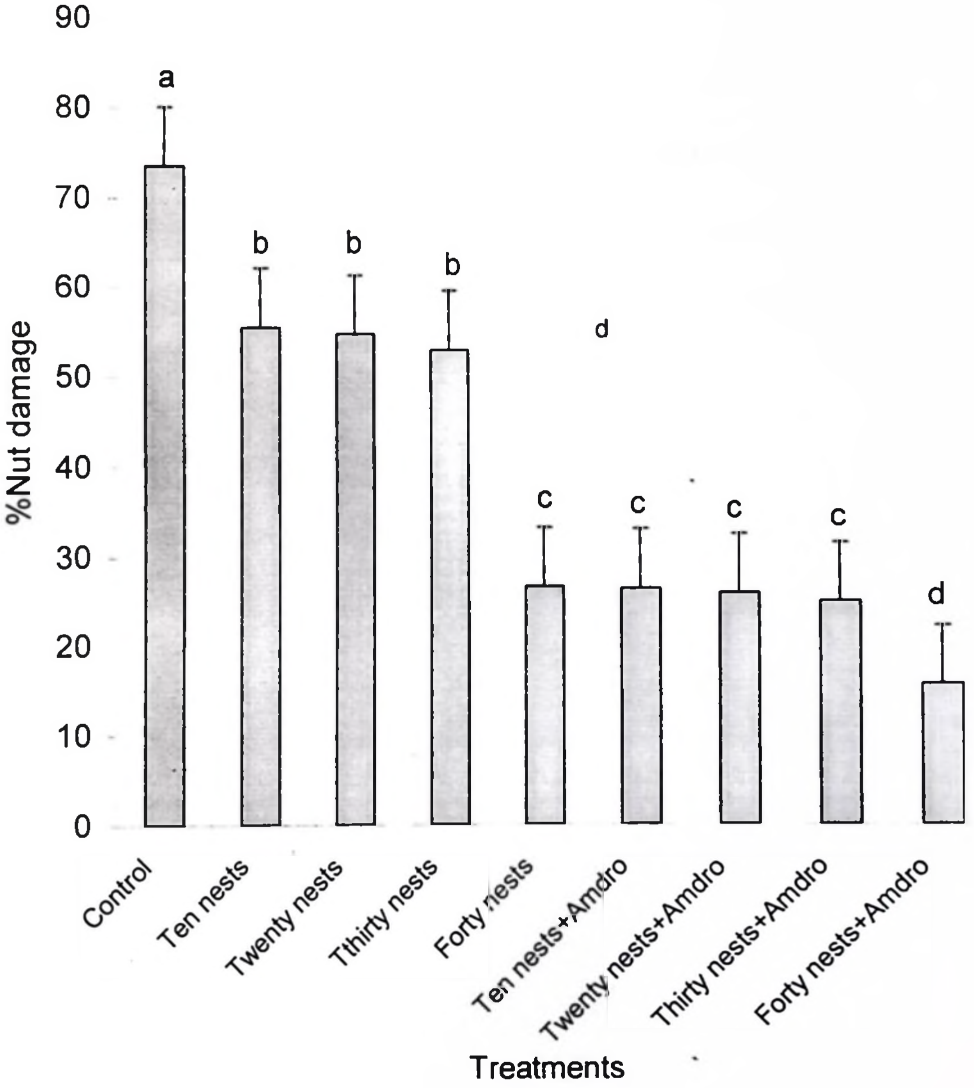

Figure 15. Percentage nut damage in cashew trees colonized by weaver ant nests alone and a combination of nests and Amdro bait.

4.5.5. Yield

There were significant differences in yield ($P \leq 0.05$) between the control and trees subjected to 40 weaver ant nests in combination with Amdro bait application. The trees occupied with 30 and 40 nests and not treated with Amdro bait had lower yield than trees treated with Amdro with the same numbers of nests (Figure 16).

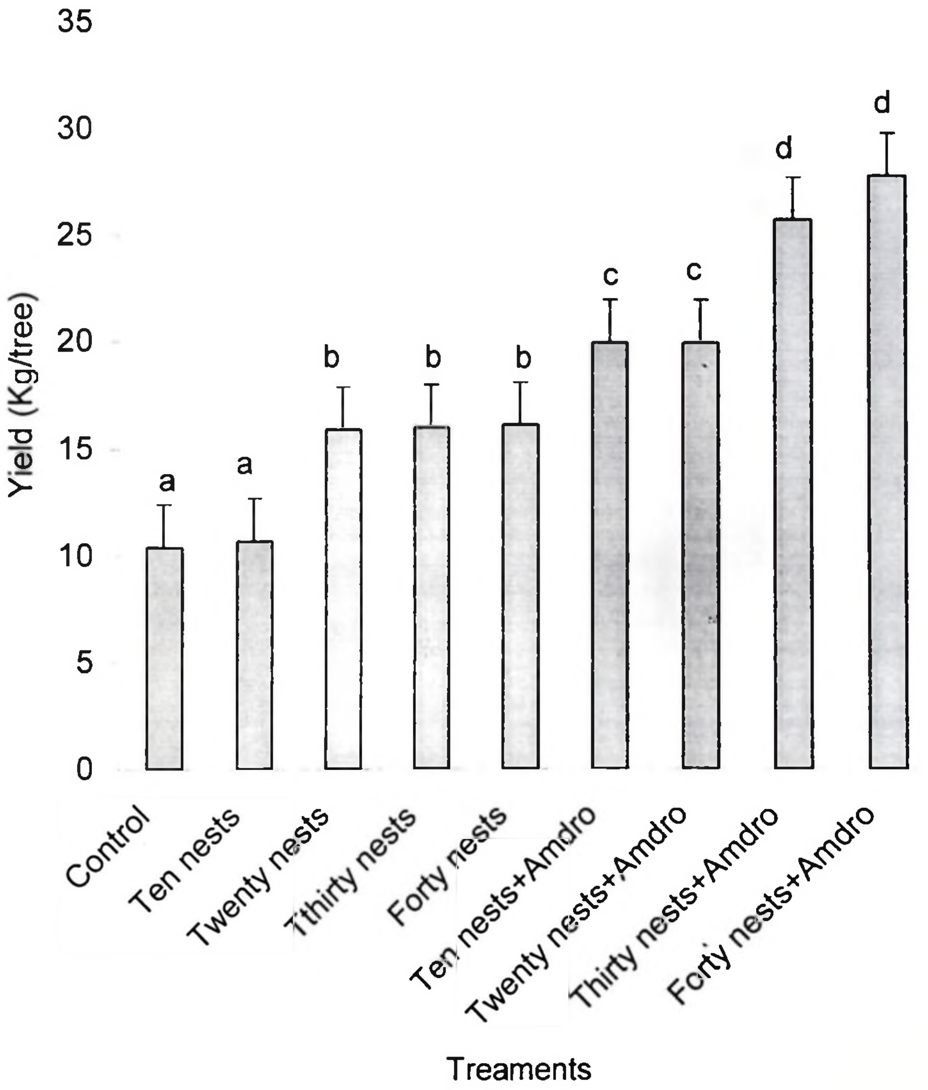

Figure 16. Yield in cashew trees colonized by weaver ant nests alone and a combination of nests and Amdro bait.

4.6 Treatment with lamda cyhalothrin (5%)

4.6.1 Population of *Helopeltis anacardii*

Helopeltis anacardii population levels in trees sprayed with karate are shown in Figure 17. Low population levels were observed in trees treated with lamda cyhalothrin (5 %). Peak *Helopeltis* bug population density occurred in September. but the population dropped in both treatment and control in November and December probably due to on set of rainfall during this time. which may have an effect on the growth and development of the nymphs.

4.6.2. Population of *Pseudotheraptus wayi*

Trees sprayed with lamda cyhalothrin (5 %) were significantly protected from damage by the pest. (Figure18) Low populations of *P. wayi* were recorded in cashew plots applied with the chemical.

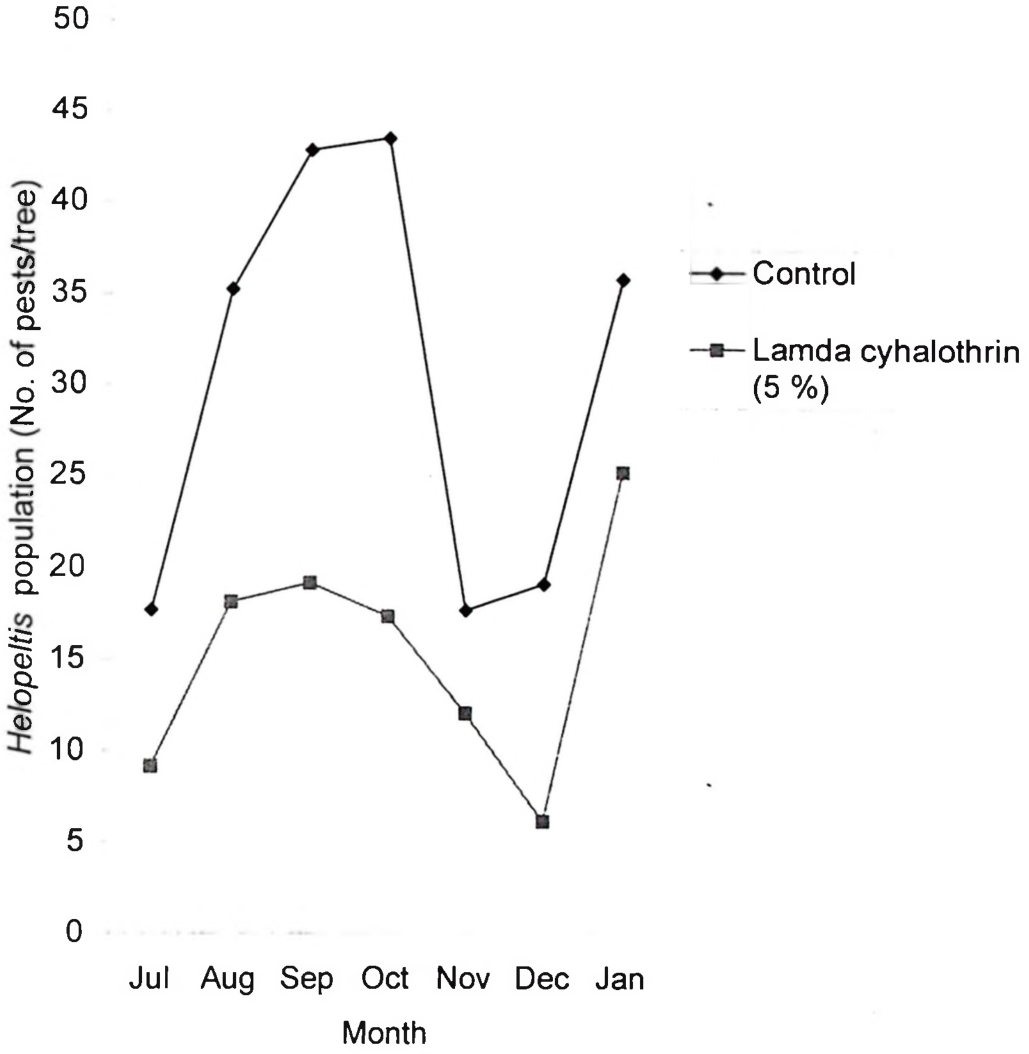

Figure 17. Monthly population size of *H. anacardii* in cashew trees treated with lamda cyhalothrin (5 %).

