Potential of *Oecophylla longinoda* (Hymenoptera: Formicidae) for management of *Helopeltis* spp. (Hemiptera: Miridae) and *Pseudotheraptus wayi* (Hemiptera: Coreidae) in cashew in Tanzania

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September 2013 _____

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DEDICATION

I dedicate this thesis to my mother Siael Olotu, spouse Estheria Olotu, children Irine and Ian and the entire family for constant love and support.

To my late father Iwatasia Olotu

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PREFACE

The use of ants as a biocontrol agent of pests has been known for many years and practiced for a long time. Around the 12th century the Chinese farmers already connected their fruit trees with bamboo sticks to provide the ants with a passage to move from one tree to another. This measure resulted in a spread of ants throughout their orchards. Successful biocontrol by ants is known from various countries, namely Vietnam, Australia, Benin and Ghana. Tanzania, as one of the major cashew producing countries, can also benefit from African weaver ant (AWA), as it provides effective control against coreid and mirid pests on cashew nuts.

The "Cashew Integrated Pest Management" (Cashew IPM) project facilitated a study dealing with this subject and I took the opportunity to get involved. After I have completed the African Regional Postgraduate Programme in Insect Sciences (ARPPIS) introductory courses training and development of a thesis proposal, I travelled to Tanzania to look at the possibilities of using AWA for biocontrol of *H. schoutedeni* and *H. anacardii* and *P. wayi*, the key pests of cashew in Tanzania. The field surveys/experiments were carried out in three consecutive growing seasons (2010-2011, 2011-2012 and 2012-2013). Most of the experimental sites used in this study belong to local smallholders; which will contribute to early dissemination of research results on the use of AWA to controlthe named sap-sucking pests.

ABSTRACT

Cashew, *Anacardium occidentale* Linnaeus, is an economically important cash crop for more than 300,000 rural households in Tanzania. Its production is, however, severely constrained by infestation by sap-sucking insects such as *Helopeltis anacardii* Miller, *H. Schoutedeni* Reuter and *Pseudotheraptus wayi* Brown. The African weaver ant (AWA), *Oecophylla longinoda* Latreille, is an effective biocontrol agent of hemipteran pests in coconuts in Tanzania; but its efficacy for the control of sap-sucking insects, especially *Helopeltis* spp. and *P. wayi,* has not been investigated so far in cashew crops in Tanzania. Field trials were carried out at the Coast region of Tanzania to evaluate the effect of seasonality and abundance of AWA on *Helopeltis* spp. and *P. wayi.* Results showed that AWA abundance expressed, as number of leaf nests per tree, and colonization of trails on main branches varied significantly between cashew-seasons and off-seasons. There was a negative correlation between numbers of nests and pest damage. AWA-colonized cashew trees had the lowest shoot damaged by *Helopeltis* spp., 4.8 and 7.5% in 2010 and 2011, respectively, compared to 36 and 30% in 2010 and 2011, respectively, in uncolonized cashew trees. Similarly, nut damage by *P.wayi* was lowest in AWA-colonized trees with 2.4 and 6.2% in 2010 and 2011, respectively, as compared to 26 and 21% in 2010 and 2011, respectively, in uncolonized trees. Interaction between AWA and dominant ant species, namely big-headed ant (BHA), *Pheidole megacephala* Fabricius, and common pugnacious ant (CPA), *Anoplolepis custodiens* Smith, was examined because of the implication that the dominant ant species may have on the efficacy of AWA in its control of sap-sucking pests of cashew. Abundance of AWA was significantly negatively correlated to BHA ($r_{(39)}$ = -0.30; P < 0.0001) and CPA ($r_{(39)}$ = -0.18; P = 0.01) at Bagamoyo in 2010. A similar trend was also observed at Mkuranga. The presence of these ant species may therefore hinder effectiveness of AWA to control sap-sucking pests in cashew in Tanzania. Therefore, suppression of these two inimical ant species should be emphasized for effective control of the sap-sucking pests in cashew fields. It

was therefore also important to establish the abundance and diversity of ant species occurring in cashew agro-ecosystems. Results from pitfall traps revealed the diversity and abundance of ants in cashew agro-ecosystems: a total of 14001 ants were trapped belonging to six subfamilies, 18 genera and 32 species. The ant species diversity was high in the cashew fields at two of the four sites, namely Mkuranga A and Kibaha during both seasons. CPA was the most abundant ants in the pitfall traps. It is an important aspect that should be addressed for effective control of sap-sucking pests in cashew fields with AWA, since the correlation between AWA and CPA abundance was found to be negative. The effect of alternative fungicides to sulphur dust used for powdery mildew disease (PMD) on AWA was also investigated. No significant difference could be found in the effect ofthe different fungicides on the number of leaf nests and colonization of trails. In order to develop AWA as a component of cashew integrated sap-sucking insect management, strategies for their conservation during cashew off-seasonswas evaluated. The use of fish and hydramethylon (Amdro®) as baits increased the number of leaf nests and colonization trails of AWA over the control during off-season; however, the increase was significantly high when both fish and hydramethylon were used together. Fish and hydramethylon can therefore be used for conservation of AWA during off-season. It can therefore be concluded that AWA effectively controls sap-sucking pests on cashew and can be conserved during off-season using disposal waste such as fish intestines. Fungicides used for the control of PMD did not have detrimental effects on AWA abundance and can therefore be integrated as a component of cashew IPM.

Key words: African weaver ant, biocontrol, cashew, diversity, integrated pest management, species richness

UITTREKSEL

Kasjoe, *Anacardium occidentale* Linnaeus, is 'n ekonomies-belangrike kontantgewas vir meer as 300,000 landelike huishoudings in Tanzanië. Produksie word egter ernstig gestrem deur infestasie van sap-suiende insekte soos *Helopeltis anacardii* Miller, *H. Schoutedeni* Reuter and *Pseudotheraptus wayi* Brown. Die Afrika nes-spin mier, *Oecophylla longinoda* Latreille, is 'n effektiewe biologiese beheeragent vir Hemiptera plae van kokosneute in Tanzanië, maar hul effektiwiteit vir die beheer van sapsuiende insekte, veral *Helopeltis* spp. en *P. wayi*, is nog nie in kasjoe ondersoek nie. Veldproewe is in die kusgebied van Tanzanië uitgevoer om die effek van seisoenaliteit en voorkoms van *O. longinoda* op *Helopeltis* spp. en *P. wayi* te evalueer. Resultate het getoon dat die veelheid van hierdie mierspesie, uitgedruk as aantal blaarneste per boom en kolonisasie van paadjies op hooftakke, betekenisvol varieer tussen kasjoe-seisoene en af-seisoene. Daar was 'n negatiewe korrelasie tussen aantal neste en skade deur díe plae. Kasjoebome wat deur *O. longinoda* gekoloniseer is, het betekenisvol minder *Helopeltis* spp. skade aan lote getoon; 4.8 en 7.5% in 2010 en 2011 onderskeidelik, in vergelyking met nie-gekoloniseerde bome, waar skade 36 en 30% in 2010 en 2011 onderskeidelik was. Skade aan neute deur *P. wayi* was ook die laagste in *O. longinoda*-gekoloniseerde bome met 2.4 en 6.2% in 2010 en 2011 onderskeidelik, in vergelyking met 26 en 21% in 2010 en 2011, in nie-gekoloniseerde bome. Interaksies tussen *O. longinoda* en die dominante mierspesies *Pheidole megacephala* Fabricius, asook die malmier, *Anoplolepis custodiens* Smith, was ondersoek weens die implikasie wat die dominante mierspesies mag hê op die effektiwiteit van *O. longinoda* vir beheer van die sapsuiende plae van kasjoe. Veelheid van *O. longinoda* was betekenisvol negatief gekorreleer met *P. megacephala* ($r_{(39)}$ = -0.30; P<0.0001) en *A. custodiens* ($r_{(39)}$ = -0.18; P=0.01) by Bagamoyo in 2010. 'n Soortgelyke tendens was by Mkuranga waargeneem. Die teenwoordigheid van hierdie miere kan dus die effektiwiteit van *O. longinoda* om sap-suiende plae van kasjoe in Tanzanië te beheer, belemmer. Onderdrukking van hierdie twee vyandige mierspesies moet uitgevoer word vir effektiewe beheer van die

sapsuiende plae in kasjoe agro-ekosisteme. Dit was dus ook belangrik om die rykheid en diversiteit van mierspesies wat in kasjoe agro-ekosisteme voorkom, te bepaal. Resultate van putvalle het die diversiteit en rykheid van mierspesies wat in kasjoe agro-ekosisteme voorkom getoon: 'n totaal van 14001 miere wat tot ses subfamilies, 18 genera en 32 spesies behoort, is versamel. Hul rykheid het betekenisvol verskil tussen lokaliteite en oor seisoene. Malmiere het die meeste in putvalle voorgekom. Dit is 'n belangrike aspek wat aangespreek moet word in die benutting van *O. longinoda*, vir beheer van sapsuiende plae in kasjoe boorde aangesien die korrelasie tussen *O. longinoda* en malmiere se rykheid negatief is. Die effek van swamdoders as alternatief tot swaelpoeier, wat gebruik word vir poeieragtige meeldou (PMD) beheer, op *O. longinoda* was ook ondersoek. Geen betekenisvolle verskil is gevind in die effek wat die verskillende swamdoders gehad het op die aantal blaarneste en kolonisasie van *O. longinoda* paadjies nie. Om *O. longinoda* as 'n komponent van geïntegreerde bestuur van sapsuiende insekte in kasjoe te ontwikkel, is strategieë vir hul bewaring in die af-seisoen geëvalueer. Die gebruik van vis en hydramethylon (Amdro®) as lokaas het die aantal blaarneste en kolonisasie paadjies van *O. longinoda* laat toeneem in vergelyking met die kontrole gedurende die af-seisoen. Die toename was betekenisvol hoër wanneer vis en hydramethylon saam gebruik word. Hierdie behandeling kan dus gebruik word vir bewaring van *O. longinoda* gedurende die af-seisoen. Die gevolgtrekking kan dus gemaak word dat *O. longinoda* sap-suiende insekte effektief beheer en dat díe miere gedurende die af-seisoen effektief bewaar kan word deur gebruik te maak van afval soos visingewande. Swamdoders wat gebruik word vir PMD beheer het nie 'n nadelige effek op *O. longinoda* rykheid nie en kan dus geïntegreer word as 'n komponent van geïntegreerde plaagbestuur in kasjoe.

Sleutelwoorde: Afrika spin-mier, biobeheer, diversiteit, geïntegreerde plaagbeheer, kasjoe, spesie rykheid

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CHAPTER ONE

General introduction and literature review

1.1 General introduction

Cashew, *Anacardium occidentale* Linnaeus, (Sapindales: Anacardiaceae) is a resilient and fast-growing evergreen tropical tree (Ohler, 1979).It has a long history of cultivation in Central and South America, South-East Asia, India, Australia and tropical Central Africa (Johnson, 1973).It was introduced from Central and South America to different parts of the world in the 16th century (Mitchell & Mori, 1987). The crop was introduced by the Portuguese for afforestation and control of soil erosion along the coastal areas of Tanzania, Kenya, Mozambique and Nigeria (Woodroof, 1979). The crop is widely believed to have remained in the coastal areas mainly as a subsistence crop for local communities until it gained economic importance after the Second World War (Anonymous, 2009). The nutritious and edible kernel produced by this crop is highly valued and traded throughout the world and is therefore an important source of foreign exchange earning for all producing countries. Africa accounts for 33.4% of the world cashew producing area and 26.4% of the world cashew nut production (FAO, 2006).

Most of the regions where it is an economically important plant are between latitudes 15º South and 15º North (Ohler, 1979). In Tanzania, cashew is grown in diverse agro-ecological landscapes from 0 to 800m above sea level (Martin *et al.,* 1997). The crop is widely cultivated in the south, mainly the in coastal districts of Mtwara, Lindi and Ruvuma, which produce about 70% of the Tanzanian cashew crop (Mitchell, 2004). It is also grown to a lesser extent in the northern coastal belt, particularly along the Coast, Dar-es-Salaam and Tanga regions. The main production areas in the Coast region are at Bagamoyo, Kibaha and Mkuranga districts (Figure 1.1).

Cashew is susceptible to morethan 60 different insect species throughout its growth period. Insect pest damage intensity varies with location, variety and

management practice (Anonymous, 2009; Dwomoh *et al.,* 2008a). In Tanzania production of cashew nut has declined mainly due to sap-sucking pests, the mirid bugs *Helopeltis anacardii* Miller, and *H. schoutedeni* Reuter (Hemiptera: Miridae), and the coreid coconut bug *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) (Boma *et al.,* 1997; Martin *et al.,* 1997; Topper *et al.,* 1997). The crop is also affected by powdery mildew disease (PMD), *Oidium anacardii* Noack (Erysiphales: Deuteromycetes) (Martin *et al.,* 1997; Shomari & Kennedy, 1999). Sap-sucking pests are generally controlled chemically with lambda cyhalothrin (Karate) and sulphur dust is usually applied to control PMD (Anonymous, 2002).

1.2 Literature review

1.2.1 Status of cashew in Tanzania

Cashew is grown in Tanzania as an important export crop. It replaced coffee that dominated since independence in terms of foreign exchange earnings. Cashew nut is the main cash crop and the leading source of income for over 300,000 households, on 400,000 ha with 40 million trees in south eastern Tanzania (Anonymous, 2009). It is an important source of livelihood, food security and income for many smallholder farmers in Sub-Saharan Africa (SSA) and contributes 50-90% to their total farm income (USITC, 2007). It therefore contributes to rural livelihoods of over 5 million smallholders in SSA which are involved in its production, processing and marketing (USITC, 2007).The average smallholder cashew farmer cultivates approximately one to two hectares of cashew trees, often intercropped with food crops, mainly cassava, grain staple crops, pineapples and legumes notably pigeon peas (Sijaona, 2002).

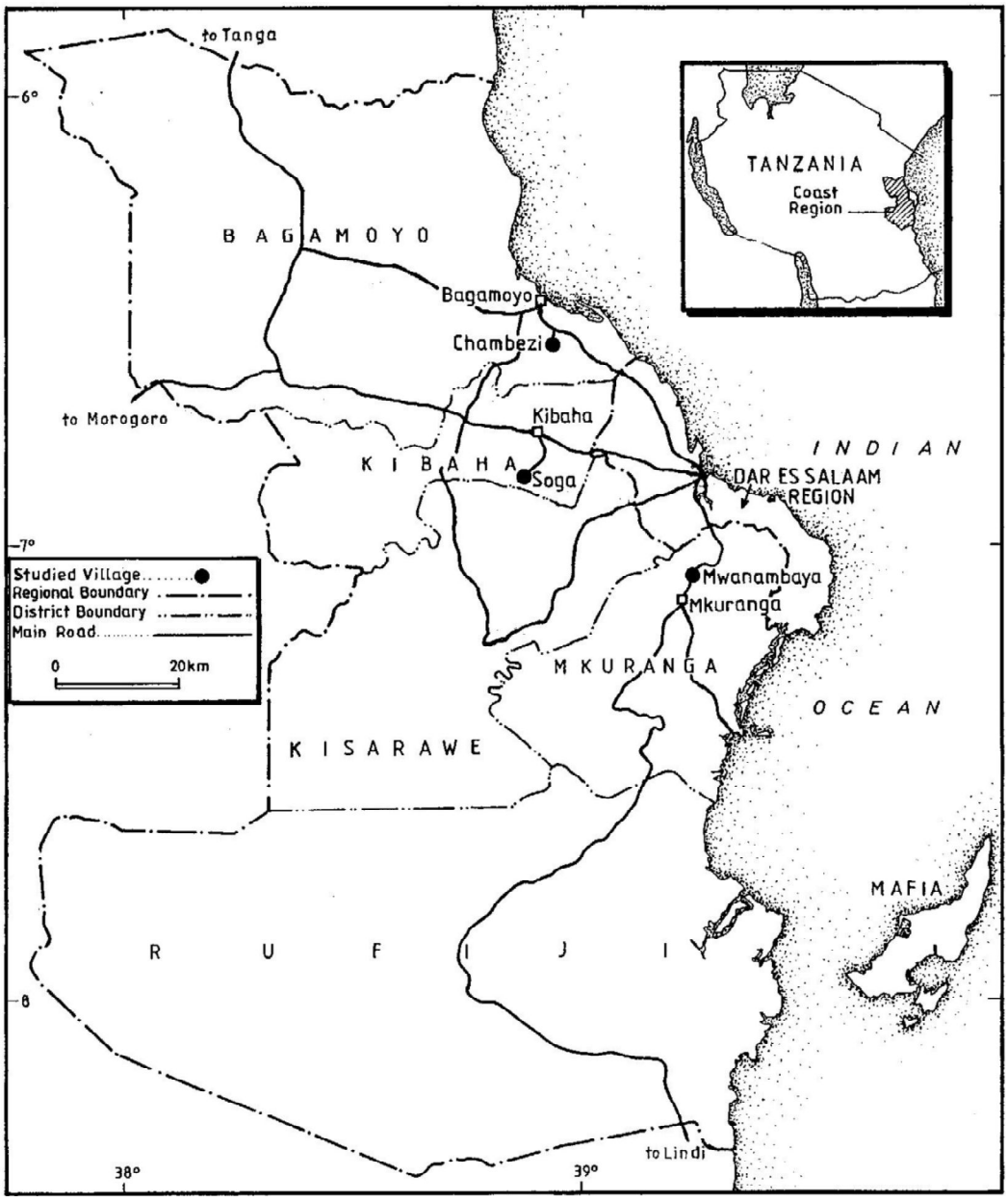


Figure 1.1 A map showing location of the study sites in Bagamoyo, Kibaha and Mkuranga districts, Coast region, Tanzania.

Most of the cashew trees in Tanzania were planted in the 1950's and 1960's, with a marked decline in planting since mid 1970's. However, new plantings started again in the early nineties and picked up in the late nineties (Topper *et al.,* 1997). The crop was also introduced in some non-traditional cashew growing areas such as Dodoma, Singida, Morogoro and Iringa (Anonymous, 2002). The massive expansion of cashew growing areas is probably due to the benefits from the crop and its ability to grow in poor soils and drought conditions. The crop tolerates a wide range of pH and salinity levels (Dedzoe *et al.*, 2001)).The ability to grow in harsh environments and to be intercropped with food crops makes it an ideal crop for small farmers in Tanzania (Mitchell, 2004) and SSA (USITC, 2007). It is the second major source of foreign exchange next to cocoa butter with exports worth $ 414 million (USITC, 2007).

1.2.2 Commercial uses of cashew

The edible kernel of cashew is a popular snack, but cashew is also used for other purposes. It also produces a pseudo fruit known as the cashew "apple" and cashew nut shell liquid (CNSL). The cashew apple is rich in vitamin C and is used in the production of juice and alcohol. CNSL is used for medicinal and industrial purposes, for example in brake linings of motor vehicles, paints, varnishes and laminated products (Bisanda, 1993). It is also used as a plywood adhesive and as a long-life, highly bioactive, antifouling coating for marine vessels (Akaranta *et al.,* 1996).The bark and leaves of the cashew are used in the treatment of gastro-intestinal disorders such as dysentery and diarrhoea (Pell, 2004). Resins obtained from the tree are of commercial importance in the book industry due to their adhesive properties. The waste biomass produced in cashew is used as a substitute to wood fuel by making charcoal through carbonization process (Das *et al.*, 2004). The cashew tree is also used in different parts of the world for reforestation, in preventing desertification and sometimes as a firebreak around forests. The tree canopy is dense, limiting grass cover under trees. The dead leaf litter is much less combustible than dry grasses and a fire spreads slowly under trees. Cashew

trees are also used to combat soil erosion and reclaim marginal land in Nigeria, Ivory Coast and Madagascar (Ohler, 1979).

1.2.3 Cashew production constraints

Cashew nut production in Tanzania was economically important after the Second World War, with 7,000 tonnes of raw nuts that were exported to India (Northwood & Kayumbo, 1970). About 10 years later, cashew production increased and in 1960 about 42,000 tonnes were exported. The reasons for this increase were good producer prices, on time payment of farmers, increase in acreage planted and improved cashew husbandry (Sijaona, 2002). There was, however, a huge decline in cashew nut production from 84,000 tonnes in 1974/75 to 16,400 tonnes in 1986/87 (Martin *et al.,* 1997). A similar trend was also noted in other African countries. Subsequently, the fortunes from cashew in Africa crashed from a global share of 70% in 1970 to 17% in 1990 (FAO, 2006). This tremendous decline in cashew nut production in SSA was attributed to a combination of factors which included socio-economic issues (low producer prices, insufficient marketing and villagisation), lack of high-performance yielding materials, losses caused by insect pests and diseases and poor agronomic practices such as overcrowding of trees (Martin *et al.,* 1997; FAO, 2006).

The resettlement policy of Tanzania in the mid 1970s resulted in the cashew groves been abandonedcausing a decline in cashew nut production (Martin *et al.,* 1997). The aim of moving people was to make it easier to provide services such as extension, mechanical cultivation and social infrastructure (i.e. schools, clinics and water supplies). Between 1970 and 1975, about 85% of the rural population was moved to registered (*ujamaa)* villages (Raikes, 1986).Communal production was highly encouraged in these villages, but it is not known how villagisation affected the cashew growing areas (Brown *et al.,* 1984). In the period from 1969 to 1977 inflation contributed to a decline in producer prices to about half the value before this period from being 70% of the export price in 1972/73, to 24% in 1980/81 (Brown *et al.*, 1984; Anonymous, 1992). In 2006, cashew accounted for 10% of the total value of

foreign exchange earning in Tanzania and brought in $ 54.1 million (Anonymous, 2009). Currently, increased production and productivity is seriously constrained by a diverse range of diseases and insect pests. The powdery mildew disease (PMD), *Oidium anacardii* Noack (Erysiphales: Deuteromycetes) has been singled out as a major disease in Tanzanian cashew plantations since the 1970's (Martin *et al.,* 1997; Shomari & Kennedy, 1999; Sijaona *et al.,* 2001). Besides susceptibility to different diseases, production of cashew nut has declined in Tanzania mainly due to a combination of factors including insect pests, especially mirid bugs *H. anacardii* and *H. schoutedeni*, and the coreid coconut bug *P. wayi* (Boma *et al.,* 1997; Martin *et al.,* 1997; Topper *et al.,* 1997).