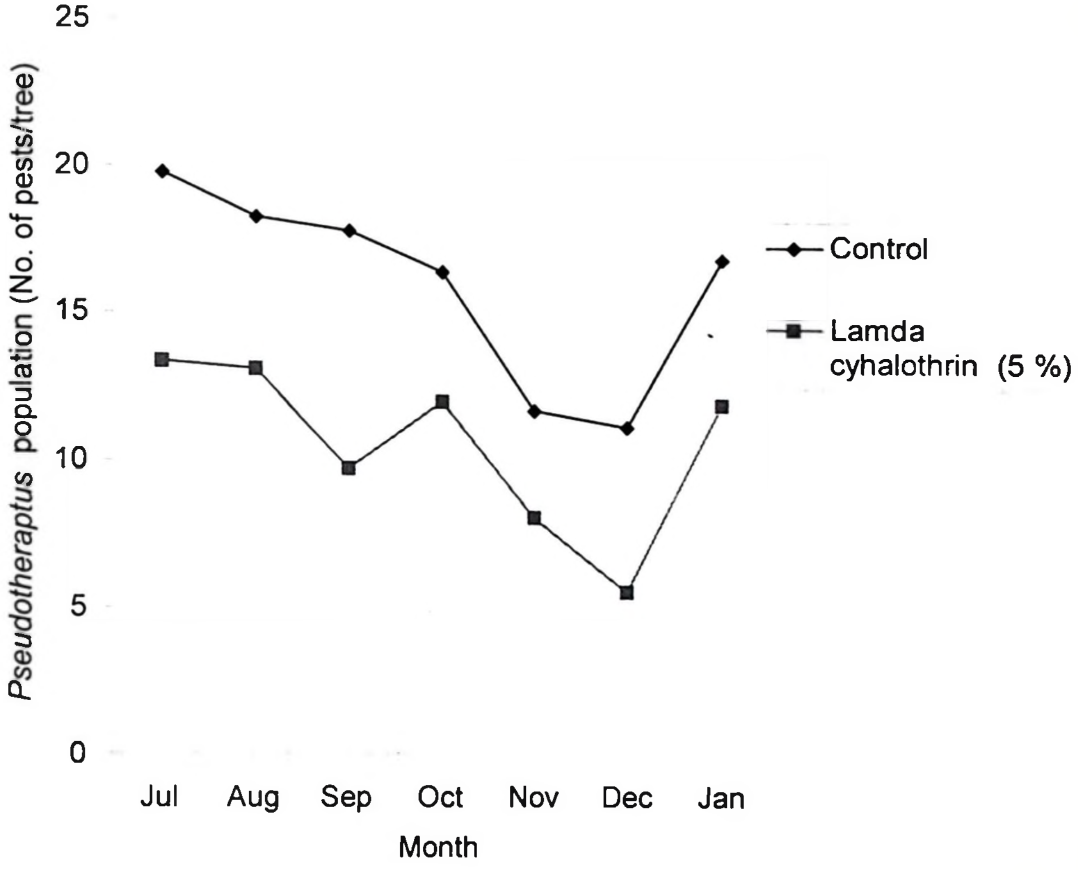

Figure 18. Monthly population size of *P. wayi* when cashew trees were treated with lamda cyhalothrin (5 %).

4.6.3.Shoot damage

Figure 19 shows that shoots damage remained high in the control during the period of observations.

4.6.4. Nut damage

Figure 20 shows that nuts were highly protected from damage when lamda cyhalothrin (5 %) was sprayed on cashew nut trees as compared to the trees in the control plots.

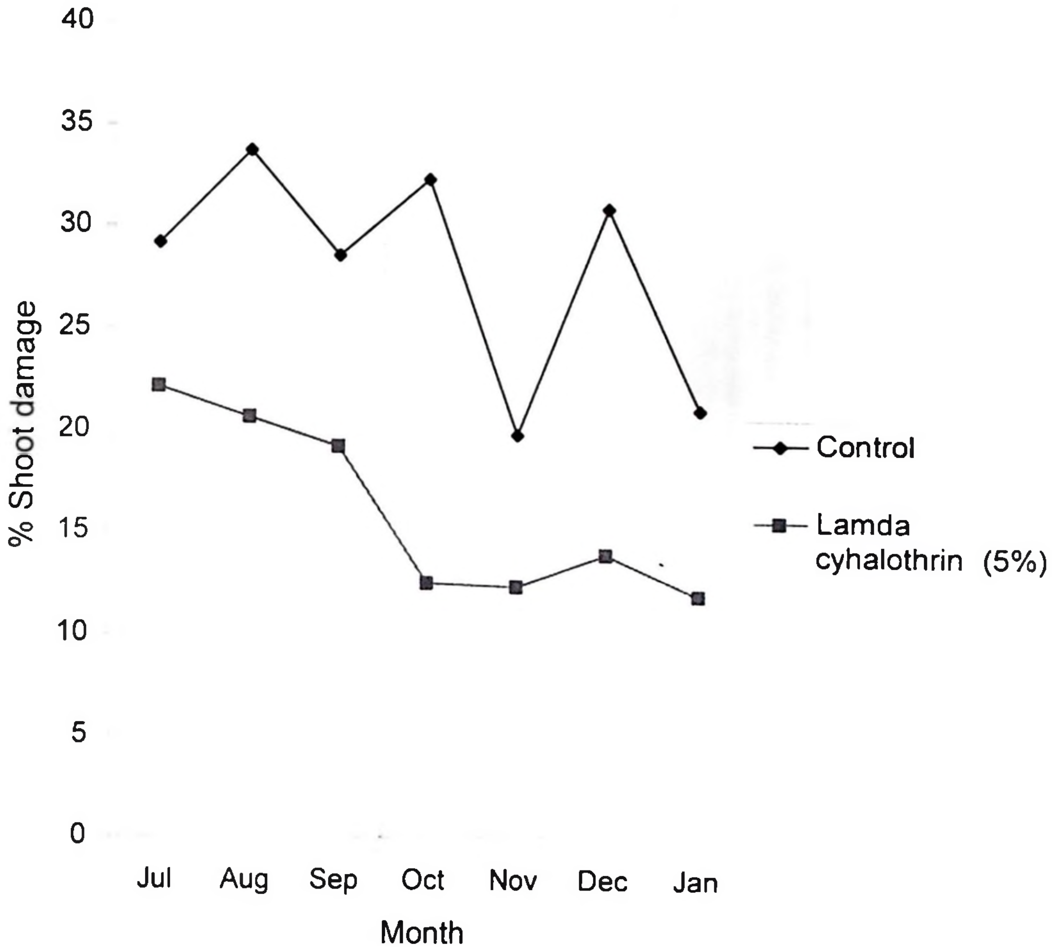

Figure 19. Monthly percentage shoot damage when cashew nut trees were treated with lamda cyhalothrin (5 %).

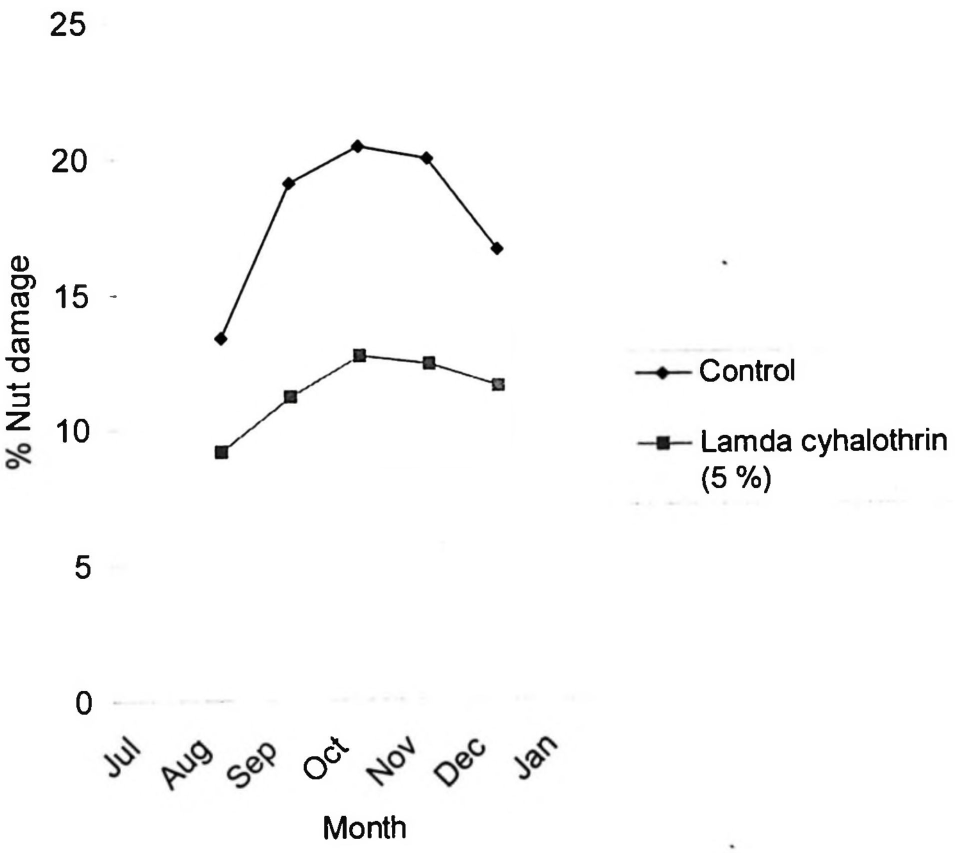

Figure 20. Percentage nut damage in cashew nut trees treated with lamda cyhalothrin (5 %).