1.2.4 Management of sap-sucking insect pests

The main management strategy largely relies on calendar-based applications of insecticides, namely lambda cyhalothrin (Karate 5EC) and trifloxistrobine (Flint 50WG), which are applied during flowering (Anonymous, 2002).Although it can reduce sap-sucking pest damage significantly, disadvantages, apart from the cost of synthetic chemical insecticides can also be numerous. These include a reduction in natural enemies and potential pollinators, increased insect resistance to insecticides, environmental pollution and negative effects on the health of the farmers, who often lack the necessary protective gear (Hill, 2008). A need therefore exists to develop an ecologically sustainable and economically viable integrated pest management (IPM) strategy for the key pests to ensure income generation and improvement of the livelihood of the cashew farmers in Tanzania. Biocontrol using the predatory African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) provides a good control of sap-sucking pests on cashew. The AWAhas been promoted for the control of mirid and coreid bugs on coconuts in East Africa (Varela, 1992; Seguni, 1997). Elsewhere, in West Africa, AWA has also been found to be effective in protecting cashew pests in Ghana (Dwomoh *et al.,* 2009) and mango pests in Benin (Van Mele *et al.,* 2007). As a prerequisite for the inclusion of AWA as a component of a cashew IPM system in Tanzania,

more information is needed on the relationships between AWA and the key cashew pests, *H. anacardii*, *H. schoutedeni* and *P. wayi*. Although AWA wassuccessfully used for biocontrol in Ghanaian cashew cropping systems (Dwomoh *et al.,* 2009), it has not been previously investigated in Tanzania.

1.2.5 Growth characteristics of cashew

Cashew is a perennial tree with an extensive root system which is supported by a deep tap root. It grows for about 25-30 years producing an economic yield from the early stages of its growth (Mitchell & Mori, 1987). The tree grows well even in sandy soils with low fertility (Ohler, 1979) and flourishes well in the hot, dry tropics around sea level. Cashew is therefore popularly known as a "poor man's crop" and is planted by many smallholders in SSA countries including Tanzania. Cashew does, however, respond well to good soil conditions (Dedzoe *et al.,* 2001; Aikpokpodion *et al.,* 2009).Soil fertility and water availability are the major factors influencing the tree performance (Ohler, 1979). Trees can reach a height of 40-50 feet under favourable conditions, but in poor soils and marginal location in which it is usually found, cashew tree is much smaller (Rosengarten, 1984). Therefore, the cashews' benefit for the smallholders is that it can still produce a nut, although low in quality, under poor soil and dry conditions. Cashew trees are planted 10-15m apart for optimal production. The tree requires good drainage, low elevation up to 1000 m above sea level, rainfall of about 1000-2000mm per annum and a pronounced dry season of three to four months (Wait & Jamieson, 1986).

The crop can thrive at temperatures of up to 40ºC but does not tolerate low temperatures as it interferes with the reproductive cycle of the tree and lead to delayed flowering and poor yields (Ohler, 1979; Peng *et al.,* 2008). In dry seasons, cashew is vulnerable to low humidity.It is also vulnerable to PMD attack on tender leaves, flowers, young nuts and fruits at a humidity of about 85% (Waller *et al.,* 1992).

1.2.6 Insect pest and disease problems of cashew in Tanzania

Insect pests and diseases are important constraints to cashew nut production in SSA, particularly in Tanzania. PMD is considered as the major constraint in Tanzanian cashew nut production and is associated with a fungus, *O. anacardii* (Intini & Sijaona, 1983; Waller *et al.,* 1992). Yield losses caused by PMD vary between 70 and 100% depending on phyto-sanitary measures (Sijaona & Shomari, 1987; Shomari, 1996). A range of control measures against PMD have been developed and disseminated to the farming community (Sijaona & Mansfield, 2001). There are also minor diseases that have been found to affect cashew production in Tanzania, namely anthracnose fungal disease (*Colletrotrichum* sp.), dieback (*Phomopsis anacardii* Early & Punith) and leaf and nut blight (*Cryptosporiopsis* sp.) (Topper *et al.,* 2003).

The most important sap-sucking insect pests in Tanzanian cashew farming are the mirid bugs *H. anacardii* and *H. schoutedeni* and the coreid bug *P. wayi* (Boma *et al.,* 1997; Martin *et al.,* 1997; Topper *et al.,* 1997). Studies have shown that damage caused by these sap-sucking pests can vary between years and localities (Boma *et al.,* 1997; Topper *et al.,* 1997). Leaves and stalks of the vegetative shoots and the flowering shoots are attacked by *Helopeltis* spp. (Bohlen, 1978; Stathers, unpublished).The site of attack is marked by angular lesions due to injection of the very toxic saliva into the stalks of the tender shoots and in connection with fungi may cause dieback of the shoots (Bohlen, 1978).

Dieback is characterized by withering of the shoot, generally starting from the tips and later advancing downwards to the main floral shoots and leaves (Stathers, unpublished). The green colour of healthy shoots progressively turns black/brown followed by withering and necrosis, and as a consequence, new shoot and fruit formation are affected (Topper *et al.,* 1997). In addition, damage in a young tree is more profound than that in an old tree and may eventually result in it being malformed or stunted (Stathers, unpublished).

Furthermore, in case of serious infestation the tree may appear as if scorched by fire.

Developing fruits are attacked by older nymphs and adults of *P. wayi* causing pockmarks (Bohlen, 1978; Stathers, unpublished).If the nuts damaged by *P. wayi* are very young, the nuts shrivel and die on the tree, frequently falling to the ground. However, this is not the case for older nuts, which instead are reduced in size and show signs of damage in the fruit wall (Stathers, unpublished). The kernels are also affected showing spots, which may lower their market value (Anonymous, 2009). *Pseudotheraptus wayi* is less important in cashew than the *Helopeltis* spp. Based on injuriousness.

An increase in *Helopeltis* spp. and *P. wayi* populations on cashew coincides with the main growing period of the tree crop, which begins shortly after the end of the rainy season in July or August (Seguni, 1997). This was also reported in the northern coastal belt where *Helopeltis* spp. and *P. wayi* reach their population peaks in July and August (Bohlen, 1978).Not many insect pests are therefore present on trees during the cashew off-season. The crop is also affected by other minor insect pests. These include the stem borer, *Mecocorynus loripes* Chevr (Coleoptera: Curculionidae); mealybug, *Pseudococcus longispinus* Zimmerman (Hemiptera: Pseudococcidae) and the thrip, *Selenothripis rubrocinctus* Giant (Thysanoptera: Thripidae) (Boma *et al.,* 1997; Martin *et al.,* 1997).

1.2.7 Biology of major cashew insect pests

1.2.7.1 *Helopeltis anacardii*

Helopeltis anacardii lay their eggs in the soft tissue near the tips of flowering or vegetative shoots. Its life cycle consists of five nymphal instars; both nymphs and adults have a knocked, hair-like projection striking upward from the thorax (Hill, 2008). Males are smaller (4.5mm) than females (6mm) and there is no clear distinction between last instarnymphs and adults. Young nymphs feed on the undersides of young leaves and older nymphs and adults

feed on young shoots and developing fruits. High nymphal numbers (10 or more per tree in case of a tree 1-2 years old), kill the terminal buds before they are able to open. Subsequent growth, if it occurs, initiates from numerous lateral axillary buds, and this gives rise to a "witches" broom type of growth and general malformation of the tree (Swaine, 1959; Hill, 2008). The total development life cycle, including the twelve day pre-oviposition period, takes about 48 days (Hill, 2008).

1.2.7.2 *Helopeltis schoutedeni*

Helopeltis schoutedeni is known to produce more viable eggs when fed on fruits or flushing shoots than when fed on hardened stems (Hill, 2008; Dwomoh *et al.,* 2008b). Eggs are laid in plant tissue singly or in small groups, often with filaments exposed (Ambika & Abraham, 1979; Dwomoh *et al.,* 2008c). Most eggs are laid in the leaf stalks or main veinsand hatch after about two weeks. As with *H. anacardii*, the life cycle of *H. schoutedeni* consists of five nymphal instars with a pin-like projection sticking up from the thorax of all nymphal instars, except the first instar. Adults are 7-10 mm long. The total nymphal period is about three weeks and the whole life cycle from egg to adult takes about 24 days (Dwomoh *et al.,* 2008c). All the nymphal stages develop faster and the rate of survival is higher when fed on fruits compared to feeding on flushing shoots or panicles (Dwomoh *et al.,* 2008b).

1.2.7.3 *Pseudotheraptus wayi*

The life cycle of *P. wayi* has been studied under greenhouse conditions (Wheatley, 1961; Mainusch, 1991). The mean generation time differs between dry season and cold season. As a result eight overlapping generations can be expected per year (Mainusch, 1991). The eggs are laid singly. Oviposition commences about three weeks after the first mating and eggs hatch 9-13 days later (Varela, 1992). *Pseudotheraptus wayi* has also five nymphal instars but its complete life cycle is much longer than that of *Helopeltis* spp., namely between two and five months.

1.2.8 Control strategies

1.2.8.1 Cultural control

Cultural methods are regular farm operations that do not require the use of specialized equipment or extra skills, designed to destroy pests or to prevent them from causing economic damage (Hill, 2008). A number of cultural controls against sap-sucking pests and PMD was identified and recommended to Tanzanian cashew growers which include pruning of water shoots before the onset of flowering and use of PMD tolerant yielding materials to control PMD (Martin *et al.,* 1997). Pruning is encouraged so as to remove dead twigs, unwanted and overlapping branches on the cashew tree canopy before flowering. This may help to build a good canopy and facilitate fruiting. It is imperative to note that most of the cultural methods do not give maximum pest protection. There is a need therefore to use cultural control methods simultaneously with other integrated pest management strategies (Hill, 2008).

1.2.8.2 Chemical control

Helopeltis spp. and *P .wayi* are generally controlled chemically from July to December (Hill, 2008). The most frequently used insecticides are lambda cyhalothrin (Karate 5EC) and trifloxistrobine (Flint 50WG) (Anonymous, 2002). When insecticides are applied to control arthropods, beneficial organisms are disrupted and natural enemies are no longer abundant (Hill, 2008).

Application of sulphur dust is a major chemical control strategy against PMD in Tanzania (Martin *et al.,* 1997; Nathaniels *et al.,* 2003). It is widely applied and it can be ascribed to its low cost compared to water-based fungicides and the fact that it does not require water for application (Martin *et al.,* 1997). The economic yield which warrants for PMD control was estimated to range from 4-6kg of nuts per tree depending on the type, price of fungicide and the existing local market price of cashew nuts (Kasuga *et al.,* 1997). However, adoption of the recommended IPM components by cashew farmers is low

(Nathaniels *et al.,* 2003). Farmers do not always adhere to the recommended dosage rates when pesticides are applied. For example 44% of cashew farmers in southern Tanzania apply more than double the recommended rate of sulphur dust (Nathaniels *et al.,* 2003). Sulphur dust is, however, applied using solo motorized mist blowers or dusters to large trees which also contribute to the cost of this control strategy (Waller *et al.,* 1992). Despite its effectiveness, sulphur dust has negative ecological impacts also. These are associated with repetitive applications of relatively large quantities of sulphur because it is essentially repetitive in nature. Earlier studies on the environmental effect of sulphur have shown a decrease in pH of some acidic soil types in southern Tanzania, which in turn boosts the rate of leaching of valuable nutrients, thereby affecting the productivity of cashew and its companion food crops (Majule *et al.,* 1997; Ngatunga *et al.,* 2003). In addition, the practice of controlling PMD by sulphur dusting has unfortunately resulted in more insect feeding damage, because of the increased availability of shoots attractive to insect pests (Martin *et al.,* 1997; Topper *et al.,* 1997). As a result, a number of water-based organic fungicides have been investigated as alternatives to sulphur dust for PMD as well as leaf and nut blight diseases on cashew in Tanzania (Topper *et al.,* 1997, Anonymous, 2009). The most frequently used fungicides as alternatives to sulphur dust are triadimenol (Bayfidan 250 EC) and triadimefon (Bayleton 25 WP) (Anonymous, 2009).

1.2.8.3 Use of *Oecophylla* as biocontrol agent

Oecophylla species are considered to be good candidates for biological control agents because they are vigilant and territorial predators of living creatures in their arboreal domain (Hölldobler & Wilson, 1990). The ability to modify their environment to suit their needs by building nests from the living foliage of numerous host plant species is advantageous and allows exploitation of a wide range of habitats (Hölldobler, 1983). The efficacy of ants as predators in general is enhanced by factors such as long term colony survival, large populations of workers and non-specificity towards the life stage of their prey (Bellows & Fisher, 1999). The genus *Oecophylla* has two

species which are geographically separated but they show significant similarities in ecology (Vanderplank, 1960; Lokkers, 1986). One of the earliest accounts of biocontrol was with the use of the weaver ant, *O. smaragdina* Fabricius, (Hymenoptera: Formicidae) to control citrus pests in China (Chen, 1962; Needham, 1986; Huang & Yang, 1987). Since then, the use of this natural enemy for biocontrol has increased tremendously in different parts of the world. Up to 2004, *O. smaragdina* was known to control over 50 species of insect pests on many tropical tree crops and forest trees (Way & Khoo, 1992; Peng *et al.,* 2004). In the Solomon Islands, the presence of *O. smaragdina* reduced damage by *Amblypelta cocophaga* (Lever Hemiptera: Coreidae) in coconut plantations (O'Connor, 1950).

Recent studies in Australia have demonstrated the successful use of *O. smaragdina* in controlling a number of insect pests of mango such as the red-banded thrip, *S. Rubrocinctus* (Peng & Christian, 2004), the mango leafhopper, *Idioscopus nitidulus* Walker, (Hemiptera: Cicadellidae) (Peng & Christian, 2005), the fruit spotting bug, *Amblypelta lutescens* Distant (Hemiptera: Coreidae) (Peng *et al.,* 2005), the fruit fly, *Bactrocera jarvisi* Tryon (Diptera: Tephritidae) (Peng & Christian, 2006), and the mango seed weevil, *Sternochetus mangiferae* Fabricius (Coleoptera: Curculionidae) (Peng & Christian, 2007). This ant species was also found to control pests of African mahoganies in Australia, namely *Gymnoscelis* spp. and *A. lutescens* (Peng *et al.,* 2010) and the shoot borer, *Hypsipyla robusta* Moore (Lepidoptera: Pyralidae) (Peng *et al.,* 2011).

AWA has been used to control *P. wayi* in coconut orchards in East Africa (Vanderplank, 1960; Varela, 1992; Seguni, 1997) and sap-sucking pests of cashew and fruit flies in mango in West Africa (Dwomoh *et al.,* 2009; Van Mele *et al.,* 2007).

1.2.9 Distribution and social behaviour of *Oecophylla* spp.

1.2.9.1 Distribution of *Oecophylla* spp.

The genus *Oecophylla,*commonlyknown also as the weaver ant, consists of two species, namely *O. longinoda* and *O. smaragdina*.The distribution of these species depends on the vegetation, physical factors such as temperature and rainfall (directly or indirectly) and the abundance of competitor ant species such as *P. megacephala* and *A. custodiens* (Lokkers, 1986). *Oecophylla* is an arboreal genus that requires thick vegetation usually with an interconnected canopy to provide both nesting sites and foraging areas (Taylor & Adedoyin, 1978). The AWA is widely distributed in SSA, particularly in the equatorial tropical forests (Hölldobler & Wilson, 1990). In East Africa, AWA is most abundant in the coastal forests of Kenya and Tanzania. More than 80 species of shrubs, cultivated and wild trees are used by AWA as host plants (Varela, 1992). This species is also found in West African countries such as Ghana and Benin. *Oecophylla smaragdina* is distributed throughout tropical Asia and Australia (Lokkers, 1986).

The biology of AWA and *O. Smaragdina* is similar although their geographical distribution is very distinct (Way & Khoo, 1992). Compared to the literature on *O. smaragdina*, not much information is available on AWA with most dating back to 1950-1960.Because both species have similar biological and ecological characteristics, information on *O. smaragdina* is used to describe the biology of both *Oecophylla* species.

1.2.9.2 Social behaviour of *Oecophylla* spp.

The genus *Oecophylla* is very diverse in colour, ranging from dark brown to pale yellow, with many overlapping colour forms. Collingwood (1977) reported dark brown and yellow forms to produce reproductive castes at different times of the year and to occupy different habitats. Differences in the colour of workers are associated with their food type (Vanderplank, 1960). For example, weaver ants fed on honeydew were light yellow in colour and less

aggressive, while weaver ants fed on protein prey were deep yellow and more aggressive (Vanderplank, 1960).

There are two types of workers, major and minor. The major workers are responsible for nest building, foraging and defending the colony (Hölldobler & Wilson, 1983a; Varela, 1992). They are also responsible for feeding and attending to the queen and sometimes share in the care of the old larvae with the minor workers. The core function of the minor workers is to take care of the brood, which includes the eggs and young larvae but they also care for the adult sexual forms.

1.2.9.3 Colonies foundation and nest building by *Oecophylla* spp.

The weaver ants are very aggressive and their main social unit is the colony. They are known to establish large polydomous colonies housed in many nests constructed in the crowns of many trees for AWA (Hölldobler, 1979) and 44 trees for *O. smaragdina* (Hölldobler, 1983). A colony may be founded by a single mated queen (Hölldobler & Wilson, 1983b) or multiple queens (Peeters & Andersen, 1989). As explored by Hölldobler and Wilson (1983b) the mated queen finds a sheltered spot to raise her first brood and her resulting worker offspring then care for the next brood.The queen produces fertile eggs that are soon distributed with young larvae by the workers to other nests (Peng *et al.,* 1998). When workers emerge, they forage, which ends the stage when brood production is directly dependent on the trophic eggs (non-viable eggs produced specifically to feed the brood) (Hölldobler & Wilson, 1983b). In addition, the individual colonies are mutually antagonistic and are demarcated by no-ant boundaries where posturing but rarely fighting may occur (Way, 1954a; Hölldobler & Wilson, 1983a). The AWA colonies may cover up to 1600 m^2, comprising of approximately a million workers and brood (Lokkers, 1986). The life of a colony might exceed five years if not destroyed by competitor ants (Vanderplank, 1960; Way & Khoo, 1992).

The process of nest building is highly organised and has been widely described by several researchers (Way, 1954a; Hölldobler & Wilson, 1983a).

It involves both the preparation of the substrate and the gluing of the substrate together with larval silk (Way, 1954a; Hölldobler& Wilson, 1990). The major workers bind the leaves of host trees by moving the silk producing larvae from one leaf to another and back until the nest is constructed (Hölldobler & Wilson, 1990), rendering them the name 'weaver ant'. Leaves which are in close proximity can be drawn together through the actions of multiple individuals aligning themselves along leaf perimeters and pulling the edges together, or via the formation of a living chain, that bridge gaps and are shortened to draw leaves together (Hölldobler & Wilson, 1990).

Both male and female final instar larvae are used for nest constructions, nevertheless male larvae are used less by the workers and contribute considerably less silk to nest construction (Wilson & Hölldobler, 1980; Varela, 1992). The leaf nests of *Oecophylla* spp. varies in size and in most cases; larger nests contain brood and reproductive individuals while smaller nests without reproductive individuals are known as 'pavilions' (Blüthgen & Fiedler, 2002). Similarly, small shelters of only a few leaves are sometimes built in the same way over the cluster of Homoptera which are being tended (Way, 1954a; Van Mele & Cuc, 2007). Preference of the tree parts to be selected for nest building varies from season to season and appears to be mainly depending on both sunlight and wind direction (Way, 1954a).

1.2.9.4 Association between AWA and Homoptera

A study on the association of AWA and various Homoptera has been conducted on clove trees *Caryophyllus aromaticus* Linnaeus (Myrtales: Myrtaceae) in Zanzibar (Way, 1954b). According to Way (1954b), AWA has been found colonising more than 89 species of trees and shrubs, and attending many different species of Homoptera that produce honeydew. AWA also deters insect pests on trees through their close association with some homopterans (Seguni *et al.,* 1997; Way, 1963). On cashew AWA is commonly associated with homopterans such as the groundnut leafhopper *Hilda patruelis* Stal (Homoptera: Tettigometridae) and the scale insect *Coccus*

hesperidum Linnaeus (Homoptera: Coccidae), which feed on the flushing leaves, panicles and nuts (Bohlen, 1978; Stathers, unpublished).

Many homopteran insects are ant tended. These mutualistic relationships enable AWA to benefit from feeding on the honeydew, whilst the homopterans receive protection against predators due to the aggressive behaviour of the ants (Way, 1963). The AWA often takes care of Homoptera in several ways, namely by protecting them from various enemies (though often accidentally), by removing honeydew and fungal contaminations, and by offering shelter (Way, 1963). However, the choice of host plants by ant species depends mainly on two factors, namely the ease of weaving the leaves into nests and the ability of the host plant to support suitable Homoptera species from which the weaver ants can obtain honeydew for food (Way, 1963). Homopterans are occasionally a source of solid protein when they are killed or collected after they have died from other causes (Way, 1963). Ants also forage for plant nectar on a diverse number of plant species (Blüthgen *et al.,* 2004).

The mutual association of AWA and homopterans increases the damage caused to the host plant (Way, 1954b). Population levels of *H. patruelis* occasionally reach extreme levels in cashew trees colonized by the common pugnacious ant (CPA), *Anoplolepis custodiens* Smith (Hymenoptera (Formicidae). Leaves and fruit are then covered by black sooty mould that grows on the excess honeydew deposited by *H. patruelis* (Stathers, unpublished). Farmers then complained because of their crops being affectedby these black layers (Stathers, unpublished). Outbreaks of scales and mealybugs caused by prolific stimulation by *A. custodiens* in other fruit trees have been reported previously (Samways *et al.,* 1982). However, such population increase of homopterans has not been reported in association with AWA. This species are known to cut off homopterans when food requirements of the colony have been met resulting in no excess honeydew or ensuing sooty mould growth (Way, 1954b). For example, the level of the *Saissetia zanzibarensis* Williams (Homoptera: Coccidae) population in an AWA colony depended on the number of ants. Scales in excess were killed or, if not

enough were present, their numbers increased to a level which satisfied the food requirements of the ant colony (Way, 1954b). Plants are also known to produce ant-repellent substances during the peak of flowering (Junker & Blüthgen, 2008; Willmer *et al.,* 2009). This strategy helps to ensure pollination without losing the protection of the ants. In Singapore, the presence of *O. smaragdina* was associated with an increase in a reproductive success of tropical shrub *Melastomia malabathricum* Linnaeus (Myrtales: Melastomataceae) by deterring less effective pollinators (Gonzálvez *et al.,* 2013).