4.6.5 Yield

The yield of nuts after treating cashew trees with lamda cyhalothrin (5 %)is summarized in Figure 21. The results show that yields increased in cashew plots sprayed with lamda cyhalothrin (5 %).

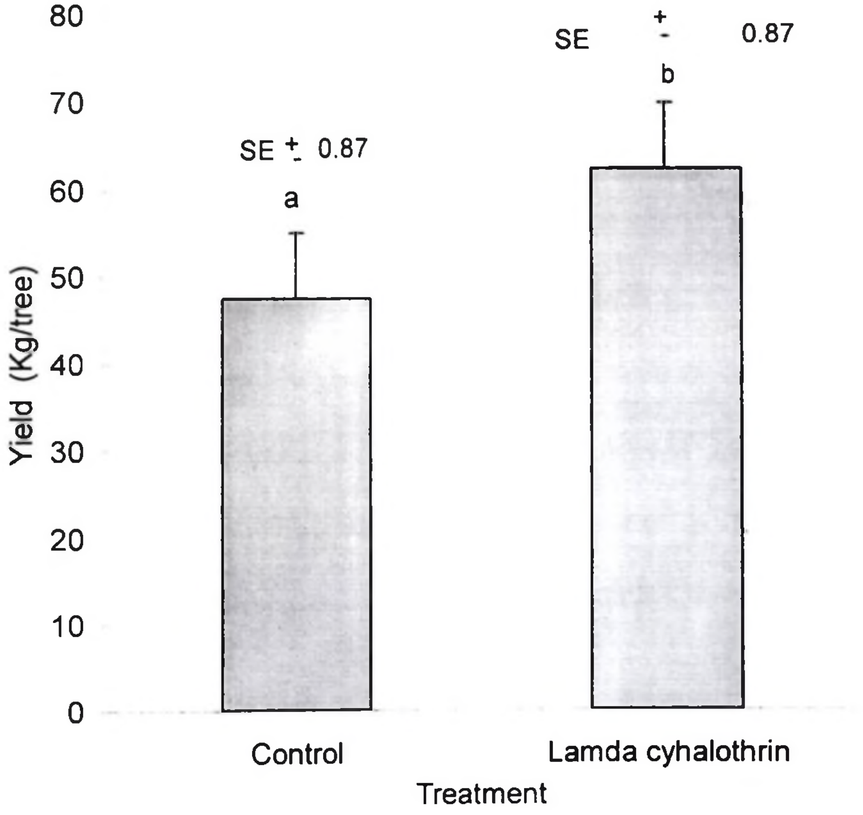

Figure 21. Cashew nut yield in control and lamda cyhalothrin (5 %) treated trees.

4.7 Control efficiency of lamda cyhalothrin (5 %) and different weaver ants nest levels.

4.7.1 Population of *Helopeltis anacardii*

Of the four weaver ants nest levels, trees with forty nests had lower *Helopeltis* population than the trees sprayed with lamda cyhalothrin (5 %). The results also show that, *Helopeltis* population in lamda cyhalothrin (5 %)treated trees was significantly lower ($P \leq 0.05$) than in trees occupied with ten, twenty and thirty nests (Figure 22).

4.7.2 Population of *Pseudotheraptus wayi*

Trees subjected to forty nests had significantly ($P \leq 0.05$) lower *Pseudotheraptus* population than trees treated with lamda cyhalothrin (5 %). However, there was no significant difference in pest population size between the lamda cyhalothrin (5 %) treated tress and those trees colonized by thirty nests (Figure 23). Also the results indicate that, cashew trees with ten and twenty nests had highest *Pseudotheraptus* population as compared to trees sprayed with lamda cyhalothrin (5 %).

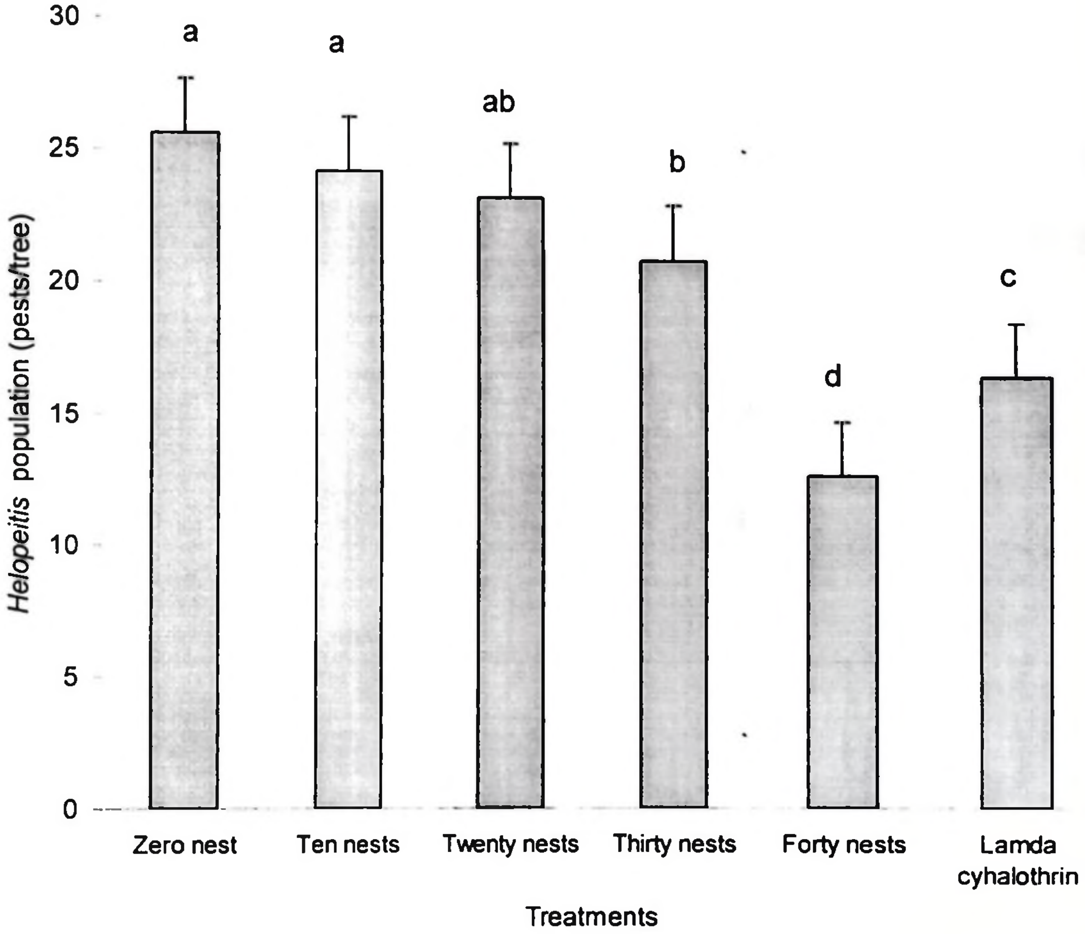

Figure 22. Population level of *H. anacardii* when cashew trees were treated with lamda cyhalothrin (5 %) and subjected to different weaver ants levels.

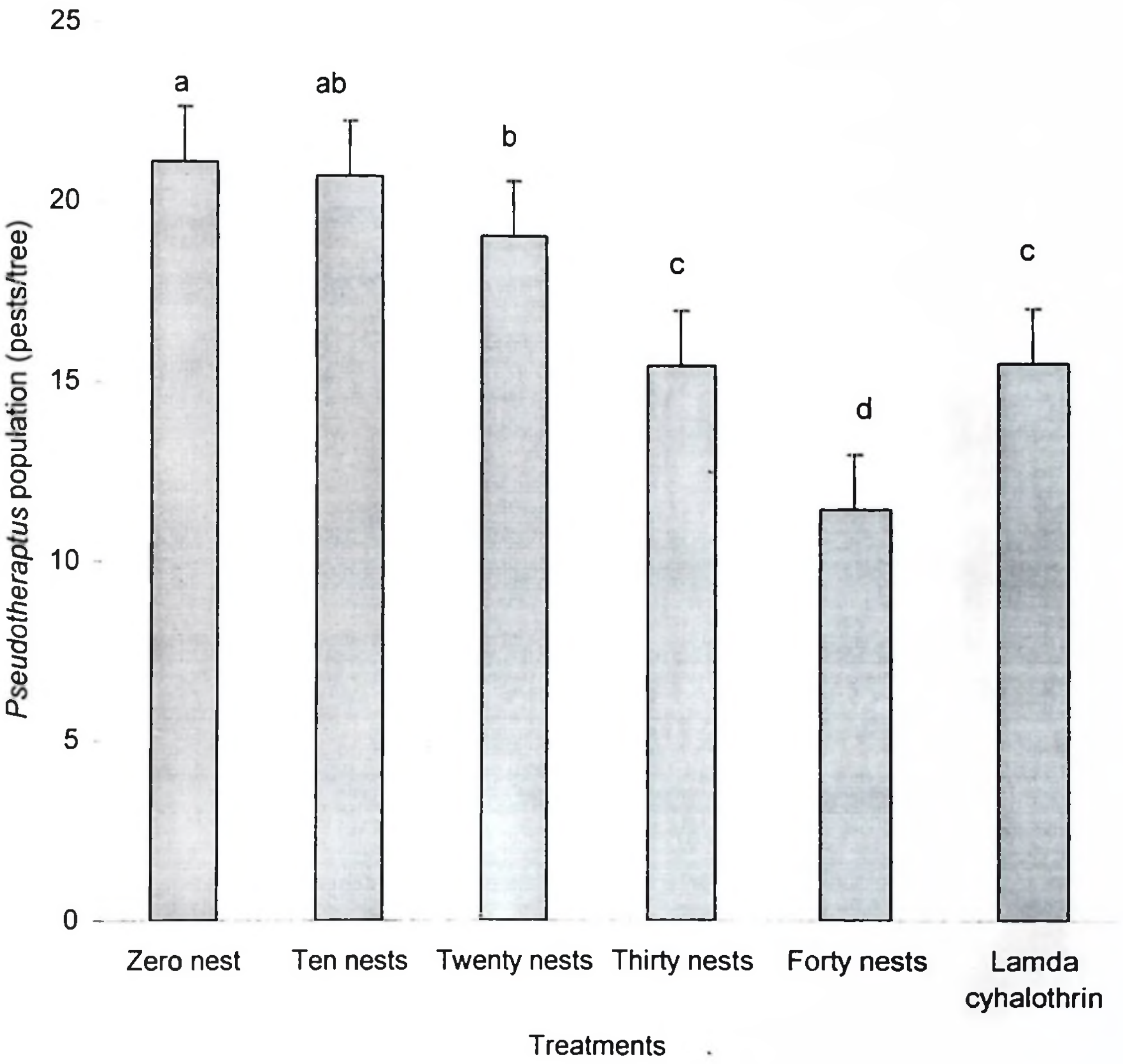

Figure 23. Population levels of *P. wayi* in cashew trees treated with lamda cyhalothrin (5 %) and subjected to different weaver ant levels

Among the nest levels, the lowest shoot damage was recorded in cashew trees colonized with forty nests, followed by trees sprayed with lamda cyhalothrin (5 %) and those occupied by thirty and twenty nests. However the shoot damage in the lamda cyhalothrin (5 %) treated trees, when compared to 30 and 20 nests was not significantly different. The results also show that, shoot damage in lamda cyhalothrin (5 %) treated trees and cashew trees colonized by forty nests was highly significant ($P \leq 0.05$) (Figure 24).

4.7 4 Nut damage

The results in Figure 25 show that the lowest nut damage was recorded in trees occupied by forty nests. Nut damage in lamda cyhalothrin (5 %) treated trees was significantly different from the control and the trees colonized by ten nests. However, nut damage in cashew trees with twenty and thirty nests didn't differ significantly ($P \leq 0.05$) from the trees sprayed with lamda cyhalothrin (5 %).

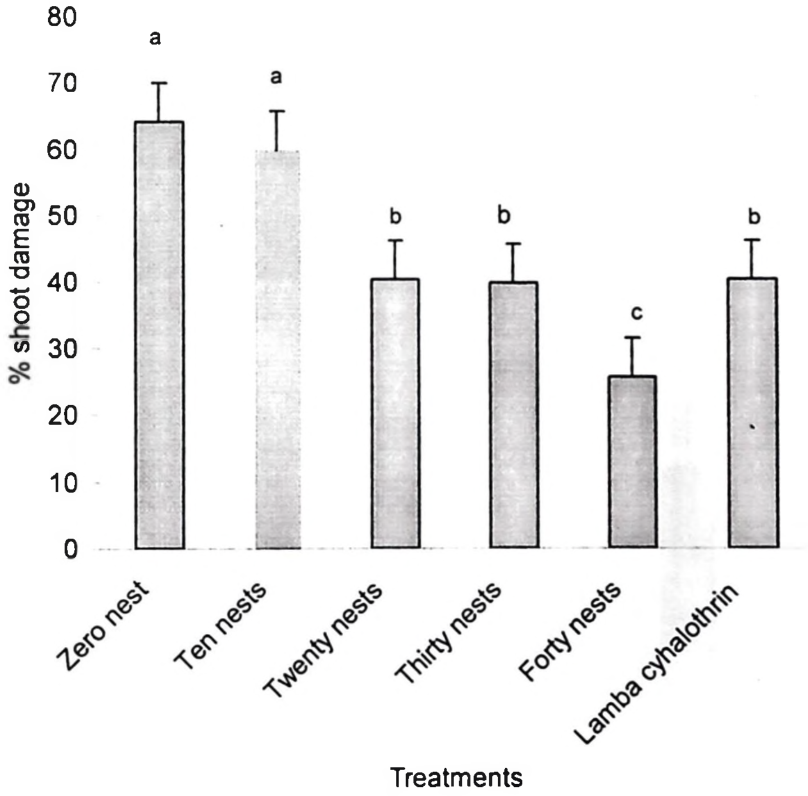

Figure 24. Percentage shoot damage when cashew trees were treated with lamda cyhalothrin (5 %) and subjected to different weaver ant nest levels

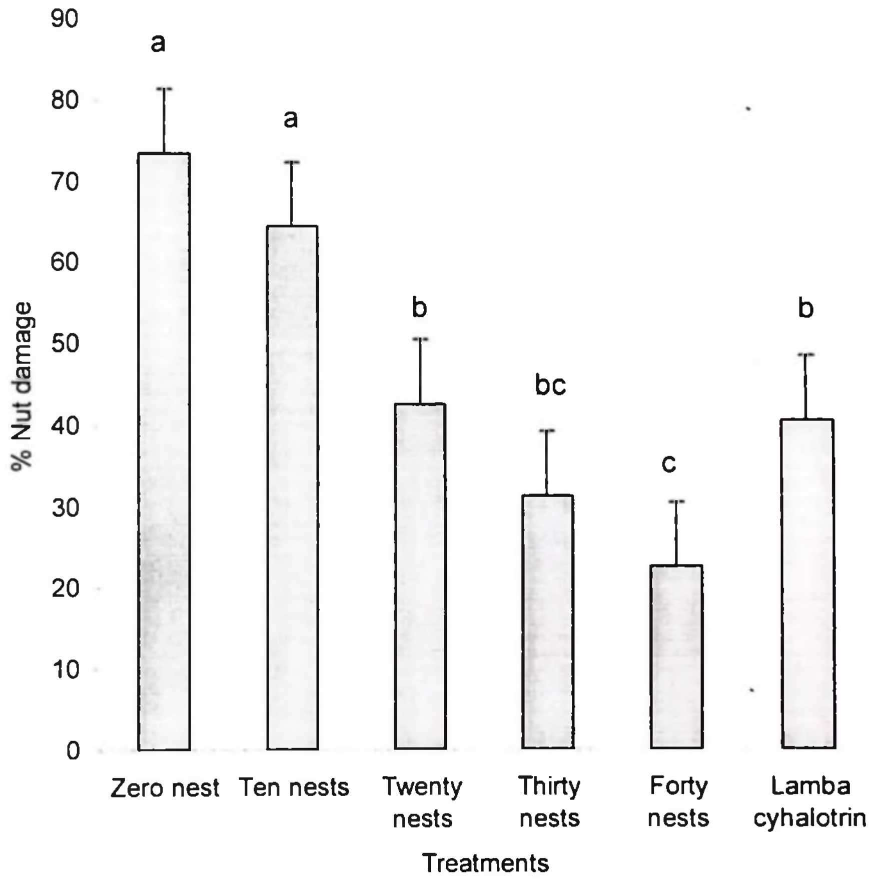

Figure 25. Percentage nut damage when cashew trees were treated with lamda cyhalothrin (5 %) and subjected to different weaver ant nest levels

4.7.5. Yield

The results in Figure 26 indicate that cashew trees subjected to forty nests had significantly ($P \leq 0.05$) higher yield than the other treatments. The difference in yield between cashew trees sprayed with lamda cyhalothrin (5 %) and those colonized by thirty nests was not significant. However, lamda cyhalothrin (5 %) sprayed trees had significantly ($P \leq 0.05$) higher yield than the trees occupied with ten and twenty nests.