1.2.9.5 Competitors of *Oecophylla* spp.

Ants may fight with one another during competition (Andersen & Patel, 1994; Gordon & Kulig, 1996) in which the fitness of one individual is lowered by the presence of another (Parr & Gibb, 2009). Competition between members of the same species is referred to as intraspecific competition and between individuals of different species is referred to as interspecific competition. Among the two types of competition, interspecific competition has been considered as the hallmark of ant ecology, which is a key mechanism in structuring ant assemblages (Hölldobler & Wilson, 1990).

Among other things, interspecific competition play substantialroles in ecology, namely spatial ant mosaics (Majer *et al.,* 1994), territoriality (Andersen & Patel, 1994), antagonistic behaviour (Andersen *et al.,* 1991) and spatial dispersion of colonies (Parr *et al.,* 2005). However, the outcome of ant competition may result in relocation of a colony, loss of brood, the inability to exploit a food resource or sometimes the loss of the entire colony (Hölldobler & Wilson, 1990).

Thebig-headed ant (BHA), *Pheidole megacephala* Fabricius (Hymenoptera: Formicidae) and CPA areknown to compete with AWA in different agro-ecosystems (Vanderplank, 1960; Varela, 1992; Seguni, 1997; Sporleder & Rapp, 1998). Among these two competitors, *P. megacephala* is considered to be the most efficient and most widely distributed competitor of AWA (Perfecto

& Castiñeiras, 1998). When AWA colonies face a strong competition, they defend their territory resulting in reduced effectiveness to control pests. The nesting habits of CPAand BHA are more or less the same. CPA is mostly confined to sandy soils with a relatively sparse ground vegetation and seems to be an exclusively ground nesting ant species (Varela, 1992). The nests of BHA are made at the base of the trunks under the bark and they sometimes also nest in spathes in the crown, which may be connected to the ground nests by runways (Varela, 1992; Seguni, 1997). Ants from the genus *Crematogaster* has also been considered as minor competitors of AWA in coconuts (Vanderplank, 1960). However, this does not seem to be the case in cashew, since workers of AWA have been observed killing *Crematogaster* spp. and to carry the dead back to their nests. Usually, strength and size of the two colonies determine whether one destroys the other and the two were rarely found to coexist together in Tanzanian cashew farming (Stathers, unpublished).

BHA is the main competitor of AWA in Tanzanian cashew farming (Stathers, unpublished). Despite the tiny size of this ant, they are able to catch and rarely kill individuals of AWA that venture to the ground (Stathers, unpublished). In addition, mutual exclusion was also observed when the two species coexist; AWA can be seen foraging on one side of the trunk and BHA on the other side. In some cases, AWA can also be found using creepers or the prop posts used to lift up the lower branches of trees, as safe routes to the ground (Vanderplank, 1960). The presence of ground vegetation has also been considered as a key strategy which enables AWA to coexist with *P. megacephala* in Tanzanian citrus farming (Seguni *et al.,* 2011).

1.2.10 Enhancement and conservation of *Oecophylla* spp.

1.2.10.1 Enhancement of *Oecophylla* spp.

A number of strategies have been developed to enhance beneficial ant species to flourish in agro-ecosystems in different parts of the world. The major strategies include suppression of inimical competing ants (Majer, 1986;

Wayi & Khoo, 1992), placement of rope connections or bridges (Van Mele & Cuc, 2007) and modification of the vegetation, which will in turn favour the beneficial ant and its competitive ability (Seguni *et al.,* 2011). Various attempts have been made to control BHA, the most important competitor of AWA with insecticides in Tanzania (Oswald, 1991) and in the Solomon Islands (Bigger, 1984). However, conventional use of insecticides is not ecologically sustainable due to its negative impacts on natural enemies, pollinators and environment. Instead, Oswald and Rashid (1992) achieved effective protection using hydramethylon ant bait (Amdro®). It has initially been developed to control the fire ant *Solenopsis invicta* Buren (Hymenoptera: Formicidae) in the United States of America (Harlan *et al.,* 1981). Hydramethylon ant bait has since been successfully used to control BHA in coconut plantations in Zanzibar (Zerhusen & Rashid, 1992), Tanzania (Varela, 1992; Seguni 1997) and in pineapple plantations in Hawaii (Su *et al.,* 1980).

Placement of rope connections with bamboo sticks or manila thread has been proposed as mechanisms for ensuring equal distribution of AWA between trees (Van Mele & Cuc, 2007). Connections are usually made when trees are young and their branches do not touch each other.Connections between trees with colonies of different ant species will, however, contribute to fighting between two colonies. It has been observed that battle between colonies endanger the life of ants and the large amounts of formic acid released by the ants during the fight sometimes causes dying of a few twigs (Van Mele & Cuc, 2007). The bite of worker ants on human skin and spray formic acid on the wound results in intense discomfort (Vanderplank, 1960). In East Africa, the painful bite earned these ants a reputation and is called 'maji ya moto'in Kiswahili, meaning hot water ant (Vanderplank, 1960). AWA nests transfer is also considered as the enhancement method in tree crops. AWA nests are usually collected early in the morning when most ants are still in the nests and are less aggressive (Varela, 1992; Seguni, 1997). Nests from the same colony should be kept together to avoid competition. AWA nests can be

transferred from citrus and coconut trees to cashew trees, placed in paper bags (Stathers, unpublished). Before introduction of AWA to a new host tree, the AWA nests should be partially opened to check their composition (Varela, 1992).

1.2.10.2 Conservation of *Oecophylla* spp.

Vegetation plays an important role in the distribution and conservation of ant species in a community (Way & Khoo, 1992). *Oecophylla* ants forage both on the ground and in trees and shrubs, attacking most insects they encounter (Way, 1954a). Diversity in vegetation, by intercropping and maintenance of ground vegetation was found by Way and Khoo (1992) and Seguni *et al.* (2011) to benefit *Oecophylla* spp. by increasing their food sources and nesting sites.

Being a generalist, the food sources of AWA can be classified into two main groups, namely protein and sugar, but they prefer protein over sugar (Vanderplank, 1960; Van Mele & Cuc, 2007). Both food sources appear to be essential for the survival and reproduction of the colony (Vanderplank, 1960). The degree of dependence of the ants on honeydew varies according to species (Way, 1963). Supplementing the diet of AWA with dried fish during the food scarce season is also one of the methods developed for conservation of *Oecophylla* species (Van Mele & Cu, 2007). In Malaysia, direct provision of food has been observed to augment weaver ant populations in a mahogany plantation (Lim, 2007). In addition, indirect provision of food has also been proposed through mixed planting of alternative host plant species with the main crop (Way & Khoo, 1991; Peng *et al.,* 1997; Van Mele & van Lanteren, 2002).

1.2.11 Abundance and diversity of ant species

Social insects often constitute more than half of the insect biomass in many terrestrial habitats (Wilson, 1990) and ants in particular are one of the most well represented groups (Hölldobler & Wilson, 1990). Previous studies

focused on the various ecological roles of ants in terrestrial ecosystems (Wilson, 1990; Gotwald, 1995). The key ecological roles played by ants are nutrient cycling, seed dispersal and regulating populations of other insects (Hölldobler & Wilson, 1990; Folgarait, 1998).Their effects are remarkable when they reach extremely highly populations. Ant populations are usually relatively stable between seasons and years. Their abundance and stability make ants one of the most crucial groups of insects in ecosystems (Wang *et al.,* 2000).

1.3 Hypotheses of the study

(i) The abundance of AWA varies significantly between cashew seasons.

(ii) Colonization of cashew by AWA has a significant impact on damage by the target pests.

(iii) There is significant interaction between AWA and dominant ant species such as BHA and CPA occurring on the cashew.

(iv) Use of the potential alternatives to sulphur dust for PMD management has significant detrimental effects on AWA.

(v) Provision of fish-based and hydramethylon ant baits can contribute to conservation of AWA.

(vi) Abundance and diversity of ant species differs significantly between cashew agro-ecosystems.

1.4 Justification of the study

The efficacy of AWA in the management of major pests in cashew has not been evaluated in Tanzanian cashew farming systems. The effect of interactions of AWA with other dominant ant species such as BHA and CPA is also unknown in the cashew growing areas in Tanzania. Furthermore, the abundance and diversity of ant species occurring in cashew agro-ecosystems and the effect of alternative fungicides to sulphur dust used for powdery mildew disease (PMD) on AWA has not been investigated.

The general aimof the study was to evaluate the efficacy of AWA in the management of *Helopeltis* spp. and *P. wayi*, the major pests of cashew in Tanzania.

The specific objectives of this study were addressed under the following topics which are addressed in separate chapters of the thesis:

(i) Effect of seasonality on abundance of AWA in cashew crops in Tanzania.
(ii) Efficacy of AWA in the control of *Helopeltis* spp. and *P. wayi* in cashew crops in Tanzania.
(iii) Interaction between AWA and dominant ant species *P. megacephala* and *A. custodiens* in cashew agro-ecosystems.
(iv) Effect of fungicides used for powdery mildew disease management on AWA, a biocontrol agent against sap-sucking pests in cashew agro-ecosystems.
(v) Efficacy of fish and hydramethylon based ant-baits for conservation of AWA during cashew off-seasons.
(vi) Abundance and diversity of ant species in cashew agro-ecosystems.

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CHAPTER TWO

Effect of seasonality on abundance of African weaver ant *Oecophylla longinoda* (Hymenoptera: Formicidae) in cashew crops in Tanzania

2.1 Abstract

The seasonality of the African weaver ant (AWA), *Oecophylla longinoda* Latreille, abundance was determined in the cashew fields at Bagamoyo and Kibaha districts in the Coast region of Tanzania. Twenty cashew trees colonized by AWA were randomly selected per site and its abundance was monitored during cashew on-seasons and off-seasons in 2011 and 2012. Results showed that abundance of AWA, expressed as mean numbers of leaf nests per tree and colonization of trails on main braches varied significantly between cashew on-seasons and off-seasons. The mean numbers of leaf nests per tree in cashew on-season and off-season varied between 8.3 and 5.0 and between 7.5 and 4.8 at Bagamoyo and Kibaha, respectively, in 2011. Similarly, in 2012 it varied between 9.5 and 5.6 and between 8.6 and 5.3 at Bagamoyo and Kibaha, respectively.The mean percentage AWA colonization of trailsin cashew on-seasons and off-seasons varied between 72.5 and 54.2% and between 73.3 and 50.9% in 2011and 2012, it also varied between 74.3 and 57.0% and between 72.6 and 54.9% at Bagamoyo and Kibaha, respectively. The abundance of AWAvaries significantly between cashew seasons at the differentsites in the Coast region of Tanzania. High numbers of AWA leaf nests per tree and strong AWA colonization of trails were recorded during cashew on-seasons compared to off-seasons.

2.2 Introduction

Ants are more abundant and ubiquitous nearly in all types of terrestrial habitats, especially in the tropics (Kaspari, 2000; Fisher, 2010). They are considered as useful tools for biodiversity evaluation and monitoring due to a number of aspects. These include permanent nests, quick response to environmental changes and relative ease of sampling (Kaspari & Majer, 2000; Bestelmeyer *et al.,* 2000; Underwood & Fisher, 2006). Ants also play key roles in ecological processes such as nutrient cycling, energy turnover, pollination, seed dispersal and regulating populations of other insects (Hölldobler & Wilson, 1990; Andersen & Majer, 1991; Gomezi & Zamora, 1992).

Ants are used as indicators of exposure to environmental stressors (Whitford, 1999; Wang *et al.,* 2000). Their distributions are determined by seasonal temperatures and rainfall patterns (Lindsey & Skinner, 2001; El Keroumi *et al*., 2012). Higher abundance and richness values of ants were recorded during the dry season in the Moroccan Argan forest (El Keroumi *et al.,* 2012). Inthe semi-arid Karoo of South Africa, ant abundance and diversity were higher during summer than in winter (Lindsey & Skinner, 2001). They also found that at species level, the common pugnacious ant (CPA), *Anoplolepis custodiens* Smith (Hymenoptera: Formicidae) was the most abundant species during summer and *Monomorium albopilosum* Emery (Hymenoptera: Formicidae) was the most abundant species during winter (Lindsey & Skinner, 2001). Increase of primary productivity is the most important factor, which determines the abundance of ant species at a given area, followed by the temperature and seasonality (Kaspari *et al.,* 2000).

Arboreal ants are partially herbivorous and they consume nectaries and hemipteran honeydew (Davidson *et al.,* 2003; Blüthgen *et al*., 2004). More importantly, arboreal ant species of the genus *Oecophylla* are efficient in controlling insect pests (Hölldobler & Wilson, 1990). The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae), plays

anessential role in regulating populations of sap-sucking pests in East Africa (Seguni, 1997; Olotu *et al.,* 2012) and West Africa (Van Mele *et al.,* 2007; Dwomoh *et al.,* 2009). AWA is one of most dominant arboreal ant species in tropical Africa (Van Mele & Cuc, 2007). In Tanzania, AWA coloniesare widely distributed in coconut orchards (Varela, 1992; Seguni, 1997) and cashew orchards in Tanzania (Stathers, unpublished; Olotu *et al.,* 2012).Itforms large polydomous colonies consisting ofin many leaf nests in the crowns of a wide range of host plant species (Varela, 1992). These host plants supply nectaries that supplement their diets (Way & Khoo, 1991; Blüthgen & Fiedler, 2002).

Despite its importance in the control of sap-sucking insects, the effect of seasonality on AWA abundance in cashew crop in Tanzaniais still unknown. The aim of this study was to investigate the abundance of AWA with respect to cashew seasons (cashew on-seasons and off-seasons) in order to design conservation strategies during off-seasons.

2.3 Materials and methods

2.3.1 Experimental sites

Experiments were conducted in cashew fields from January to December in 2011 and 2012at Bagamoyo (S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l) and Kibaha (S 06° 33.4', E 38° 54.7', 150.57 m.a.s.l), Coast region of Tanzania. Cashew off-season was considered as the inactive reproductive phase or period of non-flowering (January to June) and cashew on-season was considered as the active cashew reproductive phase which is marked by new flushes of shoots and mass flowering followed by fruit and nut development (July to December).

2.3.2 Quantification of AWA abundance

Abundance of arboreal antsis usually estimated indirectly by counting leaf nests per treeand ant trails on main branches (Peng & Christian, 2006) or counts of ants on selected plant parts (Blüthgen *et al.,* 2004). Direct methods to count the ants are always disruptive to nest inhabitants, for example the

partial opening of nests for enumerative purposes (Peng *et al.,* 1998). AWA abundance can be considered as the total number of AWA leaf nests per trees andmean percentage of AWA trails on the main branches (AWA colonization).Twenty cashew trees were selected randomly per site. AWA abundance on each tree was quantified as follows: (i) all the leaf nests were carefully counted with the aid of binoculars, and (ii) the total number of main branches with AWA trails was recorded. More than ten AWA walking along a main branch was recorded as one AWA trail. Between one and ten AWA along the main branch was recorded as 0.5 AWA trail (Peng & Christian, 2006). The individual percentage of AWA trails on main branches was calculated as (i), the mean percentage of AWA trails in occupied trees in the field was calculated as (ii) and the average number of nests per AWA occupied tree was calculated as (iii).

(i) (Number of main branches with a weaver ant trail in a tree) /(Number of main branches in the tree) x 100

(ii) Mean AWA trail colonization based on trails per tree was calculated asthe average of AWA colonization per field

(iii) Mean number of nests on AWA occupied trees per field was calculated as the sum of all nests counted / 20 trees

AWA on a tree was treated as 'abundant' when more than 50% of the main branches had AWA trails, or as 'fewer' when less than 50% of the main branches had AWA trails. Twenty cashew trees with abundant AWA were randomly selected per site. Quantification of AWA abundance (i.e. leaf nests and trails) was done each month for two consecutive years.

2.3.3 Data analysis

Count and proportion data was transformed to Log (n+1) before being subjected to statistical analysis. Total number of AWA leaf nests during on- and off seasons was analysed by means of the Behrens-Fisher t-test. Repeated measures ANOVA was used to compare AWA abundances over

time using STATISTICA version 11 (Stasoft, Inc., Tulsa, Oklahoma, USA).Bonferroni correction was used to adjust for multi means comparisons. The Bonferroni correction has been frequently considered as the most common way to control the familywise error rate (McDonald, 2009).

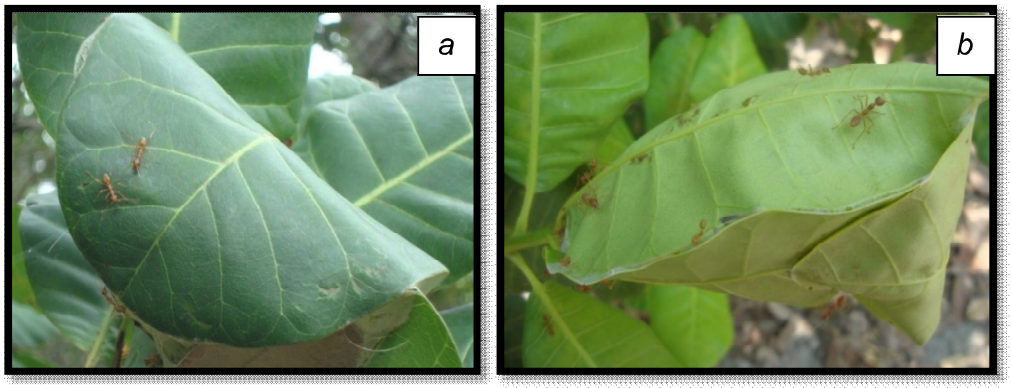


Plate 2.1 Leaf nests of AWA: (a) a nest consisting of a single cashew leaf and (b) a nest consisting of multiple cashew leaves.

2.4 Results

2.4.1 AWA leaf nests

The nest of AWA is illustrated in Plate 2.1; it is constructed by gluing a single cashew leaf or multiple leaves with larval silk.Numbers of AWA leaf nests per treein the cashew fields at Bagamoyo and Kibaha varied significantly at $P < 0.05$ between cashew on-seasons and off-seasons.At both sites more AWA leaf nests were recorded during cashew on-season than during off-season in both 2011 and 2012 (Figure 2.1). For example in 2011, 933 and 903 leaf nests were recorded during cashew on-seasons as compared to 593 and 577 leaf nests during off-seasons at Bagamoyo and Kibaha, respectively (Figure 2.1). The mean numbers of AWA leaf nests per tree varied according tomonth of the yearat both sites: Bagamoyo ($F_{(11,209)} = 12.74$; $P < 0.001$) and ($F_{(11,209)} = 26.25$; $P < 0.001$) during 2011 and 2012, respectively; Kibaha ($F_{(11,209)} = 23.66$; $P < 0.001$) and ($F_{(11,209)} = 35.71$;$P < 0.001$) in 2011 and 2012, respectively (Figures2.2 and 2.3).

2.4.2 AWA trails colonization

Similar to AWA leaf nests, AWA trails colonization was higher during cashew on-seasons than during off-seasons in the two cashew fields at Bagamoyo and Kibaha during 2011 and 2012 monitoring periods (Figures 2.4 and 2.5). For example in 2011, 72.5 and 73.3% were recorded during cashew on-seasons as compared to 54.2 and 50.9% during off-seasons at Bagamoyo and Kibaha, respectively (Figure 2.4). The AWA trails colonization also varied according to season, with higher mean percentage during cashew on-seasons in both sites: Bagamoyo ($F_{(11,209)} = 11.76$; $P < 0.001$ and $F_{(11,209)} = 18.90$; $P < 0.001$) during 2011 and 2012 respectively; Kibaha ($F_{(11,209)} = 24.02$; $P < 0.001$) and $F_{(11,209)} = 20.45$; $P < 0.001$) in 2011 and 2012, respectively (Figures 2.4 and 2.5).

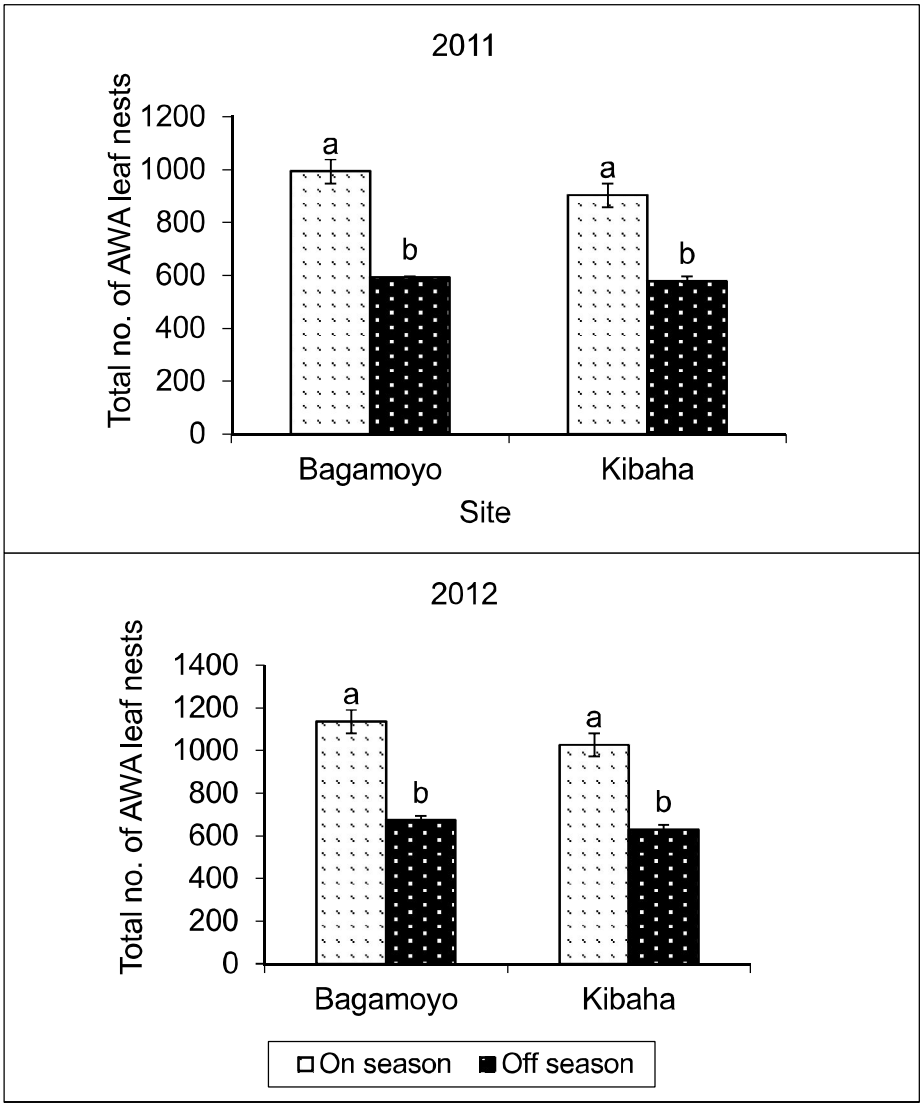


Figure 2.1 Total numbers of AWA leaf nests in cashew fields at Bagamoyo and Kibaha during the 2011 and 2012 seasons. Paired means indicated by different letters differed significantly at $P < 0.05$. Bars indicate SE.