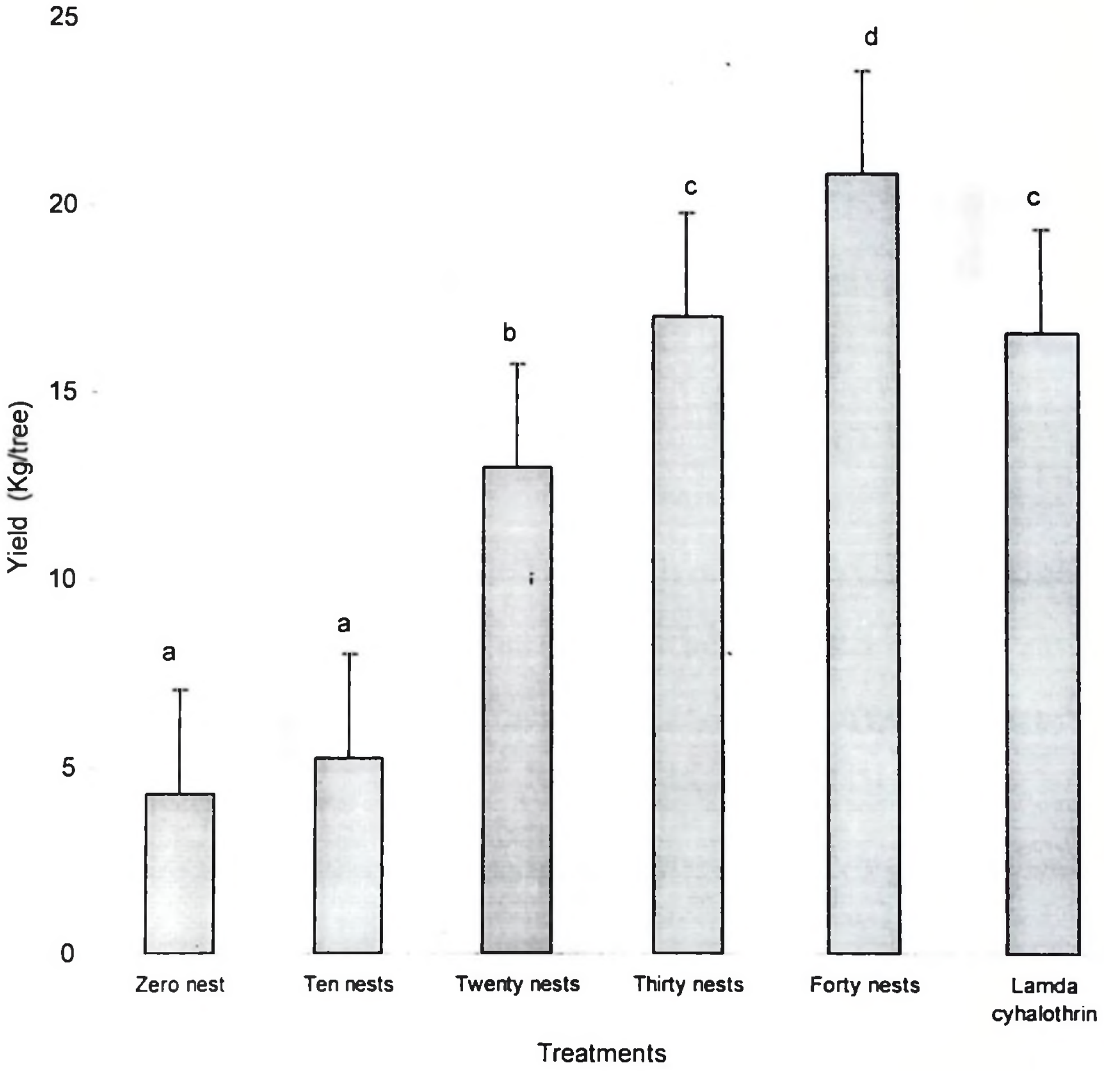

Figure 26. Cashew nut yield when trees were treated with lamda cyhalothrin (5 %) and subjected to different weaver ant nest levels

DISCUSSION

5.1 Protective effects of *O. longinoda*

In the current study, all the four-tested nest levels (10, 20, 30, and 40) gave effective protection to shoots and nuts against pest attack. The damage levels achieved at different numbers of weaver ant nests, and the reduced damage symptoms give an indication of the potentiality of this biological agent. From this study, the damage, both in shoots and nuts was reduced as numbers of nests increased.

Also, high incidence of damage for both shoots and nuts occurred at 10 and 20 nests levels, which suggests that the use of 10 and 20 nests is not enough to provide total protection to the cashew trees particularly on shoots and nuts. This shows that shoots and nuts are most protected at high nests levels than at low levels. The potential of weaver ants in reducing damage levels was also reported by Stanthers (1995) where a significant reduction in shoots and nuts damage was obtained when cashew trees are occupied with 25 nests of weaver ants per tree.

The pests' population varied depending on number of nests. The high pest infestation observed in this study in trees occupied with low number of nests suggests that effective pest suppression can only be attained at high nest levels. Sijaona (1998) also reported a decrease in pests' population of *P. anacardii* and *P. wayi* in cashew trees when colonized by weaver ants. Peng *et al.* (1995) also observed decrease of the population of *P. anacardii* and *P. wayi* when studying the effects of another species, *Oecophylla simaragdina* in Northern Australia, but there were no recommendations for the optimum number of nests that may be required for effective control .In the current study it is inferred that 40 nests of weaver ants would provide adequate control. of *P. wayi* and *P. anacardii.*

When the two populations of pests are compared. *H. anacardii* occurred in greater abundance than *P. wayi.* This was observed in every month for the whole study period. This observation is an indication that the large proportion of the damage noted in shoots and nuts was caused by *H. anacardii* .It further suggests that *H. anacardi* is a major pest of economic importance as compared to *P. wayi.* The difference in abundance between the two pests is difficult to explain. However. *P. wayi* is an important pest of coconut and only recently it was found attacking cashew trees. Most probably cashew trees are not very suitable as they are for *H. anacardii.*

The fluctuating population size of the two pests is probably due to differences in food supply from the cashew tree. particularly new flushes and presence of young nuts. Several authors including Chung and Wood (1989). Tan (1974). Boma *et al.* (1995). Julia and Mariau (1978) reported that. cashew trees become vulnerable to pest attack depending on the productive stage reached by a given cashew tree. Also in a different study on cocoa. Conway (1971); and Tan (1974a). reported that *Helopeltis anacardii* tend to build up in numbers when pods become abundant

The increased yield in cashew trees subjected to 40 nests implies that at high levels of weaver ants. the predation activity is enhanced. thus resulting to reduced pest population which eventually leads to low damage levels to shoots and nuts. However. other factors like flower abortion. limited moisture supply. and diseases

have been reported to influence yield levels in cashew (Pillai and Pillai 1975: Patnaik *et al.*, 1985). Also Peng *et al.* (1999) reported that when cashew trees were subjected to high nests levels, less damage by the sucking bugs was noted.
Sporleder and Rapp (1998) in studies of the effect of *O. longinoda* against *P. wayi* in coconut also reported that palms with varying degree of *O. longinoda* colonization showed an increasing yield with corresponding increase of *O. longinoda* activity.

The decrease in pest population and damage levels in shoots and nuts when cashew trees were subjected to low levels of weaver ants at 10 and 20 nests, had no effects on yield. This is different from what was expected that a reduction of damage in shoots and nuts would be associated with an increase in yield. From this study an increase in yield was only obtained when cashew trees were subjected to high nest levels.

5. 2 Effects of controlling the antagonistic ant

Most of the cashew trees were less foraged by *P. megacephala* as a result of the application of Amdro bait. This suggests that the applied rate of 4gm/tree was enough to give effective control of the ant. The effects of Amdro bait on *P. megacephala* was reported by Seguni (1993) and Mwaiko *et al.* (1998). In these studies, Amdro bait significantly reduced the population of *P. megacephala* in cashew and coconut. However, the findings in the present study are not in agreement with those reported by Sijaona (2000) in which effective control of *P. megacephala*. was obtained when the Amdro bait was applied at a rate of 7gm/tree.

The study also revealed that partial control of the antagonistic ant led to an increase in population of *O. longinoda* as most of the trees were heavily populated. This suggests that *P. megacephala* is one of the major factors limiting abundance of *O. longinoda* in cashew trees. Other workers have reported high levels of the biological agent in plots where the antagonistic ant was suppressed (Zerhusen and Rashid. 1992; Seguni. 1993; and Sijaona. 2000).

The present study has also shown that *O. longinoda* population. varied considerably between months. Highest weaver ants' population was recorded during the dry spell between August and October. The population decreased at the onset of short rains between November and January. These differences in population abundance were most probably due to effects of rainfall. as reported by Brain (1983) and Topper *et al.*(1997). In the current study the deactivation of the Amdro bait by rain. may explain the inadequate control of the antagonistic ant in the field. This. therefore. resulted to increasing number of the antagonistic ants. which hindered further build up of *O. longinoda* population.

The populations of *H. anacardii and P. wayi* in cashew trees were lowest when *P. megacephalla* was controlled resulting to higher predation rates by *O. longinoda* These results are in agreement with earlier findings by Stanthers (1995). Sijaona (1999) similarly reported a significant reduction in pest population of both *H. anacardii* and *P. wayi* bugs when the antagonistic ant was suppressed.

The importance of controlling the antagonistic ant before the establishment of *O. longinoda* in the cashew field is also confirmed by the comparison made between cashew trees subjected to weaver ants alone, and when treated in combination with Amdro bait. The lowest damage in shoots and nuts occurred when cashew trees were applied with a combination of weaver ants nests + Amdro bait and the highest damage level was obtained from trees subjected to weavers ants alone. This indicates the importance and efficiency of the Amdro bait. In the present study the performance of 40 nests alone in reducing damage levels of shoots and nuts was as good as 10 nests + Amdro bait application. This suggests that damage levels can be reduced by 10 nests of weaver ants provided the trees are also treated with Amdro bait.

Trees subjected to weaver ants alone were more dominated by the antagonistic ant. The limited or failure in the establishment of *O. longinoda* in these trees resulted to a build up of the pests to relatively high population levels.

The higher yield recorded in cashew trees subjected to 40 nests + Amdro bait application gives an indication of the good performance of this combination in increasing yield in cashew nuts.

5.3 Effect of lamda cyhalothrin (5 %).

Lamda cyhalothrin (5 %) provided enough protection to the cashew trees against pest attack when applied once at a rate of 5g a.i. per tree. However, Sijaona (1997) reported different results where effective control was attained when the chemical was applied three times. Lamda cyhalothrin (5 %) should be applied during the peak period when new flushes and nut development occurs. During this period the pest population is also high.

A comparison between different levels of weaver ants and Lamda cyhalothrin (5 %). suggests that high levels of weaver ants are more effective than Lamda cyhalothrin (5 %). in giving protection to cashew trees against damage. However. lamda cyhalothrin (5 %) has performed better than the control and 10 nests of weaver ants showing that at low nest levels lamda cyhalothrin (5 %) is still superior. From this study it has clearly been shown that the use of 40 nests provides effective protection to shoots and nuts as compared to lamda cyhalothrin (5 %).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1.CONCLUSIONS

Results obtained from this study showed that the use of *O. longinoda* as a biological agent provides a potentially valuable alternative to chemicals. It is evident that *O. longinoda* can protect cashew trees from damage by *H. anacardii* and *P. wayi.* The study revealed that most of trees subjected to high levels of weaver ants were significantly protected from pest attacks as compared to the control. Thirty and forty nests were found to be more effective among the tested levels Suppression of pests led to high nuts production per tree due to reduced shoots and nuts damage. However, *P. megacephala* limits the establishment and foraging ability of the biological agent, *O longinoda* in cashew fields. Even though there were differences in the incidence of damage within months but this didn't affect the effectiveness of the biological agent in providing the necessary protection. The application of Amdro (0.8% hydramethylnon) was very effective for the control *P. megacephela.* Application of the bait at once at a rate of 4 gm/tree was enough to suppress the competitor ant over a period of 7 months. When comparing the performance of weaver ants, either in combination with Amdro bait application or subjected alone, promising results were obtained when the cashew trees were both subjected with weaver ants and applied with Amdro bait

6.2 RECOMMENDATIONS:

1. Although Amdro bait appears to be promising in controlling antagonistic ant (*P. megacephala*) and leading to effective enhancement of *O. longinoda* more work need to be done. Areas of concentration may include application rates and frequency, secondary effect of Amdro bait, economies of Amdro bait application, and use of botanical derived biocides.