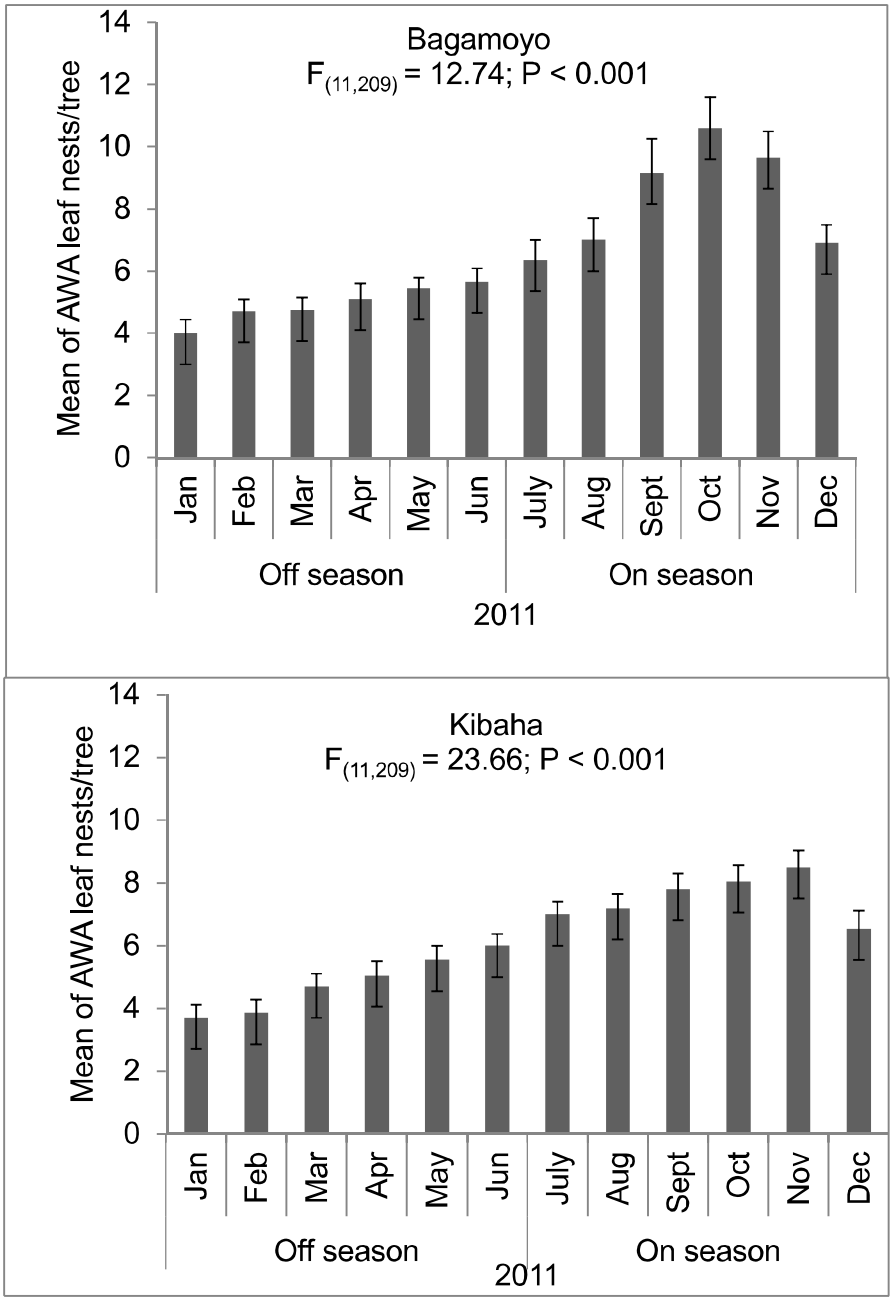


Figure 2.2 Mean numbers of AWA leaf nests in cashew fields at Bagamoyo and Kibaha during the 2011season. Bars indicate SE.

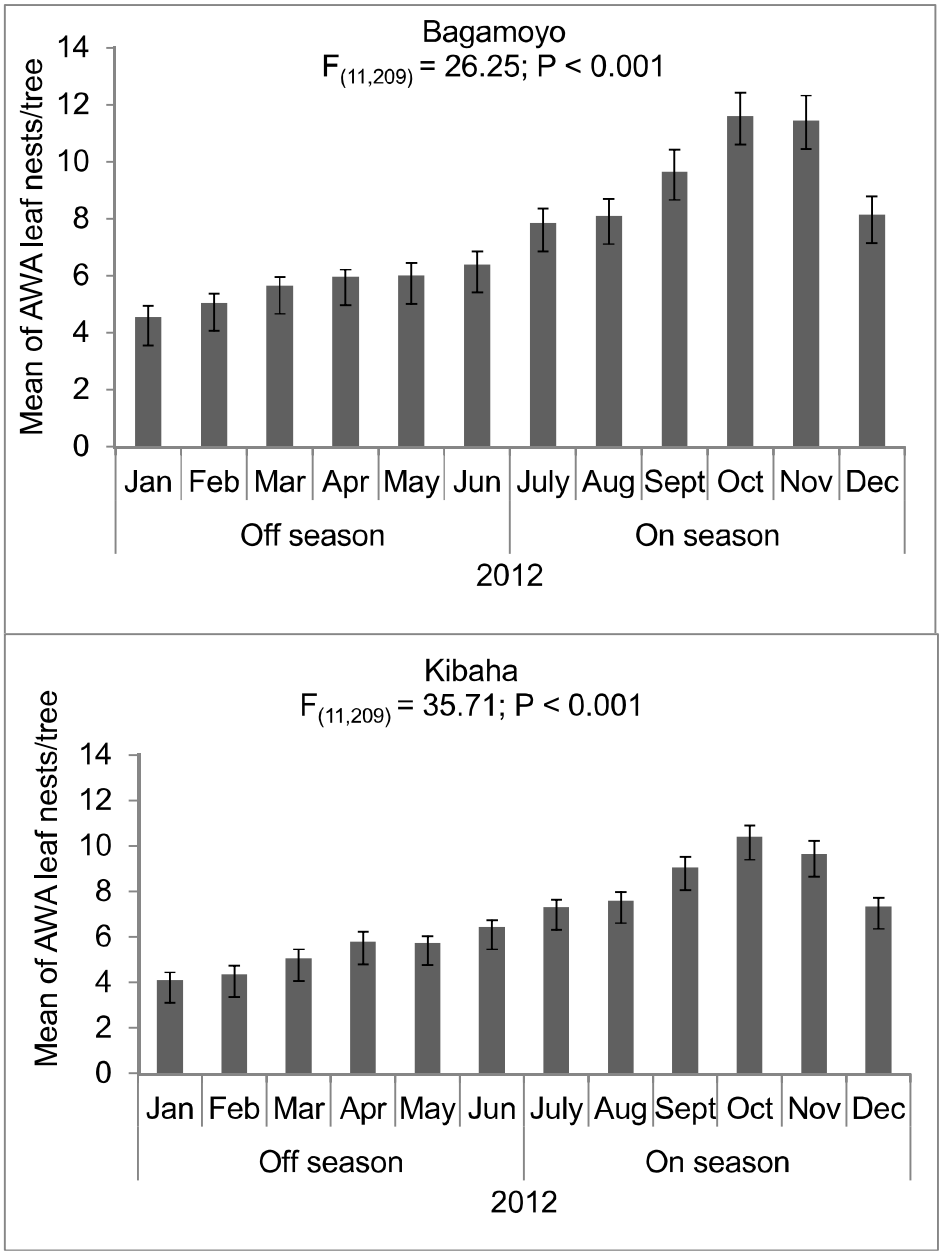


Figure 2.3 Mean numbers of AWA leaf nests in cashew fields at Bagamoyo and Kibaha during the 2012 season.Bars indicate SE.

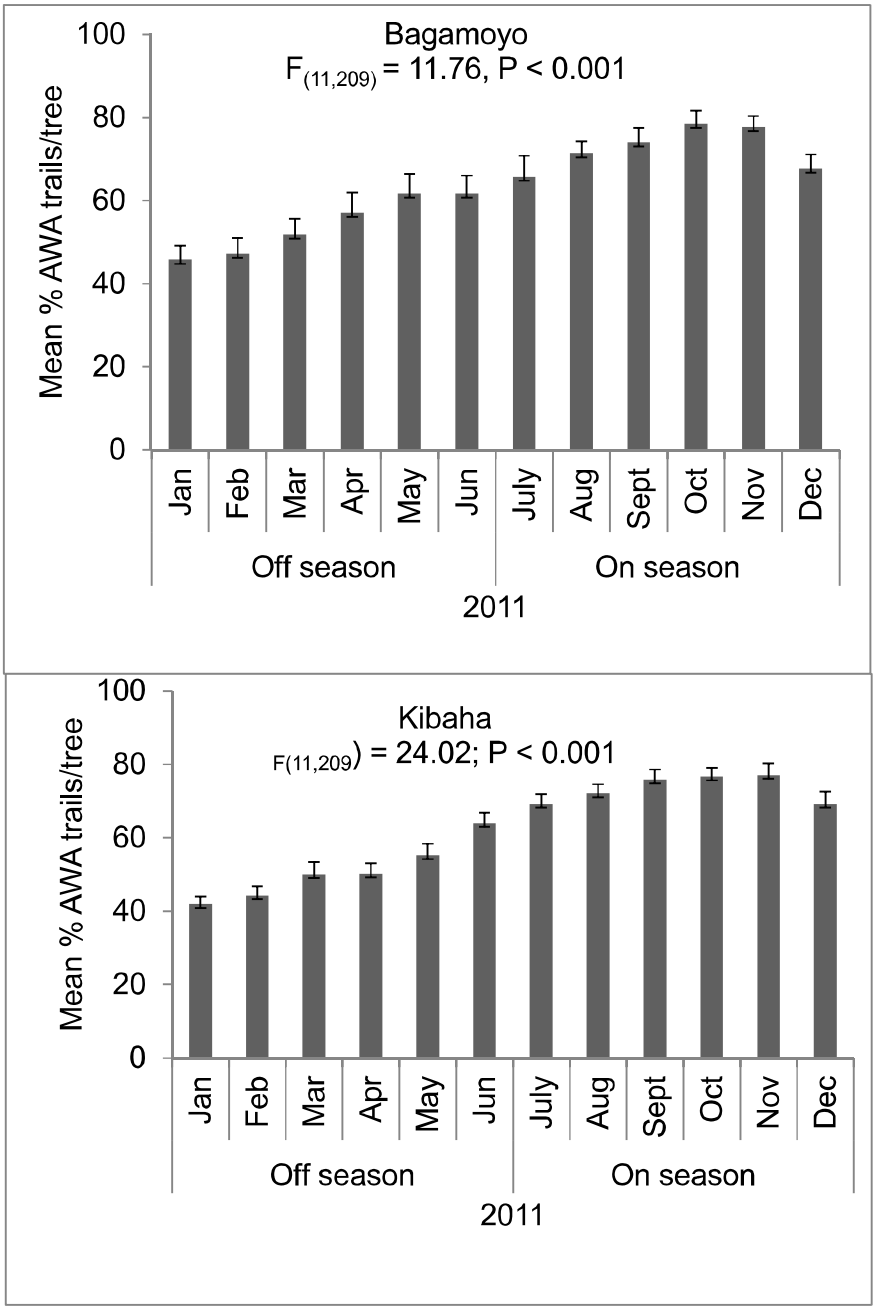


Figure 2.4 Percentage AWA trails colonizationper 20 occupied treesin cashew fields at Bagamoyo and Kibaha during the 2011 season.Bars indicate SE.

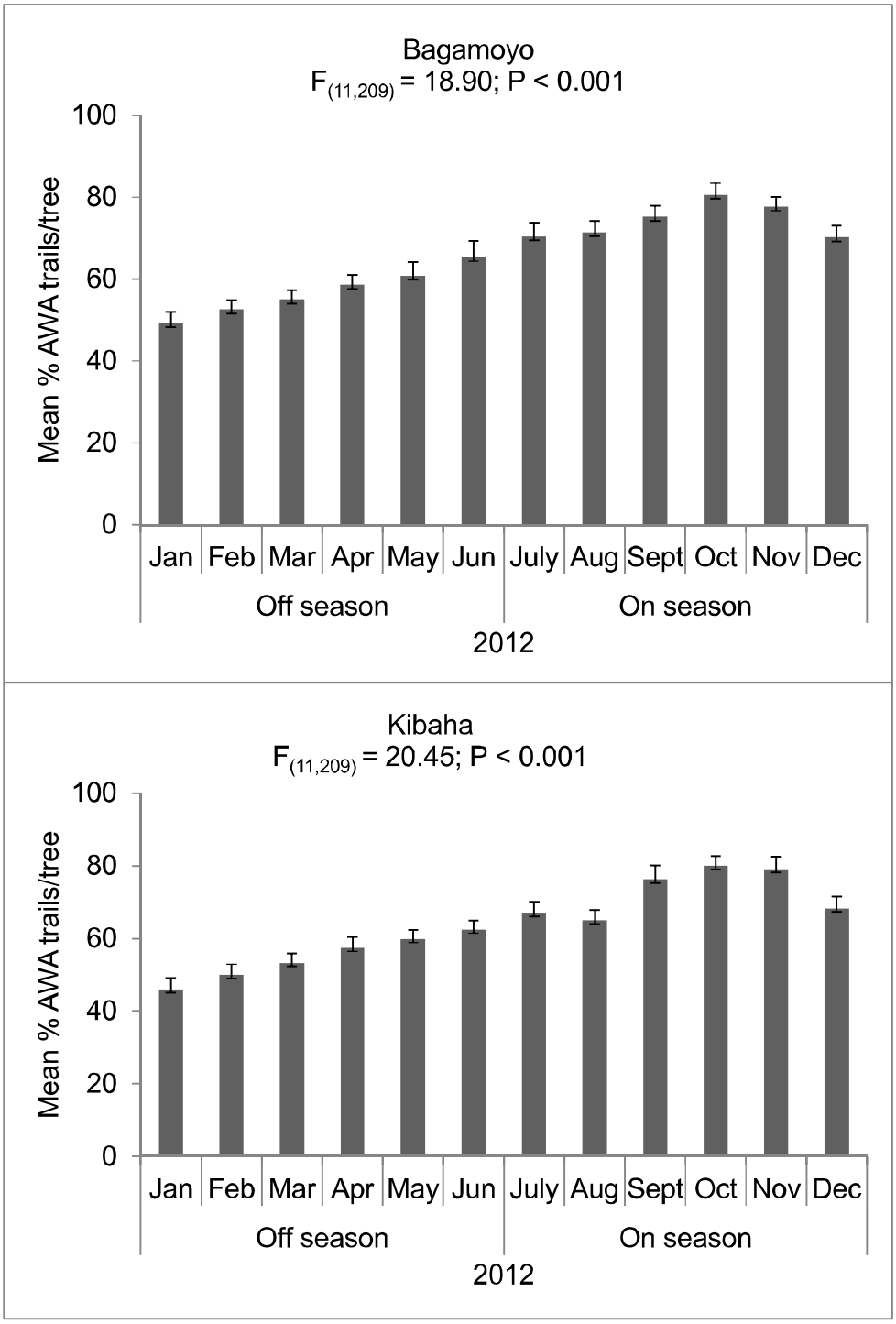


Figure 2.5 Percentage AWA trails colonization per 20 occupied trees in cashew fields at Bagamoyo and Kibaha during the 2012 season.Bars indicate SE.

2.5 Discussion

The abundance of AWA (i.e. total number of AWA leaf nests per tree and their trails on the main branches) was high and more stable during cashew on-seasons than during off-seasons in the two sites and both seasons (2011 and 2012). This was probably due to cashew flowering, which occurs during the dry season of the year (Wait & Jamieson, 1986). The crop reproductive season in the different sites of the Coast region of Tanzania is from August to December (Olotu *et al.,* 2012). Fluctuations in food resource availability during seasons vary greatly because nectar is only available during particular seasons (Gottlieb *et al.,* 2005; Stone *et al.,* 1999).

During mass flowering, cashew trees provide nectaries mainly for pollination attraction. However, these nectaries have also been reported to attract other insect fauna such as homopteran insects, *Coccus hesperidum* Linnaeus (Homoptera: Coccidae) and *Hilda patruelis* Stål (Homoptera: Tettigometridae) (Stathers, unpublished). As a result, AWA also tended the homopteran insects for honeydew in cashew crops (Dwomoh *et al.,* 2009; Olotu *et al.,* 2012).

High abundance of AWA during cashew on-seasons could also be attributed to the occurrence of sap-sucking pests, *Helopeltis anacardii* Miller, and *H. schoutedeni* Reuter (Hemiptera: Miridae), and *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) during on-seasons. A similar observation was reported in coconut orchards, where an increase in *Helopeltis* spp. and *P. wayi* populations coincides with the main growing period of the crop, which begins shortly after the end of the rainy season in July or August, resulting in high abundances of AWA (Seguni, 1997). The increase in AWA abundance could also be attributed to more nest building by established colonies. The major workers are responsible for nest building, foraging and defending the colony (Hölldobler & Wilson, 1983; Varela, 1992).

In conclusion, the abundance of AWA varies significantly between cashew seasons at the different sites of the Coast region of Tanzania. High numbers of AWA leaf nests per tree and stable AWA trail colonization were recorded

during cashew on-seasons compared to off-seasons. Therefore, conservation of AWA during cashew off-seasons is needed for high and stable AWA abundance throughout the year.

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CHAPTER THREE

Efficacy of the African weaver ant *Oecophylla longinoda* in the control of *Helopeltis* spp. and *Pseudotheraptus wayi* in cashew crops in Tanzania

3.1 Abstract

Cashew, *Anacardium occidentale* Linnaeus, is an economically important cash crop for more than 300,000 rural households in Tanzania. Its production is, however, severely constrained by infestation by sap-sucking insects *Helopeltis anacardii* Miller, *H. schoutedeni* Reuter and *Pseudotheraptus wayi* Brown. The African weaver ant (AWA), *Oecophylla longinoda* Latreille, is an effective biocontrol agent of hemipteran pests in coconuts in Tanzania but its efficacy in the control of *Helopeltis* spp. and *P. wayi* in Tanzanian cashew has not been investigated so far. The aim of this research was therefore to evaluate the efficacy of AWA in the management of these insect pests in the cashew crop at different sites of the Coast region of Tanzania. Colonization levels of AWA trails, varied from 57.1 to 60.6% and from 58.3 to 67.5% in 2010 and 2011, respectively. The mean number of leaf nests per tree varied from five to eight in 2010 and from five to nine in 2011. There was a negative correlation between numbers of nests and pest damage. AWA-colonized cashew trees had the lowest shoot damaged by *Helopeltis* spp. of 4.8 and 7.5% in 2010 and 2011, respectively, compared to uncolonized cashew trees with 36 and 30% in 2010 and 2011, respectively. Similarly, nut damage by *P. wayi* was lowest in AWA-colonized trees with only 2.4 and 6.2% in 2010 and 2011, compared to uncolonized trees with 26 to 21%.

Oecophylla longinoda is an effective biocontrol agent of the sap-sucking pests of cashew in the Coast region of Tanzania.

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3.2 Introduction

Cashew trees, *Anacardium occidentale* Linnaeus (Anacardiaceae), are grown in many tropical countries. It has a long history of cultivation in Central and South America, South-East Asia, India, Australia and tropical Central Africa (Johnson, 1973).It was introduced from Central and South America to different parts of the world in the sixteenth century (Mitchell & Mori, 1987). The crop was introduced by the Portuguese for afforestation and control of soil erosion along the coastal areas of Tanzania, Kenya, Mozambique and Nigeria (Mitchell & Mori, 1987; Woodroof, 1979). The crop is widely believed to have remained in the coastal areas mainly as a subsistence crop for local communities until it gained economic importance after World War II (Anonymous, 2009). Cashew nut is the main cash crop and the leading source of income for over 300,000 households, grown on 400,000 ha with 40 million trees mainly in south eastern Tanzania (Anonymous, 2009). In 2006, cashew nut accounted for 10% of the total value of foreign exchange earning in Tanzania and represented US $ 54.1 million (Anonymous, 2009).

The production of cashew nut is being constrained by numerous insect pests, including sap-sucking insect pests, of which the mirid bugs *Helopeltis anacardii* Miller, *Helopeltis schoutedeni* Reuter (Hemiptera: Miridae) and the coreid bug *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) are the most important in Tanzania (Boma *et al.,* 1997; Martin *et al.,* 1997; Topper *et al.,* 1997).*Helopeltis* spp. attack leaves and stalks of the vegetative and flowering shoots. All tissues above the feeding location of these insects die, and, if an attack comes early in the growing season each affected branch produces no leaves or flowers and fruits for the year (Stathers, unpublished). The sites of attack are marked by angular lesions due to injection of toxic saliva into the stalks of the tender shoots. Secondary infection by fungi may cause dieback of the shoots (Martin *et al.,* 1997), which is characterized by withering of the shoots, generally starting from the tips and later advancing downwards to the main floral shoots and leaves (Stathers, unpublished). *Pseudotheraptus wayi* feeds on developing nuts causing them to shrivel, dry and blacken before they

are shed. A characteristic sunken spot develops at the site of puncture and mature kernels show black, sunken spots (Topper *et al.,* 1997; Stathers, unpublished). The increase in sap-sucking pest populations coincides with the main growth period of the tree crop, which begins shortly after the end of the long rainy season (Stathers, unpublished; Seguni, 1997). Damage by these sap-sucking insects can vary between years and localities (Boma *et al.,* 1997; Topper *et al.,* 1997).