2. The present information on the biology and ecology of *O. longinoda* and the sucking pests *H. anacardii* and *P. wayi* is still inadequate, further studies on their distribution is essential.

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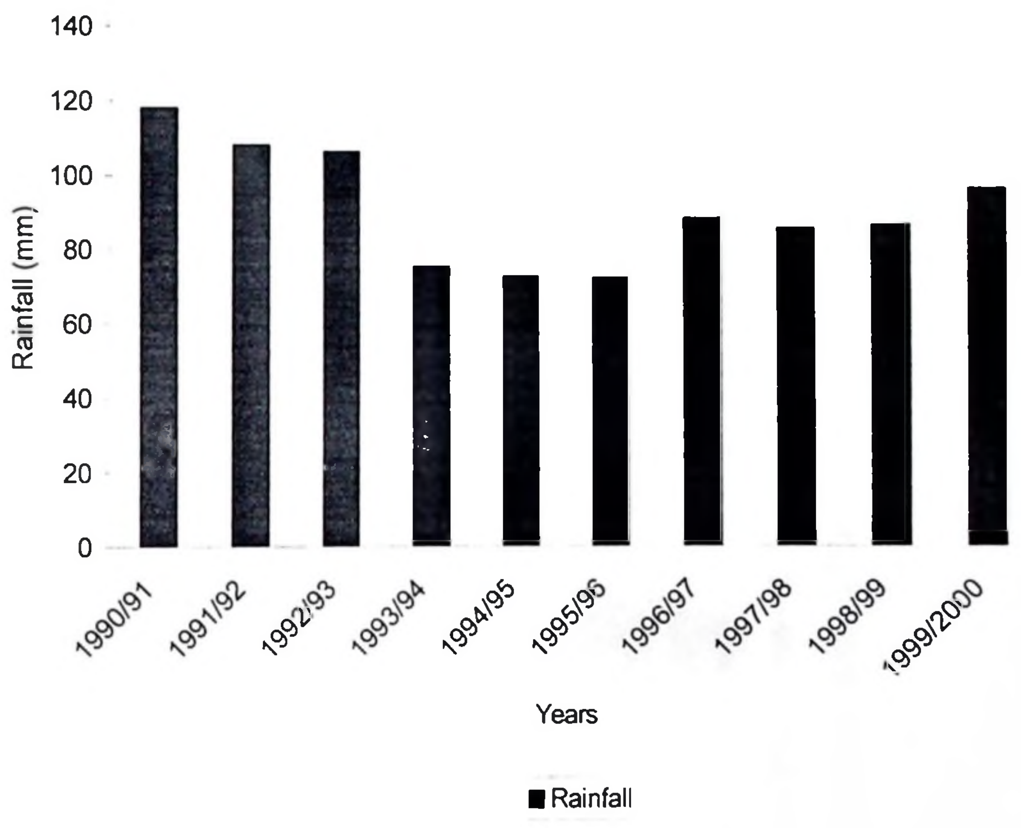
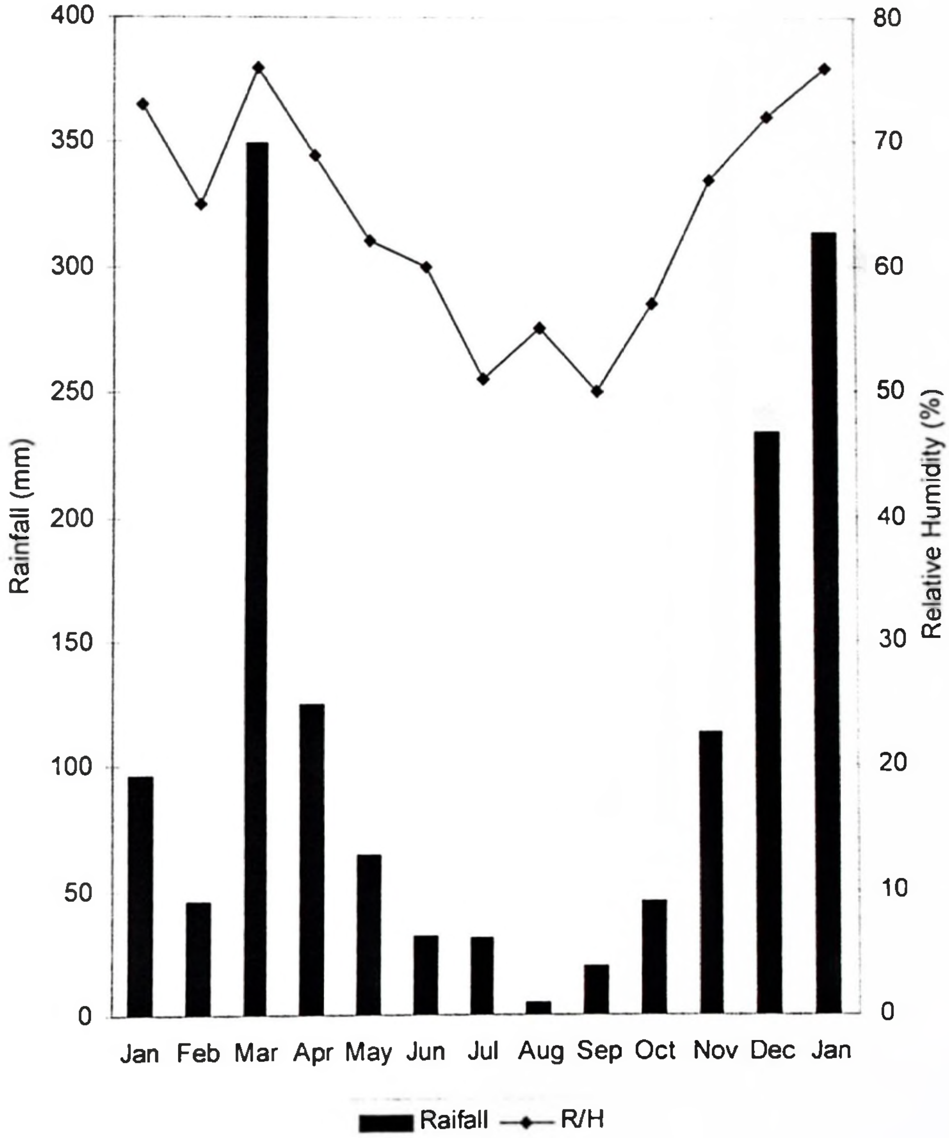
APPENDICES

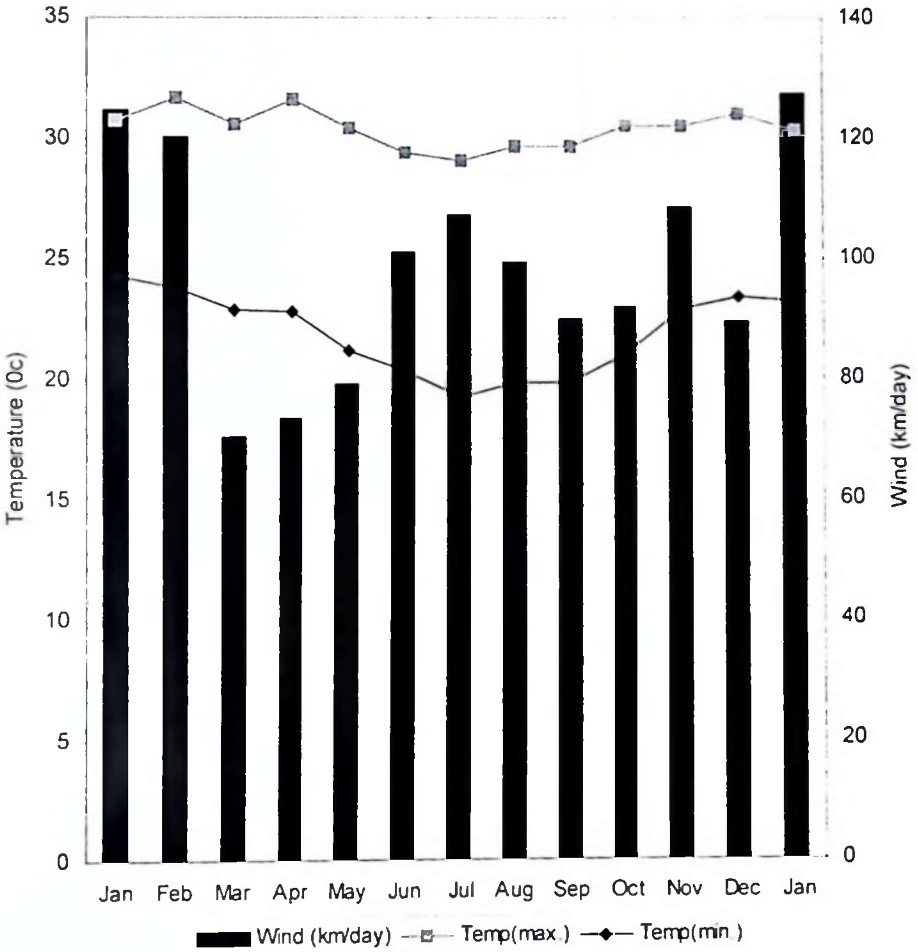
Appendix 1. Rainfall distribution over the past 10 years (1991 - 2000) at ARI - Naliendele



Appendix 2. Rainfall and Relative Humidity from January 2000 – January 2001 at ARI – Naliendele.



Appendix 3. Temperature (Max. and Min.) and wind speed from Jan 2000 – Jan 2001



Appendix 4. Shoot damage at different nest numbers of *O. longinoda*

	% Shoot damage							
No. of Nests	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
0	26.75^{a}	23.8^{a}	25.78^{a}	59.03^{a}	61.95^{a}	48.55^{a}	28.08^{a}	31.3
10	21.93^{b}	21.6^{ab}	23.23^{ab}	49.40^{ab}	54.05^{b}	39.95^{b}	21.50^{b}	25.1
20	20.75^{b}	20.9.3^{ab}	22.18^{bc}	44.23^{b}	45.33^{c}	32.95^{c}	18.05^{b}	23.0
30	15.78^{c}	19.6^{b}	20.93^{bc}	40.60^{c}	33.67^{d}	25.80^{d}	13.30^{c}	18.9
40	15.23^{c}	18.0^{b}	19.50^{c}	28.18^{c}	23.68^{c}	18.13^{c}	9.15^{c}	15.1
S.e ±	0.7	0.9	0.78	3.09	1.66	1.06	1.01	-
CV (%)	7.02	8.99	6.97	13.95	7.60	6.38	11.17	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 5. Nut damage at different nest numbers of *O. longinoda*

		% Nut damage						
No. of Nests	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
0	-	23.6^{a}	22.33^{a}	61.55^{a}	60.05^{a}	54.43^{a}	-	44.4
10	-	21.1^{ab}	18.548^{ab}	49.65^{ab}	49.98^{b}	44.56^{b}	-	34.2
20	-	19.0^{cb}	17.00^{b}	48.23^{b}	35.15^{c}	32.83^{c}	-	29.2
30	-	16.7^{c}	11.83^{c}	32.53^{c}	27.38^{c}	28.15^{c}	-	23.6
40	-	15.5^{c}	11.63^{c}	21.18^{c}	16.43^{d}	18.43^{d}	-	17.7
S.e±	-	0.9	0.93	2.70	1.91	1.67	-	-
CV (%)	-	8.99	11.46	12.68	10.13	9.36	-	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's analysis method

Appendix 6. Effects of nest numbers of *O. longinoda* on population levels of *H. anacardii*

	H. anacardii population (counts/tree)							
No. of nests	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Mean
0	31.05^{a}	25.75^{a}	27.40^{a}	19.04^{a}	18.95^{a}	22.03^{a}	25.54^{a}	16.2
10	27.12^{b}	22.23^{b}	23.07^{b}	16.38^{b}	15.98^{ab}	17.83^{b}	20.47^{b}	13.6
20	23.50^{c}	21.63^{b}	20.52^{bc}	16.26^{b}	15.23^{ab}	13.23^{c}	18..36^{bc}	12.3
30	16.74^{d}	16.38^{c}	16.36^{dc}	14.93^{bc}	13.42^{b}	12.34^{c}	17.27^{c}	10.3
40	16.44^{d}	15.25	14.48^{d}	13.11^{c}	12.48^{b}	11.53^{c}	13.97^{d}	7.9
S.e±	0.74	0.09	0.89	0.54	0.85	0.66	0.59	-
CV (%)	6.42	5.26	8.75	6.76	11.15	8.59	6.16	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 7. Effects of nest numbers of *O. longinoda* on population levels of *P. wayi*.

No. of nests	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Mean
0	18.71^{a}	15.17^{a}	16.27^{a}	10.69^{a}	10.64^{a}	12.69^{a}	15.03^{a}	14.17
10	16.08^{b}	12.82^{b}	13.38^{b}	8.92^{b}	8.66^{ab}	9.89^{b}	11.65^{b}	11.63
20	13.67^{c}	12.42^{b}	11.63^{b}	8.86^{b}	8.15^{b}	6.82^{c}	10.24^{bc}	10.26
30	9.16^{d}	8.92^{c}	9.24^{cd}	7.95b^{c}	6.95^{b}	6.23^{c}	9.51^{c}	8.28
40	9.96^{d}	8.17^{c}	7.66^{d}	6.74^{c}	6.32^{b}	5.69^{c}	7.32^{d}	7.21
S.e±	0.49	0.35	0.59	60.36	0.56	0.44	0.39	
CV (%)	7.40	6.17	10.26	8.30	13.87	10.67	7.30	

Means followed by the same letters are not significantly different at (P ≤ 0.05) according to Tukey's analysis method

Appendix 8. Effects of nest numbers of *O. longinoda* on cashew nut yield

	Yield (Kg/tree)		
No. of nets	Sept	Oct	Mean
0	18.00^{a}	11.00^{a}	14.50
10	18.20^{a}	11.20^{a}	14.70
20	19.20^{a}	12.20^{a}	15.70
30	20.85^{b}	13.85^{b}	17.35
40	22.30^{c}	15.30^{c}	18.80
Se ±	0.29	0.29	-
CV (%)	2.95	4.58	-

Means followed by the same letters are not significantly different at (P ≤ 0.05) according to Tukey's analysis method

Appendix 9. Monthly population of *P. megacephala* when controlled by Amdro bait

	P. megacephala population							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	250.60^{a}	208.00^{a}	235.60^{a}	197.00^{a}	176.6^{a}	190.60^{a}	187.8^{a}	206.51
Amdro	149.76^{b}	156.39^{b}	149.23^{b}	139.40^{b}	154.87^{b}	149.00^{b}	174.60^{b}	153.30
S.e ±	8.45	5.70	4.61	7.09	4.24	4.95	3.85	-
CV (%)	9.44	7.00	5.36	9.43	5.72	6.52	4.75	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 10. Monthly population of *O. longinoda* when the competitor ant *P. megacephala* was controlled by Amdro bait.

	O. Longinoda population							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	136.80^{a}	149.23^{a}	160.56^{a}	159.25^{a}	180.98^{a}	135.57^{a}	130.92^{a}	150.47
Amdro	158.72^{b}	208.22^{b}	208.16^{b}	212.50^{b}	204.51^{b}	170.98^{b}	164.06^{b}	189.59
S.e ±	5.93	4.22	3.07	3.03	12.83	2.11	4.46	--
CV (%)	8.97	5.30	3.72	3.64	14.89	3.08	6.76	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 11. Population levels of *H. anacardii* after controlling the competitor ant *P. megacephala*, by Amdro bait.

	H. anacardii population (counts/tree)							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	29.76^{a}	36.75^{a}	24.09^{a}	20.32^{a}	14.79^{a}	18.69^{a}	25.22^{a}	24.23
Amdro	27.81^{b}	24.14^{b}	19.65^{b}	15.77^{b}	14.31^{a}	14.82^{b}	19.33^{b}	20.80
S.e ±	0.36	0.62	0.54	0.25	0.23	0.44	0.56	-
CV (%)	2.81	4.55	5.55	3.08	3.59	5.89	5.65	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 12. Population levels of *P. wayi* after controlling the competitor ant *P. megacephala*, by Amdro bait.

	P .wayi population (counts/tree)							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	15.18^{a}	17.90^{a}	14.85^{a}	13.60^{a}	12.88^{a}	12.16^{a}	14.44^{a}	14.40
Amdro	12.40^{b}	12.14^{b}	9.91^{b}	7.72^{b}	5.20^{b}	8.20^{b}	13.92^{a}	9.92
S.e ±	0.70	0.45	0.61	1.42	0.56	0.13	0.31	-
CV (%)	11.38	6.72	10.96	29.84	14.26	2.84	4.81	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 13. Monthly percentage of shoot damage after the competitor ant to *O longinoda*. the *P. megacephala* was controlled by Amdro bait.

	% Shoot damage							
	Jul	Aug	Sept	Oct.	Nov	Dec	Jan	Mean
Control	26.60^{a}	30.06^{a}	28.66^{a}	34.00^{a}	33.94^{a}	28.90^{a}	24.50^{a}	29.51
Amdro	20.96^{b}	22.38^{b}	21.70^{b}	24.36^{b}	26.38^{b}	20.06^{b}	21.20^{b}	22.44
S.e ±	0.60	0.35	0.32	0.86	0.94	1.03	0.67	-
CV (%)	5.68	2.99	2.88	6.60	6.98	9.38	6.50	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's analysis method

Appendix 14. Monthly percentage of nut damage after the competitor ant to *O. longinoda*. the *P. megacephala* was controlled by Amdro bait.

	% Nut damage							
	Jul	Aug	Sept	Oct.	Nov	Dec	Jan	Mean
Control	0.00	20.86^{a}	31.14^{a}	24.52^{a}	30.22^{a}	34.04^{a}	0.00	20.11
Amdro	0.00	11.80^{b}	25.28^{b}	19.70^{b}	22.24^{b}	23.44^{b}	0.00	14.48
S.e ±	0.00	1.96	1.56	0.46	0.89	0.90	0.00	-
CV (%)	0.00	26.85	12.36	4.65	7.58	6.96	0.00	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's analysis method

Appendix 15. Cashew nut yields when the ant *P. magacephala* was controlled by Amdro bait.