The main management strategy largely relies on calendar-based applications of insecticides, namely lambda cyhalothrin (Karate 5EC) and trifloxistrobine (Flint 50WG), which are applied during flowering (Anonymous, 2002). Although it can reduce insect pest damage significantly, disadvantages, apart from the cost of synthetic chemical insecticides can also be numerous. These include a reduction in natural enemies and potential pollinators, increased insect resistance to pesticides, environmental pollution and negative effects on the health of the farmers, who often lack the necessary protective gear (Hill, 2008).There is a need, therefore, to develop an ecologically sustainable and economically viable integrated pest management (IPM) strategy for control of these key pests. Weaver ants, *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) are used as biocontrol agents in cashew and mango orchards in Australia (Peng *et al.,* 1995; Peng & Christian, 2005). The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) has already been used to control *P. wayi* in coconut in East Africa (Varela, 1992; Seguni, 1997; Sporleder & Rapp, 1998), cashew pests [(*H. schoutedeni*, *Pseudotheraptus devastans* Distant and *Anoplocnemiscurvipes* Fabricius (Hemiptera: Coreidae)] in Ghana (Dwomoh *et al.,* 2009) and fruit flies [(*Ceratitis* spp. and *Bactrocera invadens* (Diptera: Tephritidae)] in mango in Benin (Van Mele *et al.,* 2007). The aim of this study was therefore to evaluate the potential of AWA in the control of *Helopeltis* spp. and *P. wayi* in cashew trees in Tanzania.

3.3 Materials and methods

3.3.1 Experimental sites

Experiments were conducted in cashew fields at Bagamoyo (S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l), Kibaha (S 06° 33.4', E 38° 54.7', 150.57 m.a.s.l) and Mkuranga (S 07° 3.5', E 39° 15', 90.53 m.a.s.l) and in the Coast region of Tanzania. The data was collected monthly for two cashew production seasons from August to December 2010 and 2011. The average annual rainfall of the region is 1000mm. The cashew fields were approximately 8, 5 and 3 ha at Bagamoyo, Kibaha and Mkuranga respectively. The cashew trees in Bagamoyo and Kibaha were 12 years old and planted in 22 and 18 rows, respectively. The plantations consisted of cashew trees planted in monoculture, and the majority of the trees were well separated from each other. The cashew trees at Mkuranga were 15 years old and were irregularly intercropped with mango, coconut and citrus trees.

3.3.2 Colonization levels Of *O. longinoda*

Mean AWA colonization level per tree was determined during the flushing shoot and flower initiation period, which coincided with high incidence of the sap-sucking pests. Forty cashew trees were selected randomly per site. The random selection was stratified, with 20trees colonized and 20 trees not colonized by AWA. Foraging AWA on main branches and leaf nests in the trees were used as indicators of colonization by AWA. Hydramethylon ant bait (Amdro®) was additionally applied at a rate of 3 g $tree^{-1}$ on AWA-colonized trees to control *Pheidole megacephala* Fabricius (Hymenoptera: Formicidae), an inimical ant to AWA to ensure a high and stable colonization level of AWA. The level of AWA colonization was measured in two ways: a) the number of nests per tree; b) the percentage of main branches with AWA trails. More than 10 weaver ants walking along a main branch was recorded as one weaver ant trail. Between one and 10 weaver ants along the main branch was recorded as 0.5 weaver ant trail (Peng & Christian, 2006).

The percentage of AWA trails on main branches (i), the mean percentage of AWA trails on occupied trees in the field (ii) and the average number of nests per AWA occupied tree (iii) were calculated according to the methods described in subsection 2.3.2, chapter 2.

3.3.3 Shoot and nut damages

An assessment of damage to flushing shoots and young nuts by *Helopeltis* spp. and *P. wayi*, respectively, was conducted on each of the selected cashew trees (Plate 3.1). A $1m^2$ quadrat was placed over the shoots approximately 1m above the tree base, the flushing shoots and nuts within each quadrat were carefully inspected and the number of shoots and nuts damaged were recorded separately. A leaf was treated as 'damaged' if more than 30% of its surface showed signs of damage (Peng & Christian, 2004). Leaves with less than 30% damage were classified as 'not damaged'. Five tender leaves per shoot were inspected, and, if any one of these leaves was affected, the shoot was treated as damaged.

Two quadrats were used to assess damage per tree. One quadrat was placed at the southern, sunny side and the other at the northern, shady side of the tree. The position of the quadrat was maintained throughout the study. Evaluation of damage to tender shoots and young nuts by the sap-sucking pests was done monthly.

The percentage of shoots damaged per quadrat was calculated as follows:

i. (Total number of damaged shoot per quadrat)/(Total number of shoots counted within the quadrat) x 100.

ii. The percentage of shoots damaged per tree was calculated as the average of the percentage of shoots damaged in the two quadrats.

A similar procedure was also used to calculate the percentage of damaged nuts per tree.

3.3.4 Data analysis

Damage to flushing shoots and young nuts expressed as a percentage was arcsine transformed before analysis. The data were analyzed using STATISTICA version 10 (Stasoft, Inc., Tulsa, Oklahoma, USA). Repeated-measures ANOVA was used to analyse percentage damaged shoots and nuts over time. Bonferroni correction was used to adjust for multi means comparisons. It is the most common way to control the familywise error rate (McDonald, 2009). The Durbin-Watson test was used to determine correlation between numbers of AWA nests and pest damage.

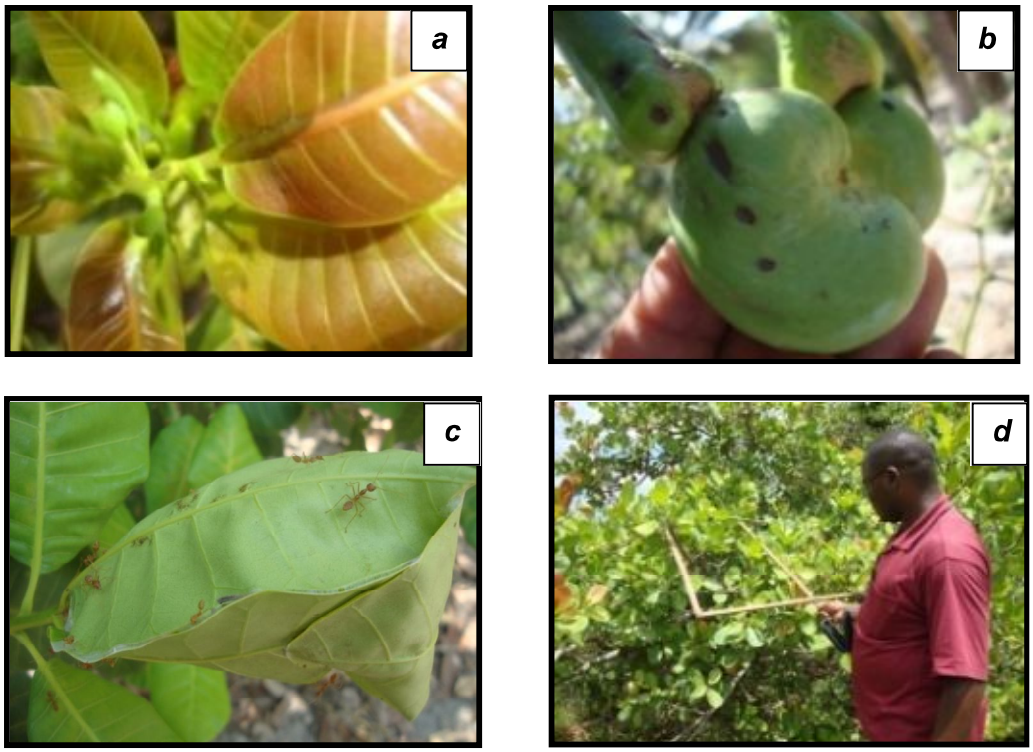


Plate 3.1 (a) Shoot damaged by *Helopeltis* spp. (b) nut damaged by *P. wayi (c)* a leaf nest of AWA (d) Scientist placing a quadrat to measure shoots and nut damages.

3.4 Results

3.4.1 Colonization levels of *O. longinoda*

Colonization levels of AWA, expressed as weaver ant trails on the main branches, were similar at the three sites during the 2010 and 2011 cashew production seasons P = 0.93 and P = 0.26, respectively (Table 3.1). Mean colonization levels ranged between 57.1 and 60.6% in 2010 and between 58.3 and 67.5% in 2011. A total of 1898 and 2182 leaf nests were counted in 2010 and 2011 cashew production seasons respectively. The mean number of leaf nests per tree were similar at the three sites in both 2010 (P = 0.92) and 2011 (P = 0.23), ranging from five to eight and from five to nine during 2010 and 2011 cashew production seasons respectively (Table 3.1).

3.4.2 Shoot and nut damage

The shoot damage levels were between 4.8 and 11.74% in the colonized trees (Figure 3.1) and in the uncolonized trees were between 19.29 and 36.26% (Figure 3.1) during both seasons. The mean percentage of shoot damage was therefore significantly lower in AWA-colonized trees than in uncolonized trees at all the three localities over two seasons ($F_{(8,228)} = 2.55$; P = 0.01). However, the mean percentage of shoot damage in the AWA-colonized trees was not significant between 2010 and 2011 cashew production seasons ($F_{(4,228)} = 0.46$; P = 0.76). A similar trend was also observed in trees that were not colonized by AWA over the two seasons ($F_{(4, 228)} = 1.81$; P = 0.13).

Table 3.1 Mean colonization level expressed as AWA trails per tree in the cashew fields at different experimental sites.

Mean number (X ± SD) of leaf nests per tree						
2010	Aug	Sep	Oct	Nov	Dec	Range
Bagamoyo	5.2 (3.8)	5.7 (4.3)	5.7 (3.7)	5.5 (3.2)	6.1 (3.1)	0.9
Kibaha	6.4 (4.1)	6.9 (4.8)	6.9 (5.9)	7.4 (6.5)	8.3 (6.9)	1.9
Mkuranga	6.4 (4.3)	6.1 (3.3)	6.3 (3.1)	6.4 (3.2)	5.9 (3.4)	0.5
			$F_{8,288} = 0.40$, P = 0.92			
2011	Aug	Sep	Oct	Nov	Dec	Range
Bagamoyo	7.7 (5.3)	7.0 (5.3)	8.1 (5.1)	7.7 (5.9)	8.0 (5.3)	1.1
Kibaha	5.5 (3.4)	6.1 (3.4)	6.3 (2.9)	4.6 (3.7)	6.3 (3.9)	1.7
Mkuranga	8.4 (5.6)	9.3 (6.0)	8.0 (5.3)	8.1 (5.2)	8.7 (4.9)	1.3
			$F_{8,288} = 1.33$, P = 0.23			
Mean percentage (X ± SD) colonization level of weaver ant trails per tree						
2010	Aug	Sep	Oct	Nov	Dec	Range
Bagamoyo	55.8 (24.2)	54.6 (22.8)	58.2 (25.9)	57.5 (21.9)	59.4 (16.1)	4.8
Kibaha	61.7 (29.0)	58.8 (27.2)	59.6 (30.7)	56.0 (24.5)	58.5 (24.4)	5.7
Mkuranga	59.6 (20.8)	54.6 (24.8)	30.0 (18.3)	64.7 (21.8)	64.2 (24.3)	5.1
			$F_{8,288} = 0.39$, P = 0.93			
2011	Aug	Sep	Oct	Nov	Dec	Range
Bagamoyo	67.8 (18.6)	62.8 (24.5)	61.9 (25.7)	60.6 (21.6)	64.7 (24.3)	7.2
Kibaha	50.0 (24.8)	54.4 (20.4)	57.5 (19.3)	55.8 (23.4)	60.8 (24.1)	10.8
Mkuranga	66.6 (23.2)	69.6 (23.1)	65.4 (27.7)	67.3 (28.3)	68.5 (29.8)	4.2
			$F_{8,288} = 1.27$, P = 0.26			

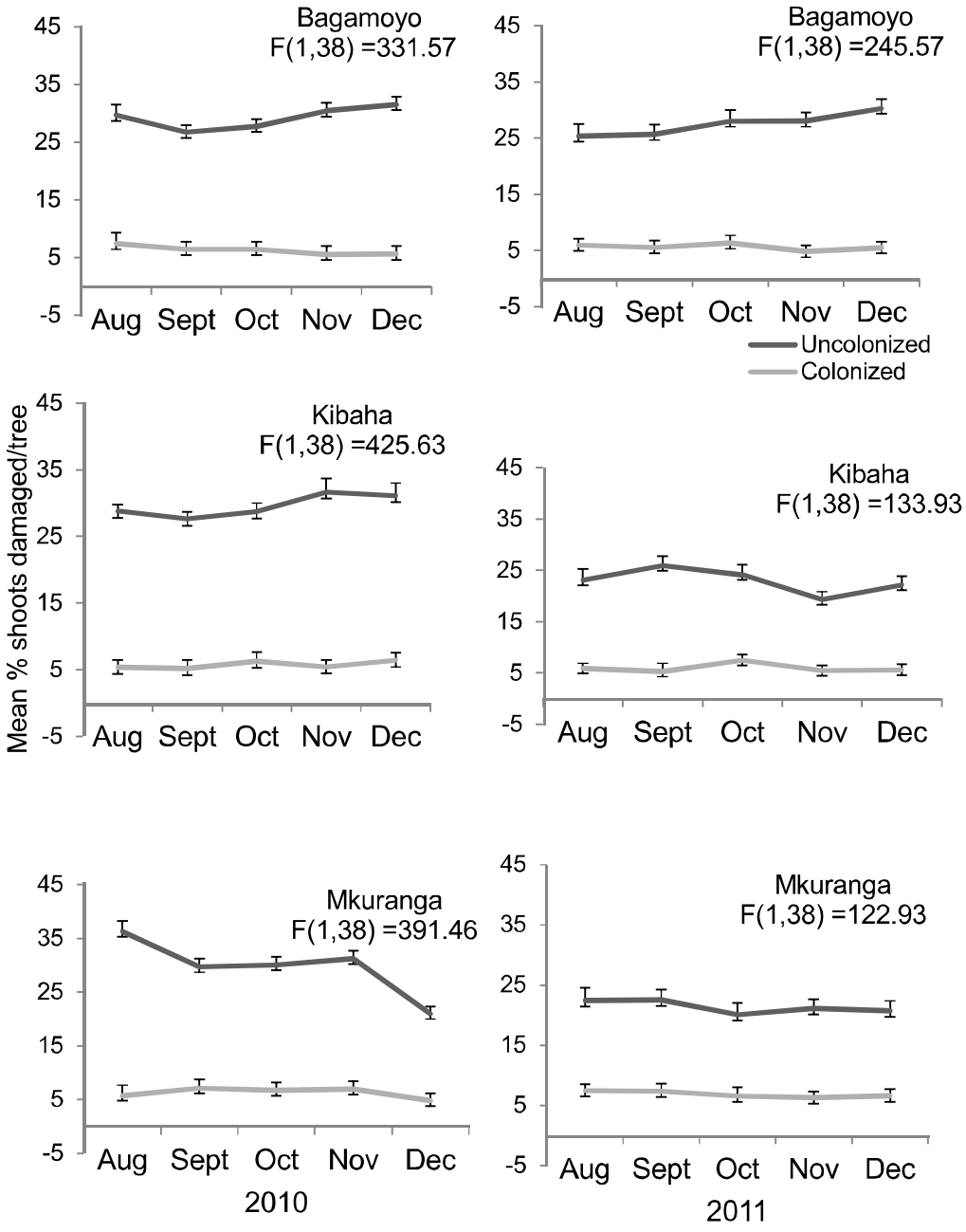


Figure 3.1 Shoot damage by *Helopeltis* spp. during the 2010 and 2011 cashew production seasons in AWA-colonized and uncolonized trees in the three cashew production areas. Bars indicate SE.

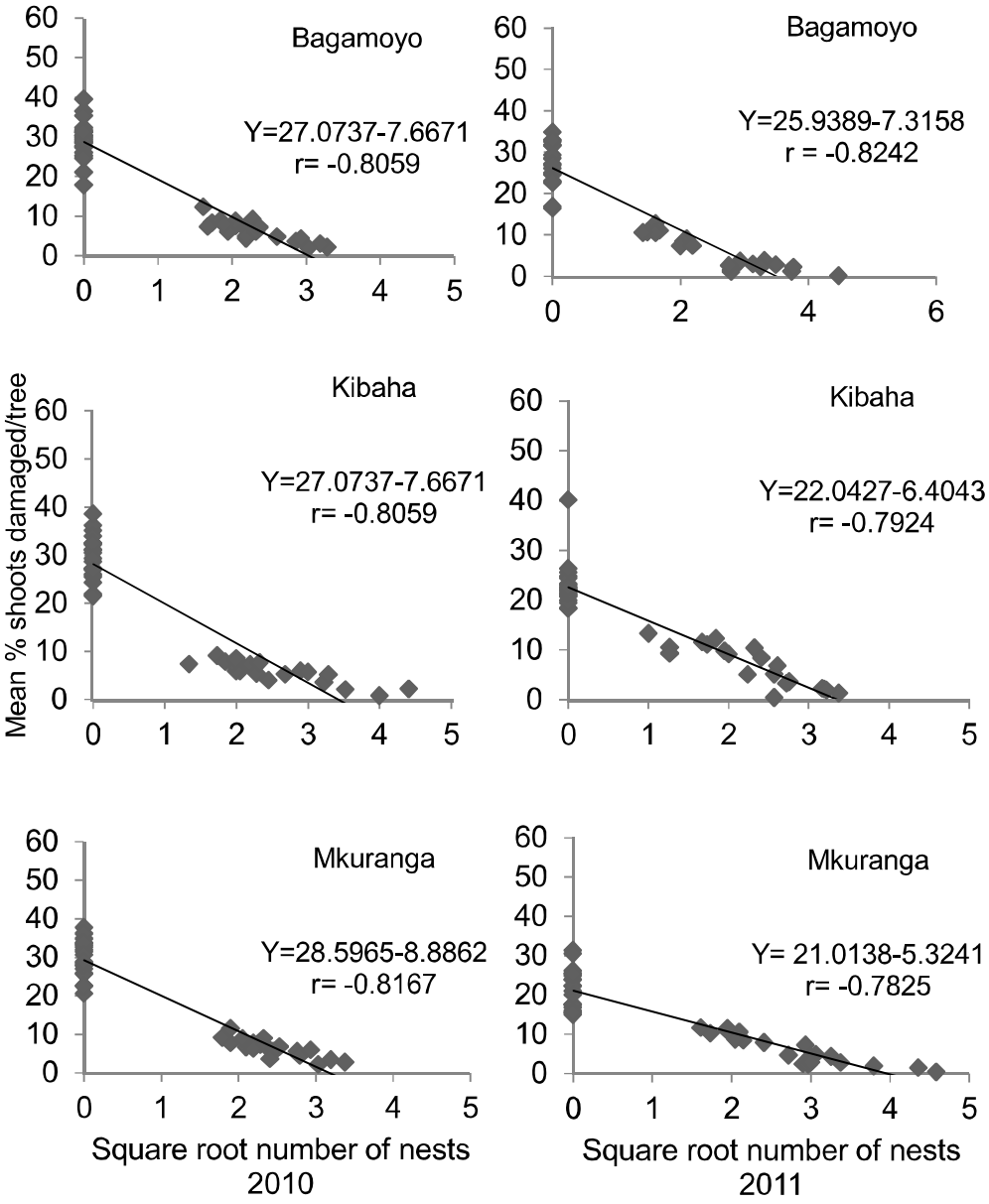


Figure 3.2 Relationship between numbers of AWA nests and shoot damage by *Helopeltis* spp. during the 2010 and 2011 cashew production seasons. Correlation coefficient indicates a negative correlation (Y = intercept, X = slope, r = correlation coefficient).

Seasonally, the incidence of shoot damage at Mkuranga differed significantly from that at Bagamoyo and Kibaha, but the latter two did not differ from each other at $P < 0.05$ (Bonferroni correction). No differences were recorded in incidence of shoots damaged between any of the sites during 2011 ($F_{(8,228)} = 1.78$; $P = 0.08$). There was a negative correlation between numbers of AWA nests and shoot damage caused by *Helopeltis* spp. during both 2010 and 2011 cashew production seasons (Figure 3.2).