	Yield (Kg/tree)		
	Sept	Oct	Mean
Control	27.20^{a}	26.00^{a}	26.6
Amdro	42.32^{b}	48.24^{b}	45.28
Se ±	0.38	1.16	-
CV (%)	4.93	14.01	-

Means followed by the same letters are not significantly different at (P ≤ 0.05) according to Tukey^{1}s analysis method

Appendix 16. Effect of treating cashew trees with lamda cyhalothrin (5 %) on *H. anacardii* population

	H. anacardii population (counts/tree)							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	17.66^{a}	35.32^{a}	42.95^{a}	43.65^{a}	17.74^{a}	19.20^{a}	36.08^{a}	30.36
Lamda cyhalothrin (5 %)	9.15^{b}	18.15^{b}	19.24^{b}	17.40^{a}	12.11^{b}	6.15^{a}	25.39^{b}	15.37
S.e ±	0.51	1.39	1.27	2.09	0.52	0.70	0.67	-
CV (%)	3.64	10.05	10.81	13.66	7.02	11.04	4.35	-

Means followed by the same letters are not significantly different at (P ≤ 0.05) according to Tukey^{1}s analysis method

Appendix 17. Effect of treating cashew trees with lamda cyhalothrin (5 %) on *P. wayi* population

	P. wayi							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	19.8^{a}	18.3^{a}	17.80^{a}	16.4^{a}	11.72^{a}	11.7^{a}	16.9^{a}	16.10
Lamda cyhalothrin (5 %)	13.35^{b}	13.10^{b}	9.73^{b}	12.00^{b}	8.06^{b}	05.55^{b}	11.93^{b}	10.23
S.e ±	0.34	0.31	0.42	0.04	0.35	0.47	0.50	-
CV (%)	4.60	3.98	6.14	5.85	7.06	10.99	6.93	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's analysis method

Appendix 18. Effect of treating cashew trees with lamda cyhalothrin (5 %) on shoot damage levels

	% Shoot damage							
	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	29.20^{a}	33.75^{a}	28.73^{a}	32.50^{a}	20.20^{a}	31.80^{a}	21.20^{a}	28.05
Lamda cyhalothrin (5 %)	22.20^{b}	20.68^{b}	19.35^{a}	12.63^{b}	13.98^{a}	23.98^{b}	11.00^{b}	17.69
S.e ±	1.09	1.54	0.49	0.73	1.12	0.25	0.4	-
CV (%)	6.79	4.32	4.10	6.51	13.08	1.84	4.84	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey's analysis method

Appendix 19. Effect of treating cashew trees with lamda cyhalothrin (5 %) on nut damage levels

	% Nut damage							
	July	Aug	Sept	Oct	Nov	Dec	Jan	Mean
Control	0.00	13.38^a	19.10^a	20.45^a	19.96^a	16.65^a	0.00	12.79
Lamda cyhalothrin (5 %)	0.00	9.28^b	11.23^b	15.40^a	12.43^b	11.63^b	0.00	8.56
S.e ±	-	0.64	0.91	0.14	1.55	0.44	-	
CV (%)	-	11.25	11.99	1.53	19.14	6.22	-	

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 20. Effect of treating cashew trees with lamda cyhalothrin (5 %) on cashew nut yield

	Sept	Oct	Mean
Control	17.97^a	29.62^a	47.59
Lamda cyhalothrin (5 %)	23.73^b	38.86^b	62.59
Se ±	0.86	1.57	-
CV (%)	14.79	15.98	-

Means followed by the same letters are not significantly different at ($P \leq 0.05$) according to Tukey^{1}s analysis method

Appendix 21. Copy spread for experiment I

Tree No.	North - South direction (D_1) (m)	East - West direction (D_2) (m)	Total $D_1 + D_2$ (m)	Average $D = D_1 + D_2/2$ (m)
1	8.5	8.3	16.8	8.4
2	9	8.45	17.45	8.73
3	9.5	11.85	21.35	10.68
4	8.55	7.95	16.5	8.25
5	11.3	11	22.3	11.15
6	8.8	11.2	20	10
7	7.8	11.2	19	9.5
8	6.2	9.65	15.85	7.93
9	7.7	11.1	18.8	9.4
10	11.4	11	22.4	11.2
11	10	11	21	10.5
12	7.9	9.7	17.6	8.8
13	11	9.3	20.3	10.15
14	12.3	8.6	20.9	10.45
15	9.1	10.1	19.2	9.6
16	8.6	10.8	19.4	9.7
17	8	8.2	16.2	8.1
18	9.4	7.2	16.6	8.3
19	9	8.1	17.1	8.55
20	9	9.4	18.4	9.2
21	8.1	10	18.1	9.05
22	9.5	11	20.5	10.25
23	8.8	9.5	18.3	9.15
24	8.75	9.5	18.25	9.13
25	10.15	9.95	20.1	10.05
26	10	10.6	20.6	10.3
27	9.6	8.5	18.1	9.05
28	8.9	8.3	17.2	8.6
29	10	11.1	21.1	10.55
30	8.5	8	16.5	8.25
31	9	8.8	17.8	8.9
32	8	10.25	18.25	9.13
33	8.2	9.7	17.9	8.95
34	9.8	8.4	18.2	9.1
35	8.75	10.2	18.95	9.48
36	8	9.4	17.4	8.7
37	9.3	8.7	18	9
38	9.1	10	19.1	9.55
39	9.4	10.27	19.67	9.84
40	8.55	8.5	17.05	8.53
Total	363.45	384.77	748.22	374.11
Average	9.09	9.62	18.71	9.35

Overall canopy spread ($D_1 + D_2$) = 9.36m

Appendix 22. Plant height for experiment I

Tree No.	Upper reading UP) (m)	Lower Reading (LR) (m)	Horizontal distance HD) (m)	Plant height (H (UP + LR x HD/100)
1	9.5	8.8	7.5	10.16
2	8	9.6	7.9	8.76
3	10.4	8.5	10.2	11.27
4	7.3	9.9	10	8.29
5	9.9	11.2	12.1	11.26
6	11.2	11	9.5	12.25
7	8.8	9.9	8.8	9.67
8	10	9.2	6.9	10.63
9	11.3	8.7	7.8	11.98
10	9.4	7.5	8.1	10.01
11	7.4	8.2	10.3	8.24
12	10.1	9.3	9.2	10.96
13	11.1	8.4	11.1	12.03
14	7	7.7	10.9	7.84
15	8.8	7.9	7.8	9.42
16	10.3	8.1	9.9	11.1
17	11.4	8	9.6	12.17
18	9	9.3	12	10.12
19	10	12	11	11.32
20	11	10.3	12	12.24
21	8.3	9.1	10	9.21
22	9.2	7.5	11.2	10.04
23	7.9	7.6	7.8	8.49
24	7.5	8.5	7.7	8.15
25	8.7	11	6.9	9.46
26	7.5	10.9	6.8	8.24
27	9.8	10.4	12	11.05
28	8.9	8.2	6	9.39
29	10.1	7.2	12.8	11.02
30	11.2	9.3	10	12.13
31	7.7	7.9	9.6	8.46
32	10	8.1	9.2	10.75
33	7	10.5	8.4	7.88
34	9.9	7.6	7.5	10.47
35	11.4	8.5	7.6	12.05
36	9.8	8.8	9.1	10.6
37	9.1	7.5	8.2	9.72
38	10.5	9	8.6	11.27
39	10.1	10	7.9	10.89
40	8.7	9.6	7.1	9.38
Total	375.2	360.7	367	408.35
Average	9.38	9.02	9.18	10.21

Overall plant height (UP + LR + HD)/100 = 10.21m

Appendix 23. Canopy spread for experiment II

Tree No.	North - South direction (D1) (m)	East - West direction (D2) (m)	Total D1 + D2 (m)	Average tree canopy D1 + D2/2 (m)
1	11.5	9	20.5	10.25
2	9.8	8.3	18.1	9.05
3	10	8.6	18.6	9.3
4	11	10.3	21.3	10.65
5	8.8	11.4	20.2	10.1
6	9.7	9.3	19	9.5
7	8.2	9.2	17.4	8.7
8	8.5	8.8	17.3	8.65
9	7.9	9.2	17.1	8.55
10	9.1	10	19.1	9.55
Total	94.5	94.1	188.6	94.3
average	9.45	9.41	18.86	9.43

Over all spread canopy (D1+ D2) = 9.43m

Appendix 24. Plant height for experiment II

Tree No.	Upper reading (UP) (m)	Lower Reading (LR) (m)	Horizontal Distance (HD) (m)	Plant height (H) UP + LR x HD/100) (m)
1	11.1	10.6	8.3	11.98
2	10.5	12.1	9.6	11.66
3	8.7	9.6	12	9.85
4	8	8.7	11.3	8.98
5	7.9	8.8	8.9	8.68
6	8.9	9.6	8.6	9.73
7	10.1	11.3	7.7	10.97
8	9.5	9.1	9.8	10.39
9	8.3	8.9	9.1	9.11
10	7.9	10.4	10.9	9.03
Total	90.9	99.1	96.2	100.39
Average	9.09	9.91	9.62	10.04

Overall plant height (UP + LR + HD/100) = 10.04m

Appendix 25. Canopy spread for experiment III

Tree No.	North - South direction (D1) (m)	East - West direction (D2) (m)	Total D1 + D2 (m)	Average tree canopy D = D1 + D2 /2 (m)
1	7.7	10	17.7	12.3
2	9.2	9.2	18.4	9.2
3	9.9	6.7	16.6	3.5
4	8.3	8.7	17	9.1
5	7.8	9.7	17.5	11.6
6	8.6	8.9	17.5	9.2
7	11	9.9	20.9	8.8
8	8.3	11.3	19.6	14.3
9	8.7	10.2	18.9	11.7
10	9.9	11	20.9	12.1
11	10.1	8.4	18.5	6.7
12	7.8	10.2	18	12.6
13	11.7	11.5	23.2	11.3
14	8.9	8.4	17.3	7.9
15	11.1	10	21.1	8.9
16	12	7.7	19.7	3.4
Total	151	151.8	302.8	152.6
Average	9.4	9.49	18.93	9.54

Over all spread canopy (D_1÷ D_2) = 9.54m

Appendix 26. Plant height for experiment III

Tree No.	Upper reading (UP) (m)	Lower reading (LR) (m)	Horizontal Distance (HD) (m)	Plant height (H) UP + LR x HD/100) (m)
1	8.1	7.9	8.3	8.76
2	8.8	9.9	9.2	9.71
3	7.7	10.2	7.9	8.51
4	11.23	11.3	12.3	12.62
5	11.1	8.2	10.2	11.94
6	10.9	9.6	9.3	11.79
7	9.9	7.5	8.1	10.51
8	9.3	8.1	7.2	9.88
9	8.7	9.3	7.7	9.42
10	11.7	12.1	8.9	12.78
11	10.4	8.9	8.2	11.13
12	11.9	7.4	9.4	12.6
13	8.4	11.6	11.5	9.73
14	8.6	10.1	7.6	9.37
15	9	7.1	8.3	9.59
16	10	7.6	9.9	10.75
Total	155.73	146.8	144	169.07
Average	9.73	9.18	9	10.57

Over all plant height for experiment III