There was also a significant difference between mean percentage of nuts damaged by *P. wayi* in AWA-colonized and uncolonized trees at all three sites ($F_{(6,228)} = 2.61$; $P = 0.02$). The incidence of nut damage in these trees at these sites was also similar during both 2010 and 2011($F_{(3, 228)} = 1.73$; $P = 0.16$). The mean percentage nut damage per tree ranged between 17 and 21% and between 16 and 26% in uncolonized trees in 2010 and 2011 respectively (Figure 3.3). The mean percentage of nuts damaged in cashew trees colonized by AWA did not differ significantly over time between the three sites during both the 2010 and 201 cashew production seasons ($F_{(2,228)} = 0.91$; $P = 0.44$) and 2011. The mean percentage damage per tree in the AWA-colonized trees ranged between 4.1 and 5.7% and between 2.4 and 6.2% during 2010 and 2011 seasons respectively (Figure 3.3). Nut damage was therefore significantly lower in AWA-colonized than in uncolonized trees during both the 2010 and 2011 cashew production seasons at all three localities ($P = 0.02$) (Bonferroni correction) (Figure 3.3). There was also a negative correlation between numbers of AWA nests and nut damage caused by *P. wayi* during both 2010 and 2011 cashew production seasons (Figure 3.4). An increase in numbers of AWA nests resulted in a reduction in nut damage caused by *P. wayi.*

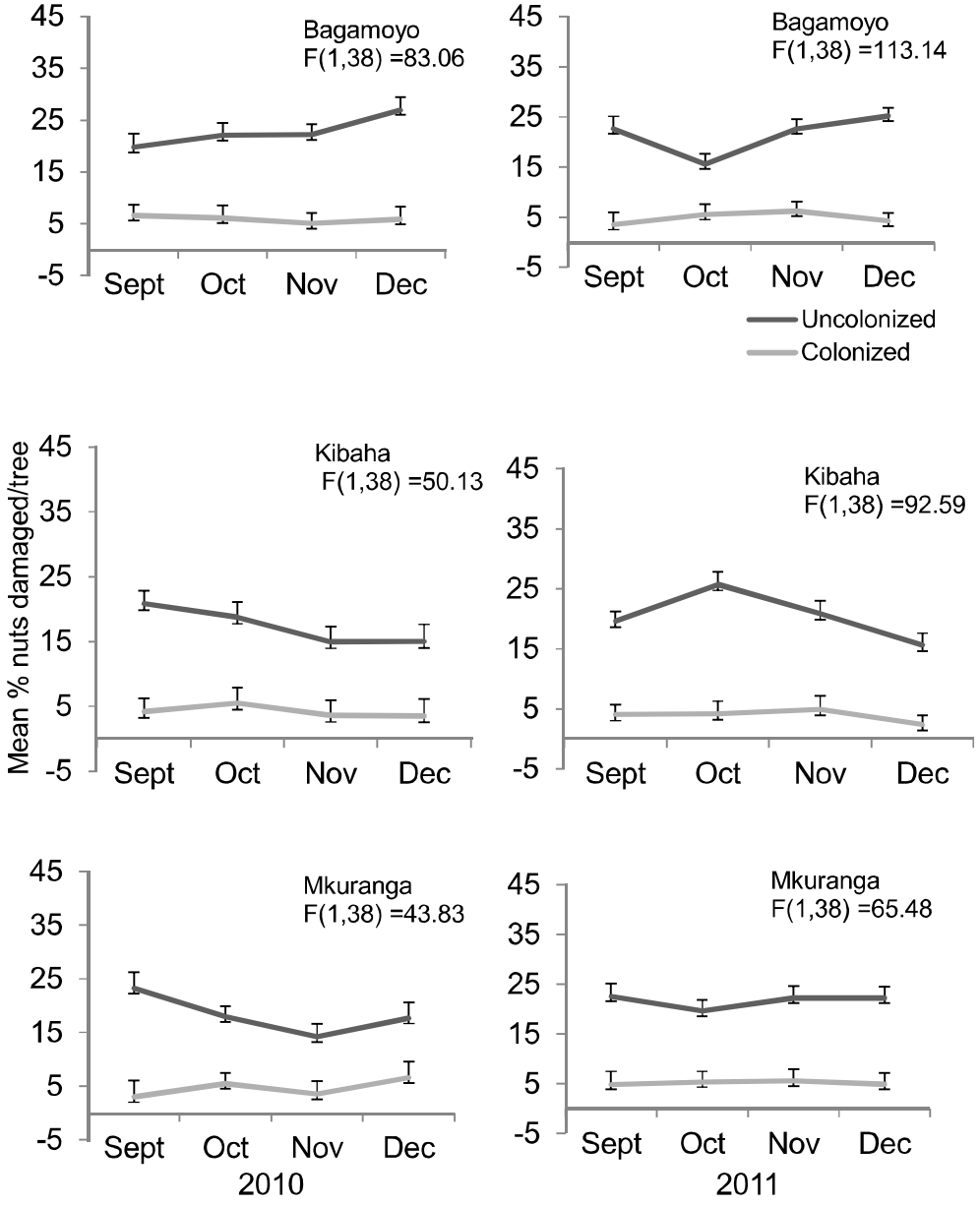


Figure 3.3 Nut damage by *Pseudotheraptus wayi* during the 2010 and 2011 cashew production seasons in AWA-colonized and uncolonized trees in the three cashew production areas. (Bars indicate SE).

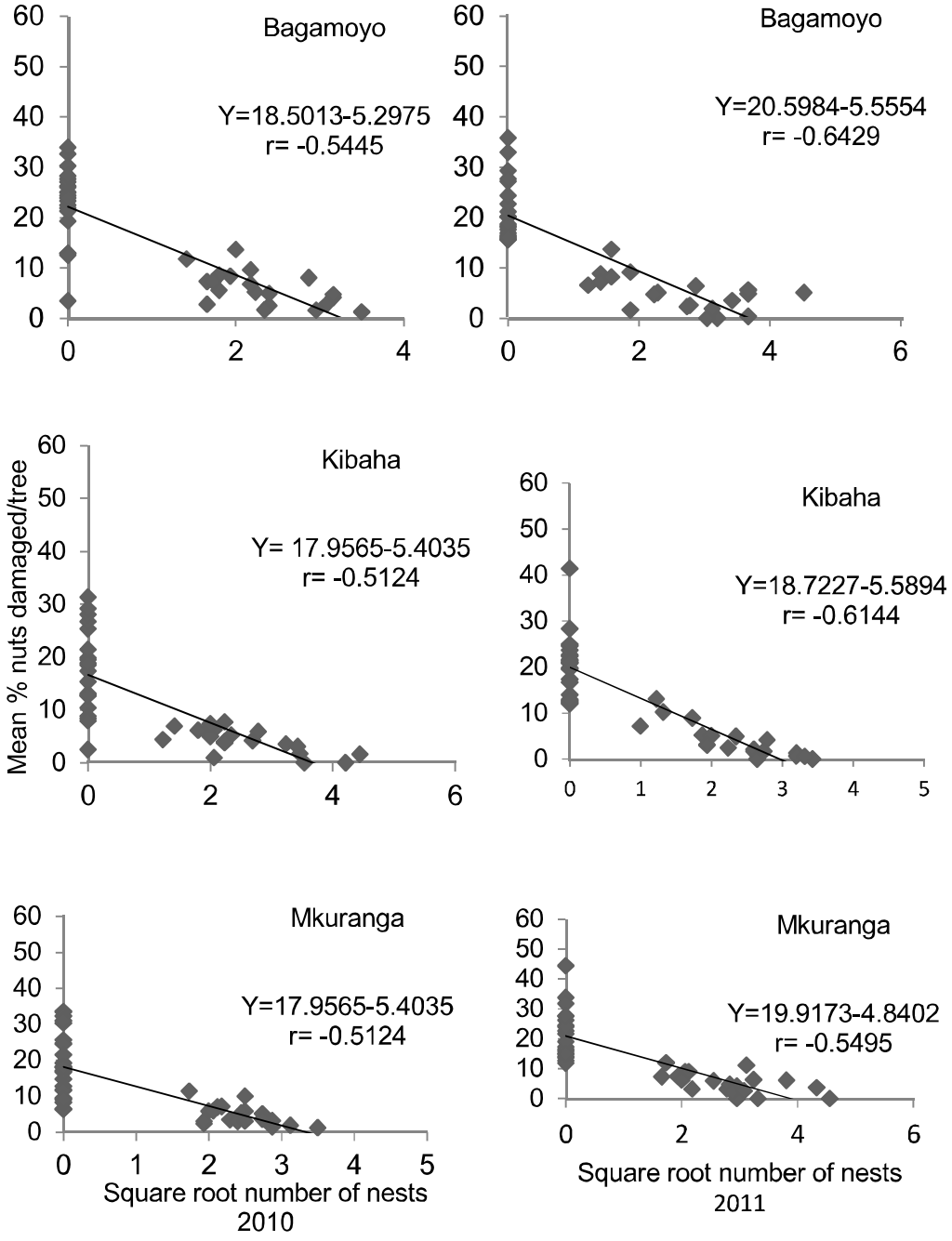


Figure 3.4 Relationship between numbers of AWA nests and nut damaged by *P. wayi* during the 2010 and 2011 cashew production seasons. Correlation coefficient indicated a negative correlation. (Y = intercept, X = slope, r = correlation coefficient).

3.5 Discussion

High colonization levels of AWA were recorded at the three sites during both 2010 and 2011 seasons. This could partly be attributed to the application of hydramethylon ant bait (Amdro®), which was applied to control the inimical ant, *P. megacephala*. The use of hydramethylon has proven to be a successful method in controlling this ant species in coconut farms (Seguni, 1997; Varela, 1992; Sporleder & Rapp, 1998), thus improving the effectiveness of AWA in controlling sap-sucking pests since it does not spend energy on defending its territory (Sporleder & Rapp, 1998).The high colonization levels of cashew trees by AWA can also possibly be ascribed to the presence of large numbers of insect symbionts (trophobionts) such as the scale insect, *Coccus hesperidum* Linnaeus (Homoptera: Coccidae) and the red tea bug, *Hilda patruelis* Stal (Homoptera: Tettigometridae) (M. Olotu, personal observation) which have been reported to be closely associated with AWA on cashew trees (Stathers, unpublished; Dwomoh *et al.,* 2009).A prerequisite is, however, that the host plant should be able to support associated Homoptera from which the antcan obtain honeydew for food (Dwomoh *et al.,* 2009; Blüthgen & Fiedler, 2002).

AWA was effective in controlling the key sap-sucking pests *Helopeltis* spp. and *P. wayi* in the Tanzanian cashew crop in terms of a reduction in flushing shoot and nut damages respectively. Similar results were reported in tree crops in West Africa (Dwomoh *et al.,* 2009; Van Mele *et al.,* 2007; Van Wijngaarden *et al.,* 2007). A negative correlation between numbers of AWA nests and pest damage was reported in cashew crops in Ghana (Dwomoh *et al.,* 2009) and mango fruit fly damage in Benin (Van Mele *et al.,* 2007). As *Helopeltis* spp. and *P. wayi* are low density pests (Stathers, unpublished), assessments of damaged shoots and nuts are therefore a more reliable way to determine their pest status in cashew fields than to monitor pest numbers. Field monitoring at the three sites for two years showed that in AWA-colonized trees, the shoot damage by *Helopeltis* spp. was significantly lower than in uncolonized trees. A similar trend was also observed in nut damage

caused by *P. wayi*. The reduction in pest damage in AWA-colonized trees might be due to the ability of AWA to prey on sap-sucking pests on cashew. Similar observations were recorded in coconuts in East Africa (Varela, 1992; Oswald & Rashid, 1992) and in cashew in West Africa (Dwomoh *et al.,* 2009). The aggressive behaviour of AWA experienced by farmers as a nuisance during harvesting is not a serious matter, as farmers collect cashew that have naturally dropped to the ground (Stathers, unpublished; Dwomoh *et al.,* 2009).

Oecophylla longinoda effectively controls sap-sucking pests in cashew in Tanzania. Fewer shoots and nuts were damaged in the trees colonized by AWA compared with the uncolonized trees. In practice, biocontrol is currently considered by farmers to be insignificant in the control of the sap-sucking pests in cashew (M. Olotu, personal observation). As a result, large scale producers rely on chemical pesticides, which is environmentally unsustainable. However, this study showed AWA to be an effective biocontrol agent for the sap-sucking pests in cashew fields in Tanzania. It should, therefore be included as an important part of an IPM system for the control of the sap-sucking pests in cashew production and may even replace the use of pesticides.

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CHAPTER FOUR

Interaction between African weaver ant *Oecophylla longinoda* and dominant ant species *Pheidole megacephala* and *Anoplolepis custodiens* in cashew fields in Tanzania

4.1 Abstract

The interaction between the African weaver ant (AWA), *Oecophylla longinoda* Latreille, and dominant ant species, the big-headed ant (BHA), *Pheidole megacephala* Fabricius, and the common pugnacious ant (CPA), *Anoplolepis custodiens* Smith, was examined in the cashew fields at Bagamoyo and Mkuranga districts, Coast region of Tanzania. Sugar-based bait was used monthly to examine the interaction between AWA, BHA and CPA, as well as other species of ants. There were significant differences in the abundance of AWA, BHA, CPA and other ant species foraging at the baits ($F_{(3,36)} = 5.43$; $P = 0.002$) and ($F_{(3,36)} = 11.69$; $P < 0.0001$) at Bagamoyo and Mkuranga respectively, in 2010. The mean abundances of AWA, BHA, CPA and 'others' were 66.6, 24.6, 35.0 and 59.5 %, respectively, at Bagamoyo in 2010. A similar trend was observed in 2011. The abundance of AWA was significantly negative correlated with BHA ($r_{(39)} = -0.30$; $P < 0.0001$) and CPA ($r_{(39)} = -0.18$; $P = 0.01$) at Bagamoyo in 2010. A similar trend was also observed at Mkuranga. The abundance of AWA was therefore negatively affected by the presence of the two dominant ants, BHA and CPA, which may hinder the effectiveness of AWA to control sap-sucking pests in cashew. Therefore, suppression of BHA and CPA should be emphasised for effective control of the sap-sucking pests using AWA.

4.2 Introduction

Ant interactions occur within colonies of the same species for mates (intraspecific interaction) and/or between colonies of different species for limiting resources (interspecific interaction) (Hölldobler & Wilson, 1990). Inter-specific interaction is predominantly considered as a major driving force structuring distribution patterns and abundance of ant communities (Andersen & Patel, 1994; Adler & Gordon, 2003; Baccaro *et al.*, 2012). Ants can also display interaction by exploitation and interference. Of the two, interference is widely spread in ants. For example, ant workers from one colony can attack intruders from another colony of the same species (Grasso *et al.,* 2004) or different species (Thomas *et al.*, 2005; Boulay *et al.,* 2010).

The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae), is strongly territorial at both intra and interspecific levels (Way & Khoo, 1992). Intra and interspecific interactions for resources and space can influence their distribution patterns (Hölldobler & Wilson, 1990). Dominant ant species have the ability to override abundances of other ant species and their community compositions (Hölldobler & Wilson, 1990). Interspecific interaction can be mutually exclusive and ranked in order of competitive ability (Hölldobler & Wilson, 1990). For example, the big-headed ant (BHA), *Pheidole megacephala* Fabricius (Hymenoptera: Formicidae), occurs throughout the tropics and subtropics and is considered as the most efficient competitor of AWA (Perfecto & Castiñeiras, 1998). BHA is the dominant ground nesting species in most of the coastal forest and agricultural areas of Tanzania (Varela, 1992). Interaction as a form of competition between AWA and BHA is exceptional due to the fact that each species can be displaced by one another (Vanderplank, 1960; Stathers, unpublished). BHA often overrides AWA during the dry seasons when conditions are more favourable for BHA and AWA wins the battle during the wet seasons (Vanderplank, 1960). However, the two species have also been observed to co-exist together in citrus groves under suitable ground vegetation (Seguni *et al.,* 2011). In coconut groves, it has been observed that crown connections enabled AWA

to bypass BHA (Varela, 1992; Seguni *et al.*, 1999), while in the absence of crown connections, BHA prevents establishment of AWA (Varela, 1992; Seguni *et al.*, 1999).

AWA has also been reported to compete with the common pugnacious ant (CPA), *Anoplolepis custodiens* Smith (Hymenoptera: Formicidae), in coconut crops in Tanzania (Varela, 1992; Seguni, 1997). CPA builds its nests in sandy soils with relatively sparse ground vegetation (Varela, 1992). Similar to BHA, CPA has been reported to co-exist with AWA under sufficient ground vegetation (Way, 1953; Verela, 1992). The level of aggression displayed during ant interaction depends on the location at which an encounter occurs (Knaden & Wehner, 2003; Tanner & Adler, 2009). However, the quality of a resource itself can also determine the intensity of aggressive display (Boulay *et al.*, 2007).

There is little information on the ecological relationship between AWA and the two dominant species, BHA and CPA in Tanzanian cashew crop (Stathers, unpublished), despite the efficacy of AWA against sap-sucking pests, *Helopeltis anacardii* Miller, *H. schoutedeni* Reuter (Hemiptera: Miridae) and *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) in cashew crops in this country (Olotu *et al.,* 2012). The aim of this study was to examine the interactions between AWA and the two dominant ant species, BHA and CPA, as well as other ant species in cashew agro-ecosystems and the implication thereof in biological control of *Helopeltis* spp. and *P. wayi*.

4.3 Materials and methods

4.3.1 Experimental sites

Experiments were conducted in cashew fields at Bagamoyo (S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l.) and Mkuranga (S 7° 3.50', E 39° 14.92', 120.70 m.a.s.l.) districts, Coast region of Tanzania. The experiment was conducted during two cashew on-seasons from August to December, 2010 and 2011. The trees in the cashew field at Bagamoyo were planted in a monoculture system and ground vegetation was rich because no weed control was done.

The trees in the cashew field at Mkuranga were irregularly intercropped with mango, coconut and citrus trees and weeding in the field resulted in little ground vegetation.

4.3.2 Determination of ant interactions

Surveys were conducted monthly in order to examine interspecific interactions between AWA and the two dominant ant species, BHA and CPA as well as other ant species. Forty cashew trees were selected randomly per site and baited with dental rolls soaked in 20% sugar solution as follows: (i) a dental roll was placed underneath at the base of the tree (Plate 4.1*a*) and (ii) another one on a trunk of the tree (about 2m from the base of the tree) (Plate 4.1*b*). Baited trees were marked with tags, showing the tree number. The baits were left for 1 h where after the tree was inspected for 10 minutes (i.e. 5 minutes at the base and another 5 minutes on the trunk). All ant species were counted, identified and were captured with a digital camera. Observations at the base of the tree covered a 2m-radius of soil surface. Ant species that were observed foraging on the trunk of the tree were also recorded separately. The abundance of AWA, BHA and CPA as well as other unidentified ant species, hereafter referred as 'others' was therefore recorded at the base and trunk of each tree, but combined and reported per tree. Ant specimens of unknown species were collected by hand picking, preserved in 70% ethanol and identified to genus level before being sent to AfriBugs laboratory, Pretoria, South Africa, for further identification.

4.3.3 Data analysis

Seasonal abundance of AWA and that of the dominant ant species, BHA, CPA and 'others' was compared by one way ANOVA using STATISTICA version 11 (Stasoft, Inc., Tulsa, Oklahoma, USA). The Spearman's correlation coefficient was used to determine correlation between abundance of AWA, BHA and CPA, and 'others'.

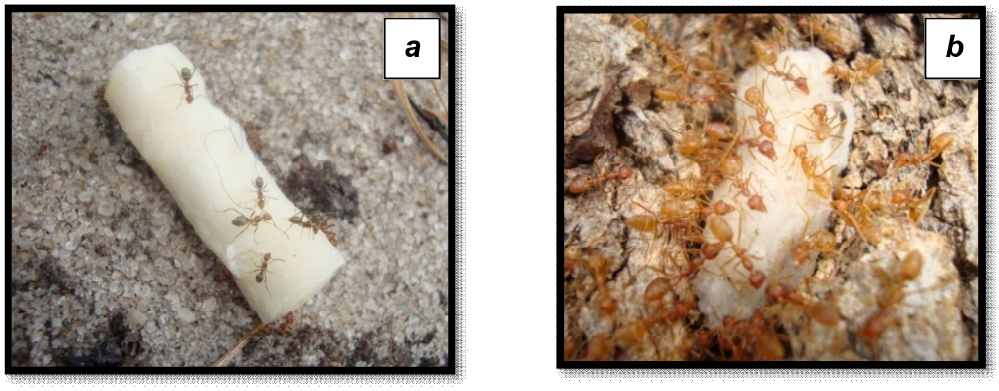


Plate 4.1 A dental roll soaked in 20% sugar solution placed (a) at a base of the tree and (b) on a trunk of the tree.

4.4 Results

4.4.1 Abundance of dominant ant species

There were significant differences in the abundance of AWA, BHA, CPA and 'others' foraging per tree ($F_{(3,36)}$ = 5.43; P = 0.002) and ($F_{(3,36)}$ = 2.84; P = 0.04) in the cashews at Bagamoyo and Mkuranga, respectively, in 2010 (Table 4.1). A similar trend was observed in the second season, 2011 (Table 4.2). AWA was the most abundant species recorded in 2010 at Bagamoyo (66.8) and Mkuranga (64.2) while BHA was the least abundant, 24.6 and 9.8 at Bagamoyo and Mkuranga, respectively (Table 4.1). A similar trend was observed in 2011, although the abundance of AWA was not significantly different from the other species at Bagamoyo (Table 4.2). A list of ant species named as 'others' is given at the end of this chapter (Appendix 4.1).

Table 4.1 Abundance (X ± S.E) of African waver ant (AWA), big-headed ant (BHA), common pugnacious ant (CPA) and other ant species ('others') observed foraging at the baits in the cashew fields at Bagamoyo and Mkuranga in 2010.

Bagamoyo 2010	X±SE	ANOVA and P-value
African weaver ant	66.8±5.8a[a]	$F_{(3,36)}$= 5.43;P=0.002
Big-headed ant	24.6±3.4b	
Common pugnacious ant	35.0±4.0b	
'Others'	59.5±4.9a	
Mkuranga 2010		
African weaver ant	64.2±6.0a[a]	$F_{(3,36)}$=11.69;P<0.0001
Big-headed ant	9.8±1.4b	
Common pugnacious ant	34.6±3.5c	
'Others'	44.4±3.5c	

[a] Means within a site followed by different letters are significantly different at P< 0.05 (Tukey's HSD)

Table 4.2 Abundance (X ± S.E) of African waver ant (AWA), big-headed ant (BHA), common pugnacious ant (CPA) and other ant species ('others') observed foraging at the baits in the cashew fields at Bagamoyo and Mkuranga in 2011.

Bagamoyo 2011	X±SE	ANOVA and P-value
African weaver ant	47.6±4.3a[a]	$F_{(3,36)}$=2.84;P=0.04
Big-headed ant	31.6±2.9a	
Common pugnacious ant	29.2±3.1a	
'Others'	34.0±2.8a	
Mkuranga 2011		
African weaver ant	47.5±4.3a[a]	$F_{(3,36)}$=12.59;P<0.0001
Big-headed ant	19.9±2.4b	
Common pugnacious ant	40.8±3.7c	
'Others'	35.8±2.7c	

[a]Means within a site followed by different letters are significantly different at P< 0.05 (Tukey's HSD)

4.4.2 Correlation between dominant ant species

The abundance of AWA was negatively correlated (P < 0.01) with BHA, CPA and 'others' in the cashew field at Bagamoyo and Mkuranga in 2010, except for the correlation between AWA and BHA at Mkuranga which was not significant ($r_{(39)}$ = -0.05; P = 0.50).

The correlation between CPA and BHA was significantly negative (P < 0.01) but positive with respect to 'others', at Bagamoyo and Mkuranga, respectively, in 2010 (Table 4.3). In 2011, the correlation between AWA and 'others' was significantly negative (P < 0.01) at both Bagamoyo and Mkuranga (Table 4.4). The correlation between BHA and CPA was significantly negative at

Bagamoyo in 2010 and positive in 2011, but not significantly (Table 4.4). Furthermore, the abundance of 'others' was significantly positive correlated with BHA and CPA at the two sites (Table 4.4).

Table 4.3 Spearman's rank correlation coefficient and P-values between abundances of AWA, BHA, CPA and 'others' observed foraging at the combined baits in the cashew fields at Bagamoyo and Mkuranga, in 2010.

Bagamoyo 2010				
	AWA Spearman's rho and P-value	BHA Spearman's rho and P-value	CPA Spearman's rho and P-value	'Others' Spearman's rho and P-value
AWA	1	$r_{(39}$=0.30;P<0.0001	$r_{(39}$=-0.18;P=0.01	$r_{(39)}$=0.55;P<0.0001
BHA	$r_{(39)}$=-0.3;P<0.0001	1	r_s=-0.32;P<0.0001	$r_{(39}$=0.48;P<0.0001
CPA	$r_{(39)}$=-0.18;P=0.01	$r_{(39)}$=0.32;P<0.0001	1	$r_{(39)}$=0.60;P<0.0001
Others'	$r_{(39)}$=-0.55;P<0.0001	$r_{(39)}$=0.48;P<0.0001	$r_{(39)}$=0.6;P<0.0001	1
Mkuranga 2010				
AWA	1	$r_{(39)}$=-0.05;P=0.50	$r_{(39)}$=0.43;P<0.0001	$r_{(39)}$=0.54;P<0.0001
BHA	$r_{(39)}$=-0.05;P=0.50	1	$r_{(39)}$=0.41;P<0.0001	$r_{(39)}$=0.19;P=0.01
CPA	$r_{(39)}$=-0.43;P<0.0001	$r_{(39)}$=0.41;P<0.0001	1	$r_{(39)}$=0.77;P<0.0001
Others'	$r_{(39)}$=-0.54;P<0.0001	$r_{(39)}$=0.19;P=0.01	$r_{(39)}$=0.77;P<0.0001	1

Table 4.4 Spearman's rank correlation coefficient and p values between abundances of AWA, BHA, CPA and 'others' observed foraging at the combined baits in the cashew fields at Bagamoyo and Mkuranga, in 2011.

Bagamoyo 2011				
	AWA Spearman's rho and P-value	BHA Spearman's rho and P-value	CPA Spearman's rho and P-value	'Others' Spearman's rho and P-value
AWA	1	$r_{(39)}$=-0.16;P=0.03	$r_{(39)}$=-0.13;P=0.07	$r_{(39)}$=-0.19;P=0.01
BHA	$r_{(39)}$=-0.16;P=0.03	1	$r_{(39)}$=-0.13;P=0.06	$r_{(39)}$=0.28;P<0.0001
CPA	$r_{(39)}$=-0.13;P=0.07	$r_{(39)}$=-0.13;P=0.06	1	$r_{(39)}$=0.26;P=0.0002
Others'	$r_{(39)}$=-0.19;P=0.01	$r_{(39)}$=0.28;P<0.0001	$r_{(39)}$=0.26;P=0.0002	1
Mkuranga 2011				
AWA	1	$r_{(39)}$=-0.13;P=0.06	$r_{(39)}$=0.36;P<0.0001	$r_{(39)}$=-0.17;P=0.02
BHA	$r_{(39)}$=-0.13;P=0.06	1	$r_{(39)}$=0.06;P=0.42	$r_{(39)}$=0.29;P<0.0001
CPA	$r_{(39)}$=-0.36;P<0.0001	$r_{(39)}$=0.06;P=0.42	1	$r_{(39)}$=0.45;P<0.0001
Others'	$r_{(39)}$=-0.17;P=0.02	$r_{(39)}$=0.29;P<0.0001	$r_{(39)}$=0.45;P<0.0001	1

4.5 Discussion

The results indicate that the interaction between AWA and the two dominant ants, BHA and CPA is antagonistic. The reduction of AWA abundance as indicated by a negative correlation can be attributed to the numerical dominance of the inimical ants, BHA and CPA. It is a known phenomenon that ants may fight with one another during competition (Andersen & Patel, 1994; Gordon & Kulig, 1996) and the fitness of one individual is lowered by the presence of another (Parr & Gibb, 2009). It has been reported that individuals of the genus *Oecophylla* can retreat and recruit nest-mates to the location of the encounter (Hölldobler & Wilson, 1978; Way & Khoo, 1992).

The numerical dominance of BHA and CPA found at the sugar bait placed at the base of the tree can possibly be ascribed to the nesting habits of the two inimical ants (CPA and BHA). The nest of CPA is usually confined to sandy

soils with a relatively sparse ground vegetation and seems to be an exclusively ground nesting ant species (Varela, 1992). The nests of BHA are at the base of the trunks under the bark and they sometimes also nest in spathes in the crown, which may be connected to the ground nests by runways (Varela, 1992; Seguni, 1997).

There was also a reduction in AWA abundance due to other ants ('others') foraging at the sugar baits. This could be attributed to presence of the genus *Crematogaster*. Major workers of AWA has been observed killing workers of *Crematogaster* (Stathers, unpublished), but occasionally this small-bodied ant can also exclude major workers of *Oecophylla* by recruiting substantial numbers of workers towards a food resource (Majer, 1976).

The workers of *Crematogaster* were also reported to emit potent chemicals for defence by raising their gaster when they encounter intruder ants (Leclercq *et al*., 2000). Different ant species can adjust their food recruitment behaviour according to the risk of injury or mortality associated with a feeding place (Nonacs & Dill, 1991) and may explain the reduction in AWA abundance when 'others' were present.

In conclusion, the numerical abundance of AWA was negatively affected by the presence of the two dominant ants, BHA and CPA. This may hinder effectiveness of AWA to control sap-sucking pests in cashew in Tanzania. Therefore, suppression of the two inimical ants should be emphasized for effective control of the sap-sucking pests in cashew fields by AWA. Hydramethylon ant bait (Amdro®) has been successfully used to control BHA in coconut (Zerhusen & Rashid, 1992; Seguni, 1997) and cashew (Olotu *et al.,* 2012), however, there is no bait yet for CPA. Thus, there is need to identify a bait for the control of CPA in cashew agro-ecosystems.

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Appendix 4.1 A list of ant species named as 'others' observed foraging at the baits in the cashew fields at Bagamoyo and Mkuranga during 2010 and 2011.

Family	Subfamilies	Species names
Formicidae	Formicinae	*Camponotus sericeus* (Fabricius)
Formicidae	Formicinae	*Camponotus* sp.1
Formicidae	Formicinae	*Polyrhachis schistacea* (Gerstaecker)
Formicidae	Myrmicinae	*Cataulacus intrudens* (Smith)
Formicidae	Myrmicinae	*Crematogaster* sp.
Formicidae	Myrmicinae	*Monomorium osiridis* (Santschi)
Formicidae	Myrmicinae	*Myrmicaria* sp.
Formicidae	Myrmicinae	*Tetramorium weitzeckeri* (Emery)
Formicidae	Pseudomyrmecinae	*Tetraponera natalensis* (Smith)

CHAPTER FIVE

Effect of fungicides used for powdery mildew disease management on African weaver ant *Oecophylla longinoda* (Hymenoptera: Formicidae) a biocontrol agent of sap-sucking pests in cashew crop in Tanzania

5.1 Abstract

The effect of application of three powdery mildew fungicides, namely triadimenol, triadimefon and sulphur on the African weaver ant (AWA), *Oecophylla longinoda* Latreille, were evaluated for two seasons in cashew fields at the Bagamoyo and Mkuranga districts, Coast region of Tanzania. These fungicides were applied at monthly intervals and dynamics of AWA were monitored monthly by counting number of leaf nests per tree and trails on main branches. There were no significant difference in the effect that the different fungicides had on the number of leaf nests ($F_{(3,35)}$ = 1.74, P = 0.18) and ($F_{(3,35)}$ = 0.39, P = 0.76) in 2011 and 2012, respectively. There were also no significant differences among the treatments on AWA at different observation dates in terms of number of leaf nests and colonization of AWA trails per tree in the two cashew fields studied. For example in August 2011, the number of leaf nests before application ranged between 7.8 and 9.0 and between 13.6 and 14.6 at Bagamoyo and Mkuranga respectively, and after application ranged between 7.8 and 10.0 and between 12.4 and 15.2 at Bagamoyo and Mkuranga, respectively. In August 2011, colonization of AWA trails before application ranged between 63.3 and 66.7% and between 66.7 and 73.3% at Bagamoyo and Mkuranga, respectively, and after application ranged between 59.2 and 68.3% and between 56.7 and 70.0% at Bagamoyo and Mkuranga, respectively. The three powdery mildew fungicides did not have detrimental effects on the abundance of AWA in cashew fields at the Bagamoyo and Mkuranga districts of the Coast region of Tanzania, and can therefore be used together with AWA as components of an integrated pest and disease management programme for cashew crops in Tanzania.

5.2 Introduction

Cashew, *Anacardium occidentale* Linnaeus (Sapindales: Anacardiaceae), is an important export crop in Tanzania. It earned US$ 54.1 million in 2006 which accounted for 10% of the total value of foreign exchange earning (Anonymous, 2009). Production of cashew nut is, however, seriously constrained by a diverse range of diseases and insect pests. The powdery mildew disease (PMD) caused by *Oidium anacardii* Noack (Erysiphales: Erysiphaceae), was first observed in 1979 and has become an annual epidemic in all cashew cultivars planted in Tanzania (Martin *et al.*, 1997; Sijaona *et al.*, 2001). The flowers, buds as well as young leaves and shoots of untreated trees are attacked by the pathogen, resulting in poor harvest and inferior nut quality (Shomari, 1996; Sijaona *et al.*, 2001). Scarring of premature nut surface is usually considered as the main symptom of nut infection (Waller *et al.*, 1992).

In the early 1980's, sulphur was identified as an effective preventive fungicide against PMD (Waller *et al.*, 1992; Shomari & Kennedy, 1999). The widespread use of sulphur dust contributed significantly to the recovery of the cashew industry in Tanzania (Topper *et al.*, 1997). However, studies showed that up to 78% of sulphur drifts away from the tree, resulting in the decrease of pH of some acidic soil types in southern Tanzania (Majule *et al.*, 1997; Smith *et al.*, 1997; Ngatunga *et al.*, 2003). As a result, the systemic fungicides triadimenol (Bayfidan®), triadimefon (Bayleton®), hexaconazole (Anvil) and penconazole (Topas®) were adopted in the early 1990's (Anonymous, 2002) as alternatives to sulphur dust for the control of PMD (Topper & Boma, 1994, Anonymous, 2002). However, according to extension officers, farmers still continue to use sulphur dust along with the above named alternative powdery mildew fungicides for the management of PMD (Anonymous, 2009).

Among the insect pests, sap-sucking insects including the mirid bugs, *Helopeltis anacardii* Miller and *H. schoutedeni* Reuter (Hemiptera: Miridae), and the coreid coconut bug, *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae), negatively affect cashew production (Boma *et al.*, 1997; Martin *et*

al., 1997; Topper *et al*., 1997). The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae), has been reported to be an effective biocontrol agent of *H. schoutedeni*, *Pseudotheraptus devastans* Distant (Hemiptera: Coreidae) and *Anoplocnemis curvipes* Fabricius (Hemiptera: Coreidae) on cashew crop in Ghana (Dwomoh *et al*., 2009) and *P. wayi* on coconut in East Africa (Varela, 1992; Seguni, 1997; Sporleder & Rapp, 1998). A recent study carried out in Tanzania has also shown that AWA can effectively control *Helopeltis* spp. and *P. wayi* on cashew crop (Olotu *et al*., 2012).

Sulphur application has been reported to negatively affect beneficial arthropods such as *Trichogramma* spp. and predatory mites (Thomson *et al*., 2000). However, there is no available information on the effects of triadimenol, triadimefon and sulphur on AWA in cashew crops (Stathers, unpublished). The aim of this study was to investigate the effect of systemic powdery mildew fungicides triadimenol, triadimefon and sulphur dust used for the control of PMD on AWA in cashew crops in Tanzania.

5.3 Materials and methods

5.3.1 Experimental sites

Experiments were conducted in cashew fields at Bagamoyo (S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l.) and at Mkuranga (S 07° 3.5', E 39° 15', 90.53 m.a.s.l.) in the Coast region of Tanzania. The average annual rainfall of the region is 1000mm. Heavy rainfall occurs for approximately 120 days between March and June annually and is widespread throughout the region. The cashew fields consisted used as trial plots were 3 and 8 ha at Mkuranga and Bagamoyo, respectively. The cashew trees at Bagamoyo were 12 years old and were planted in 22 rows in a monoculture system. The trees at Mkuranga were 15 years old and were irregularly intercropped with mango, coconut and citrus trees.

5.3.2 Evaluation of fungicides

The data were collected monthly for two cashew production seasons, from August to November 2011 and 2012. During the cashew production season new shoot flushes and flowering occur, coinciding with high incidence of insect pests and PMD (Stathers, unpublished). Two fungicides triadimenol (Bayfidan®250 EC) and triadimefon (Bayleton® 25WP) were used and their effects on AWA were compared to that of sulphur. Triadimenol was applied at a rate of 10ml ℓ^{-1} and triadimefon at the rate 15g ℓ^{-1} per tree. Sulphur dust was added as a check and was applied at the recommended rate of 250g per tree. In the control treatment, trees were left untreated. Fungicides were applied using a 15-ℓ Solo motorised mist sprayer (Yancheng Central Great Machinery Manufacturing Co., Ltd.) at monthly intervals for four months. Each treatment was applied to five cashew trees of similar size and age in a randomised completed block design. Application of fungicides was done early in the morning when the wind was not intense to avoid the effect of spray drift. Each replicate was separated by buffer zones (i.e. two rows) of untreated cashew trees.

The abundance of AWA was determined monthly for four months before and fortnightly after application of fungicides. It was expressed as number of AWA leaf nests per tree and number of trails on the main branches. Leaf nests were counted using binoculars and the total number of main branches with AWA trails per tree was also recorded. More than 10 AWA walking along a main branch was recorded as one AWA trail. Between one and 10 weaver ants along the main branch was recorded as 0.5 AWA trail (Peng & Christian, 2006). The percentage AWA colonization level was calculated according to the method described in 2.3.3 (Chapter 2).

5.3.3 Data analysis

Repeated measures ANOVA was used to analyse the effect of fungicide treatments on number of AWA leaf nests and percentage colonization level over time using STATISTICA version 11 (Stasoft, Inc., Tulsa, Oklahoma,

USA). Percentage colonization level and number of leaf nests before and after application of fungicides were analysed by means of a dependant t-test.

5.4 Results

5.4.1 AWA leaf nests

There were no significant difference in the effects of the different fungicides on the number of leaf nests ($F_{3,35}$= 1.74; P = 0.18) and ($F_{3,35}$ = 0.39; P = 0.76) in 2011 and 2012, respectively. The number of leaf nests did, however, differ between Bagamoyo and Mkuranga during both years ($F_{1,35}$ = 184.91; P = 0.0001) and ($F_{1,35}$ = 12.12; P = 0.001). The effect of the different treatments (triadimenol, triadimefon, sulphur and control) on AWA leaf nests was compared within a site at each of the four months annually. There were no significant differences between the number of nests in all the treatments, at both sites, each month during both years (Tables 5.1 and 5.2). The only significant differences between the number of leaf nests before and after application of fungicides were for triadimenol in November 2011 at Mkuranga and after application of triadimefon in November 2012 at Bagamoyo (Tables 5.1 and 5.2). For example in August 2011, the number of leaf nests before application ranged between 7.8 and 9.0; and between 13.6 and 14.6 at Bagamoyo and Mkuranga respectively, while after application ranged between 7.8 and 10.0; and between 12.4 and 15.2 at Bagamoyo and Mkuranga respectively (Table 5.1). The same trend was observed in September, October and November 2011 (Table 5.1). In August 2012, the number of leaf nests before application ranged between 8.4 and 11.2; and between 10.4 and 12.4 at Bagamoyo and Mkuranga respectively, while after application ranged between 7.4 and 10.0; and between 10.0 and 12.4 at Bagamoyo and Mkuranga respectively (Table 5.2).

Table 5.1 Monthly mean number (X±SE) AWA leaf nests per tree before and after application of triadimenol, triadimefon, sulphur and control in cashew fields at the Bagamoyo and Mkuranga in 2011.

Bagamoyo 2011				
Treatment	Month	Mean number of leaf nests (X±SE)		Dependent t-test
		Before treatment	After treatment	and P-value
Triadimenol	August	8.2 ±0.8	9.2 ± 0.7	t=1.83; P=0.14
Triadimefon		7.8 ± 0.7	7.8 ± 0.7	t=0.00; P = 1.00
Sulphur		8.8 ± 0.6	7.8 ± 0.6	t=-1.83; P=0.14
Control		9.0 ± 1.0	10.0 ± 0.9	t=1.20; P=0.30
		$F_{(3,16)}$=0.50;P=0.69	$F_{(3,16)}$=2.35;P=0.11	
Triadimenol	September	8.6 ±0.8	8.4 ± 1.0	t=-0.27; P=0.80
Triadimefon		9.0 ±0.6	9.2 ± 0.6	t=0.19; P=0.86
Sulphur		8.2 ±0.8	10.2 ± 1.5	t=1.09; P=0.34
Control		9.4 ± 0.5	10.2 ± 1.0	t=0.69; P=0.53
		$F_{(3,16)}$=0.57;P=0.64	$F_{(3,16)}$=0.66;P=0.57	
Triadimenol	October	9.0 ± 1.3	9.6 ± 1.0	t=-0.61; P=0.57
Triadimefon		8.0 ± 1.0	9.6 ± 1.2	t=-1.75; P=0.16
Sulphur		10.0 ± 1.3	8.4 ± 0.8	t=0.96; P=0.39
Control		10.6 ± 1.1	10.0 ± 1.1	t=0.48; P=0.66
		$F_{(3,16)}$=0.99;P=0.42	$F_{(3,16)}$=2.45;P=0.72	
Triadimenol	November	9.2 ±1.2	8.6 ± 1.1	t=0.69; P=0.53
Triadimefon		9.0 ± 1.1	9.2 ± 1.2	t=0.20; P=0.85
Sulphur		7.8 ±0.9	9.4 ± 1.0	t=1.21; P=0.29
Control		9.6 ± 0.6	10.4 ± 1.4	t=0.57; P=0.60
		$F_{(3,16)}$=0.64;P=0.60	$F_{(3,16)}$=0.38;P=0.77	
Mkuranga 2011				
Triadimenol	August	13.6 ±0.9	12.4±0.8	t=1.81;P=0.15
Triadimefon		14.2 ±0.7	14.6±1.1	t=-0.79;P=0.48
Sulphur		13.8 ±0.6	15.2±1.0	t=-1.25;P=0.28
Control		14.6 ±0.2	14.6±0.5	t=0.00;P=1.00
		$F_{(3,16)}$=0.44;P=0.73	$F_{(3,16)}$=1.95;P=0.16	
Triadimenol	September	13.4 ±0.8	13.6±0.5	t=-0.23;P=0.83

Triadimefon		13.8 ±0.7	13.8±0.9	t=0.00;P=1.00
Sulphur		13.8 ±0.6	13.2±1.2	t=0.40;P=0.71
Control		14.8 ±0.4	14.8±0.6	t=0.00;P=1.00
		$F_{(3,16)}$=0.96;P=0.43	$F_{(3,16)}$=0.62;P=0.61	
Triadimenol	October	14.2 ±1.0	13.2±1.2	t=0.61;P=0.58
Triadimefon		13.4 ±0.3	14.2±0.6	t=-2.14;P=0.10
Sulphur		13.4 ±0.3	14.0±1.1	t=0.58;P=0.59
Control		14.4 ±0.4	15.0±1.1	t=-0.80;P=0.47
		$F_{(3,16)}$=0.91;P=0.46	$F_{(3,16)}$=0.54;P=0.66	
Triadimenol	November	13.6 ±0.6*	15.6±0.8*	t=-3.65;P=0.02
Triadimefon		13.8 ±0.7	13.6±1.0	t=0.12;P=0.91
Sulphur		14.0 ±0.6	15.2±0.6	t=-1.12;P=0.32
Control		14.8±0.4	14.8±0.6	t=0.00;P=1.00
		$F_{(3,16)}$= 0.83;P=0.50	$F_{(3,16)}$=1.30;P=0.31	

* denotes means which are significantly different at P < 0.05*t*-tests

Table 5.2 Monthly mean number (X±SE) AWA leaf nests per tree before and after application of triadimenol, triadimefon, sulphur and control in cashew fields at the Bagamoyo and Mkuranga in 2012.

Bagamoyo 2012				
Treatment	Month	Mean number of leaf nests (X±SE)		Dependent t-test
		Before treatment	After treatment	and P-value
Triadimenol	August	9.6±0.9	8.8±1.3	t=1.00; P=0.37
Triadimefon		8.4±0.8	8.4±1.2	t=0.00; P=1.00
Sulphur		9.2±1.2	7.4±0.8	t=2.45; P=0.07
Control		11.2±1.4	10.0±1.5	t=1.24; P=0.28
		F(3,16)=1.13;P=0.37	F(3,16)=0.78;P=0.52	
Triadimenol	September	10.0±0.9	9.6±0.9	t=0.67; P=0.54
Triadimefon		10.0±0.9	10.8±2.5	t=-0.38; P=0.72
Sulphur		9.6±1.2	9.8±1.7	t=-0.08;P =0.94
Control		11.0±1.1	9.6±1.8	t=0.63; P=0.56
		F(3,16)=0.33;P=0.81	F(3,16)=0.10;P=0.96	
Triadimenol	October	10.0±0.7	10.2±1.1	t=-0.13; P=0.91
Triadimefon		8.8±1.0	8.0±1.6	t=0.83; P=0.46
Sulphur		11.8±.1.1	9.6±1.2	t=1.08; P=0.34
Control		11.2±0.7	9.0±0.9	t=2.06; P=0.11
		F(3,16)=2.20;P=0.13	F(3,16)=0.60;P=0.63	
Triadimenol	November	9.0±1.1	8.6±1.5	t=0.36; P=0.74
Triadimefon		9.2±1.1*	7.4±0.7*	t=3.09; P=0.04
Sulphur		9.2±1.1	6.8±1.5	t=1.16; P=0.31
Control		10.0±0.6	10.0±1.1	t=0.00; P=1.00
		F(3,16)=0.21;P=0.89	F(3,16)=1.34;P=0.30	
Mkuranga 2012				
Triadimenol	August	11.0±1.4	10.2±1.8	t=1.00; P=0.38
Triadimefon		10.6±3.0	10.0±3.0	t=1.00; P=0.37
Sulphur		12.4±0.7	12.4±0.7	t=0.00; P=1.00
Control		10.4±1.3	10.4±1.3	t=0.00; P=1.00
		F(3,16)=0.25;P=0.86	F(3,16)=0.34;P=0.80	
Triadimenol	September	10.8±1.5	11.0±1.4	t=-1.00; P=0.37
Triadimefon		11.2±1.7	11.2±1.7	t=0.00; P=1.00

Sulphur		13.2±1.4	13.2±1.4	t=0.00; P=1.00
Control		11.2±0.9	11.2±0.9	t=0.00; P=1.00
		F(3,16)=0.60;P=0.62	F(3,16)=0.57;P=0.65	
Triadimenol	October	10.2±1.2	11.2±1.2	t=0.00; P=1.00
Triadimefon		12.4±1.2	12.4±1.2	t=0.00; P=1.00
Sulphur		13.8±1.6	13.8±1.4	t=0.00; P=1.00
Control		11.6±0.5	11.6±0.5	t=0.82; P=0.46
		F(3,16)=1.59;P=0.23	F(3,16)=1.59;P=0.23	
Triadimenol	November	11.4±1.6	11.6±1.6	t=-1.00; P=0.37
Triadimefon		12.4±1.2	12.4±1.2	t=0.00; P=1.00
Sulphur		11.4±1.4	11.4±1.4	t=0.00; P=1.00
Control		10.6±1.3	10.4±1.2	t=1.00; P = 0.37
		F(3,16)=0.28;P=0.84	F(3,16)=0.35;P=0.79	

* denotes means which are significantly different at P < 0.05 *t*-test

5.4.2 AWAtrails colonization

There were no significant difference in the effect the different fungicides on the percentage colonization of AWA trails ($F_{3,35}$= 1.81; P = 0.16) and ($F_{3,35}$ = 0.10; P = 0.96) in 2011 and 2012, respectively. The percentage AWA trail colonization did also not differ significantly between sites ($F_{1,35}$ = 1.13; P = 0.30) and ($F_{1,35}$ = 0.61; P = 0.44) in 2011 and 2012, respectively. Similarly, the monthly applications of fungicides did not affect the mean percentage colonization expressed as AWA trails within the sites for both seasons significantly (Tables 5.3 and 5.4). In August 2011, AWA colonization before application ranged from 63.3-66.7% and from 66.7-73.3% at Bagamoyo and Mkuranga, respectively, and ranged from 59.2-68.3% and from 56.7-70.0% at Bagamoyo and Mkuranga, respectively (Table 5.3). The same trend was also observed in September, October and November 2011(Table 5.3). In August 2012, AWA colonization before application ranged from 65.0-70.0% and from 73.3-76.7% at Bagamoyo and Mkuranga, respectively, and after application ranged from 58.3-65.5% and from 63.0-68.3% at Bagamoyo and Mkuranga, respectively (Table 5.4). The same trend was also observed in September, October and November 2012 (Table 5.4).

Table 5.3 Monthly AWA trails colonization (X±SE) before and after application of triadimenol, triadimefon, sulphur and control in cashew field at the Bagamoyo and Mkuranga in 2011.

Bagamoyo 2011

Treatment	Month	Percentage AWA trails (X±SE)		Dependent t-test
		Before treatment	After treatment	and P-value
Triadimenol	August	64.2±4.1	59.2±3.8	t=1.50; P=0.21
Triadimefon		63.3±4.0	61.2±3.1	t=0.93; P=0.40
Sulphur		65.0±6.7	68.3±9.3	t=-0.59; P=0.59
Control		66.7±4.6	68.3±5.1	t=-0.22; P=0.84
		$F_{(3,16)}$=0.08;P=0.97	$F_{(3,16)}$=0.67;P=0.58	
Triadimenol	September	68.3±5.5	57.5±7.3	t=1.86; P=0.14
Triadimefon		64.2±4.1	61.2±3.1	t=1.62; P=0.18
Sulphur		63.3±5.7	63.3±5.7	t=1.00; P=0.37
Control		68.3±5.5	71.0±5.9	t=-0.39; P=0.72
		$F_{(3,16)}$=0.26;P=0.85	$F_{(3,16)}$=1.00;P=0.42	
Triadimenol	October	65.8±4.6	64.2±4.1	t=0.54; P=0.62
Triadimefon		64.5±5.5	63.2±3.5	t=0.31; P=0.77
Sulphur		68.3±5.5	58.3±5.3	t=1.50; P=0.21
Control		70.0±5.7	71.7±6.2	t=-0.17; P=0.87
		$F_{(3,16)}$=0.21;P=0.89	$F_{(3,16)}$=1.27;P=0.32	
Triadimenol	November	65.8±5.3	72.5±4.1	t=-0.93; P=0.41
Triadimefon		64.5±5.5	74.8±6.6	t=-2.13; P=0.10
Sulphur		65.0±6.1	65.0±11.3	t=0.00; P=1.00
Control		66.7±4.6	80.7±3.7	t=-2.37; P=0.08
		$F_{(3,16)}$=0.03;P=0.99	$F_{(3,16)}$=0.83;P=0.50	
Mkuranga 2011				
Triadimenol	August	73.3±1.7	66.7±4.6	t=1.37; P=0.24
Triadimefon		66.7±4.6	60.8±7.4	t=1.61; P=0.18
Sulphur		69.2±2.5	56.7±8.9	t=1.79; P=0.15
Control		71.7±5.7	70.0±5.0	t=1.00; P=0.37
		$F_{(3,16)}$=0.55;P=0.66	$F_{(3,16)}$=0.79;P=0.52	
Triadimenol	September	73.3±1.7	73.3±8.1	t=0.00; P=1.00

Triadimefon		66.7±4.6	61.7±8.9	t=0.74; P=0.50
Sulphur		71.7±3.3	68.3±9.3	t=0.54; P=0.62
Control		70.0±2.0	76.7±6.1	t=-1.21;P=0.29
		$F_{(3,16)}$=0.83;P=0.50	$F_{(3,16)}$=0.63;P=0.61	
Triadimenol	October	70.0±5.7	70.0±5.7	t=0.00; P=1.00
Triadimefon		65.0±4.1	63.3±5.7	t=0.41; P=0.70
Sulphur		68.3±4.9	60.0±6.1	t=1.58; P=0.19
Control		70.0±2.0	73.3±6.1	t=-0.67; P=0.54
		$F_{(3,16)}$=0.29;P=0.83	$F_{(3,16)}$=1.07;P=0.39	
Triadimenol	November	66.7±7.0	66.7±7.0	t=1.00; P=0.37
Triadimefon		64.2±4.1	70.8±7.4	t=-0.61; P=0.58
Sulphur		61.7±7.3	75.0±3.7	t=-1.37; P=0.24
Control		70.0±2.0	80.0±9.4	t=-0.91; P=0.41
		$F_{(3,16)}$=0.41;P=0.75	$F_{(3,16)}$=0.64;P=0.60	

Table 5.4 Monthly AWA trails colonization (X±SE) before and after application of triadimenol, triadimefon, sulphur and control in the cashew field at Bagamoyo and Mkuranga in 2012.

Treatment	Month	Percentage AWA trails (X±SE)		Dependent t-test
		Before treatment	After treatment	and P-value
Bagamoyo 2012				
Triadimenol	August	68.3±4.9	62.7±6.9	t=1.17; P=0.31
Triadimefon		70.0±2.0	65.5±5.2	t=0.67; P=0.54
Sulphur		65.0±6.7	58.3±7.5	t=0.93; P=0.41
Control		68.3±4.9	63.3±9.7	t=0.45; P=0.66
		$F_{(3,16)}$=0.18;P=0.91	$F_{(3,16)}$=0.16;P=0.92	
Triadimenol	September	73.3±4.1	66.3±7.5	t=0.89; P=0.43
Triadimefon		67.5±5.7	64.7±4.9	t=0.46; P=0.67
Sulphur		73.3±7.2	65.5±6.4	t=1.38; P=0.24
Control		71.7±5.7	71.0±5.9	t=0.25; P=0.82
		$F_{(3,16)}$=0.23;P=0.88	$F_{(3,16)}$=0.20;P=0.89	
Triadimenol	October	70.8±6.5	70.3±5.6	t=0.05; P=0.96
Triadimefon		67.5±5.7	65.8±4.9	t=0.23; P=0.83
Sulphur		71.6±10.4	72.8±3.5	t=-0.13; P=0.91
Control		73.3±8.5	69.3±5.3	t=0.52; P=0.63
		$F_{(3,16)}$=0.09;P=0.96	$F_{(3,16)}$=0.35;P=0.79	
Triadimenol	November	67.5±5.7	68.3±1.7	t=-0.14; P=0.90
Triadimefon		67.5±5.7	75.8±6.7	t=-1.82; P=0.14
Sulphur		65.0±6.7	69.2±6.2	t=-0.50; P=0.64
Control		73.3±6.1	76.5±5.1	t=-0.31; P=0.78
		$F_{(3,16)}$=0.34;P=0.80	$F_{(3,16)}$=0.65;P=0.60	
Mkuranga 2012				
Triadimenol	August	75.0±2.6	66.7±8.7b	t=1.29; P=0.27
Triadimefon		73.3±6.1	63.0±8.3b	t=1.06; P=0.35
Sulphur		75.0±3.8	68.3±5.5b	t=2.15; P=0.10
Control		76.7±3.1	66.7±7.0b	t=2.06; P=0.11
		$F_{(3,16)}$=0.11;P=0.95	$F_{(3,16)}$=0.09;P=0.96	

Triadimenol	September	76.7±3.1	62.5±7.9	t=2.56; P=0.06
Triadimefon		73.3±3.1	67.5±5.6	t=1.60; P=0.18
Sulphur		70.0±5.7	65.0±7.8	t=0.59; P=0.59
Control		73.3±8.1	68.3±4.9	t=0.47; P=0.67
		$F_{(3,16)}$=0.25;P=0.86	$F_{(3,16)}$=0.16;P=0.92	
Triadimenol	October	73.3±6.1*	67.7±5.1*	t=3.30; P=0.03
Triadimefon		75.0±6.5	69.3±5.3	t=0.66; P=0.55
Sulphur		73.3±3.1	68.0±8.3	t=0.81; P=0.47
Control		75.0±2.6*	64.1±4.1*	t=3.00; P=0.04
		$F_{(3,16)}$=0.04;P=0.99	$F_{(3,16)}$=0.14;P=0.93	
Triadimenol	November	75.0±7.0	78.5±6.1	t=-0.70; P=0.52
Triadimefon		72.6±4.2	68.7±5.5	t=0.54; P=0.62
Sulphur		73.3±3.1	68.3±4.9	t=0.89; P=0.43
Control		71.7±2.0	66.7±4.6	t=1.50; P=0.21
		$F_{(3,16)}$=0.10;P=0.96	$F_{(3,16)}$=1.03;P=0.41	

* denotes means which are significantly different at $P < 0.05$ *t*-test

5.5 Discussion

Applications of powdery mildew fungicides did not affect the abundance of AWA in the two cashew growing areas at Bagamoyo and Mkuranga districts. This finding is in contrast to that of Gowans (2013) who reported that sulphur based fungicides act differently than insecticides, targeting different species of insects and these fungicides can reduce number of ants.

The strength of AWA colonies recorded was similar to that reported in a previous study (Olotu *et al*., 2012). Similar results were recorded with the three powdery mildew fungicides in the southern Tanzania (Sijaona, personal communication). Application of triadimenol and sulphur fungicides for PMD control in grapevine in South Africa was also reported not to affect the abundances of predaceous mite, *Ambyseius addoensis* Van der Merwe & Ryke (Acari: Phytoseiidae) (Schwartz, 1993).

In conclusion, the use of the three powdery mildew fungicides (triadimenol, triadimefon and sulphur) does not have detrimental effects on the abundance

of AWA in cashew fields at Bagamoyo and Mkuranga districts of the Coast region of Tanzania, and can therefore be used together with AWA as components of an integrated pest and disease management programme for cashew crops in Tanzania.

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CHAPTER SIX

Efficacy of fish and hydramethylon-based baits for conservation of African weaver ant *Oecophylla longinoda* during cashew off-seasons in Tanzania

6.1 Abstract

The efficacy of fish and hydramethylon-based baits for conservation of African weaver ant (AWA), *Oecophylla longinoda* Latreille, during the off-season was evaluated in the cashew fields at Bagamoyo and Mkuranga districts, Coast region of Tanzania. The baits were applied at monthly intervals and dynamics of AWA were monitored by counting number of leaf nests per tree and colonization trails on main branches. The numbers of leaf nests recorded before baiting were not significantly different at both sites and both seasons and ranged between 3.5 and 5.3. The number of leaf nests did, however, differ after baiting. It ranged between 3.2 and 11.6; and between 3.0 and 10.2 at Bagamoyo and Mkuranga, respectively. The colonization of AWA trails recorded before baiting was also not significantly different at both sites and both seasons, it ranged between 37.9 and 50.0%. The colonization of AWA trails differ after baiting, it ranged between 35.9 and 75.1% and between 34.6 and 79.2% at Bagamoyo and Mkuranga, respectively. The provision of fish and hydramethylon-based baits can effectively contribute to conservation of AWA during cashew off-seasons. Of the two conservation baits, fish-based bait is cheaper and more affordable by local farmers and can therefore be used as an alternative diet for AWA during cashew off-season.

6.2 Introduction

The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) is an effective biocontrol agent of the sap-sucking pests in coconut (Varela, 1992; Seguni, 1997) and cashew in Tanzania (Olotu *et al.,* 2012). It also effectively controls mango pests in Benin (Van Mele *et al.,* 2007) and cashew pests in Ghana (Dwomoh *et al.,* 2009). In East Africa, AWA occurs naturally in more than 80 species of shrubs as well as in wild and cultivated trees along the coastal forest of Kenya and Tanzania (Varela, 1992). The abundance of AWA varies significantly with cashew seasonality. For example, stable AWA colonies were observed during cashew on-seasons in contrast to those that occurred during off-seasons (see Fig. 2.1; Chapter 2). During cashew on-seasons, AWA abundance is reported to build up, which coincides with occurrence of sap-sucking pests, *Helopeltis anacardii* Miller, and *H. schoutedeni* Reuter (Hemiptera: Miridae), and *Pseudotheraptus wayi* Brown (Hemiptera: Coreidae) (Olotu *et al.,* 2012). Except for the effect of cashew seasonality, AWA abundance has also been reported to be affected by the presence of dominant competing ant species particularly the inimical ant, *Pheidole megacephala* Fabricius (Hymenoptera: Formicidae) that can displace it (Way & Khoo, 1992).

For an effective sap-sucking pest management programme on cashew by AWA, strategies to enhance its abundance need to be developed and promoted. Synthetic chemical insecticides have been used to control competing ants in order to allow natural increase of *Oecophylla* spp. populations (Way & Khoo, 1992). For example, the hydramethylon ant bait (Amdro®) has been used successful in selectively controlling *P. megacephala* in East Africa (Zerhusen & Rashid, 1992; Varela, 1992; Seguni, 1997) where the ant is a major competitor of AWA (Way, 1953). Similar results were also reported in cashew crops in Tanzania where the use of the hydramethylon ant bait resulted in stable AWA colonies in cashew crops (Olotu *et al*., 2012). Initially, hydramethylon ant bait had been developed to control the red imported fire ant *Solenopsis invicta* Buren (Hymenoptera: Formicidae) in the

U.S.A (Williams *et al.,* 1980) and later to control the big headed ant in pineapple in Hawaii (Su *et al*., 1980). In Africa, it was first registered in South Africa to control *P. megacephala* (Samways, 1981).

Since ants prefer food high in protein for larval nourishment (Hölldobler & Wilson, 1990; Haack *et al.,* 1995; Blüthgen & Fiedler, 2004), their conservation can also be achieved by supplementing their diets during seasons when food is scarce (Van Mele & Cuc, 2007; Peng *et al.,* 2009). Provision of food resources with high protein can facilitate ant colony expansion (Haack *et al.,* 1995). Ants have been reported to invest more energy searching for food resources with high protein during scarcity (Kay, 2002). Fish-based baits have been used to strengthen colonies of green tree ants, *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) (Lim, 2007; Offenberg & Wiwatwitaya, 2010). Dried fish has also been used in Africa to supplement diet of AWA during the food scarce seasons (Van Mele & Cuc, 2007). Similar to fish food provision, cultural practices such as maintenance of ground vegetation by regular slashing (Seguni, 1997) and inter-planting of alternative host plant species with the main crop (Way & Khoo, 1991; Peng *et al.,* 1997; Van Mele & van Lanteren, 2002) are also effective in strengthening AWA colonies. The aim of the present study was to evaluate strategies for conservation of AWA colonies during cashew off-seasons for sustainable management of sap-sucking insect pests in cashew crops.

6.3 Materials and methods

6.3.1 Experimental sites

Experiments were conducted in cashew fields at Bagamoyo (S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l) and Mkuranga (S 07° 3.5', E 39° 15', 90.53 m.a.s.l), Coast region of Tanzania. The experiment was conducted during two cashew off-seasons, when there were no shoot flushes or flowers, from January to June 2011 and 2012. The cashew field at Bagamoyo consisted of trees planted in monoculture and the majority of them were well separated from

each other. The cashew trees at Mkuranga were irregularly intercropped with mango, coconut and citrus trees.

6.3.2 Provision of fishand hydramethylon-based baits

Discarded fresh fish intestines were collected from a fish market in Dar-es Salaam and were provided to AWA workers at the rate of 15g per tree. Fish-based bait was prepared in cups made from water bottles (70mm diameter and 60mm height) (Plate 6.1*a*). Cups were secured onto main branches at 2m above soil level using manila thread. Hydramethylon ant bait (Amdro®) used to suppress *P. megacephala* was provided at the rate of 3g per tree by sprinkling the granules around the bases of the selected cashew trees (Plate 6.1*b*).

Ten cashew trees per treatment were selected at random and assigned the following treatments: (i) cashew trees were provided with fresh fish intestines alone; (ii) cashew trees were baited with hydramethylon alone; (iii) cashew trees baited with both fish and hydramethylon, and (iv) cashew trees were left without provision of baits and were used as controls. The selected trees under observation were recorded on a piece of flagging tied to the trunk with detailed information such as date, tree number and type of treatment. Fish and hydramethylon-based baits were provided once a month.

6.3.3 Quantification of AWA

The abundance of AWA was determined once before provision of baits and monthly for four months after provision of baits. It was expressed as number of AWA leaf nests per tree and number of AWA trails on the main branches. It was determined according to the method described in Chapter 2 (2.3.2).

6.3.4 Dataanalysis

Repeated measures ANOVA was used to analyse the effect of provision of baits on number of AWA leaf nests and percentage trail colonization over time using STATISTICA version 11 (Stasoft, Inc., Tulsa, Oklahoma, USA).

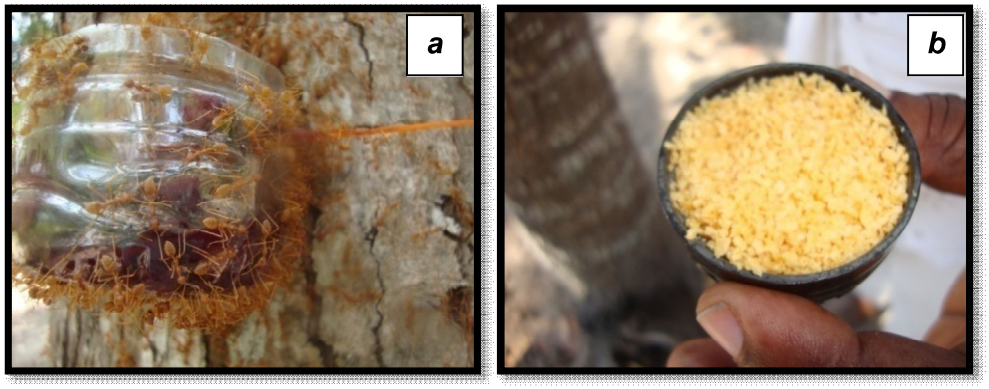


Plate 6.1 Two baits, (a) a cup containing 15g of fresh fish intestines and (b) a cup containing 3g of hydramethylon ready for sprinkling around the base of the tree.

6.4 Results

6.4.1 AWA leaf nests

The number of AWA leaf nests recorded per tree before baiting was not significantly different at both sites and both seasons (Figures 6.1 and 6.2) and ranged between 3.5 and 5.2. Following provision of the baits, the number of AWA leaf nests generally remained similar in the control throughout the experiment, but increased significantly in all the treatments ($F_{(3,36)} = 18.89$; $P < 0.001$) at Bagamoyo in 2011. There were however significant differences between the different treatments (Figures 6.1 and 6.2). A similar trend was observed in 2012 at Mkuranga in 2011, but there were no significant differences in the number of AWA leaf nests in treatments where fish and hydramethylon were used alone. However, the number of AWA leaf nests was higher in combined fish and hydramethylon treatments ($F_{(3,36)} = 36.09$; $P < 0.001$) (Figure 6.1).

6.4.2 AWA trails colonization

Similar to AWA leaf nests, the percentage colonization of trails recorded before baiting was not significantly different at both sites and both seasons (Figures 6.3 and 6.4). A similar trend was observed in 2012 (Figure 6.4). At Mkuranga, there were no significant differences in the percentage trails colonization in treatments where fish and hydramethylon were used alone (Figures 6.3 and 6.4). However, the percentage trails colonization was higher in combined fish and hydramethylon treatments ($F_{(3,36)} = 41.28; P < 0.001$ (Figure 6.3).

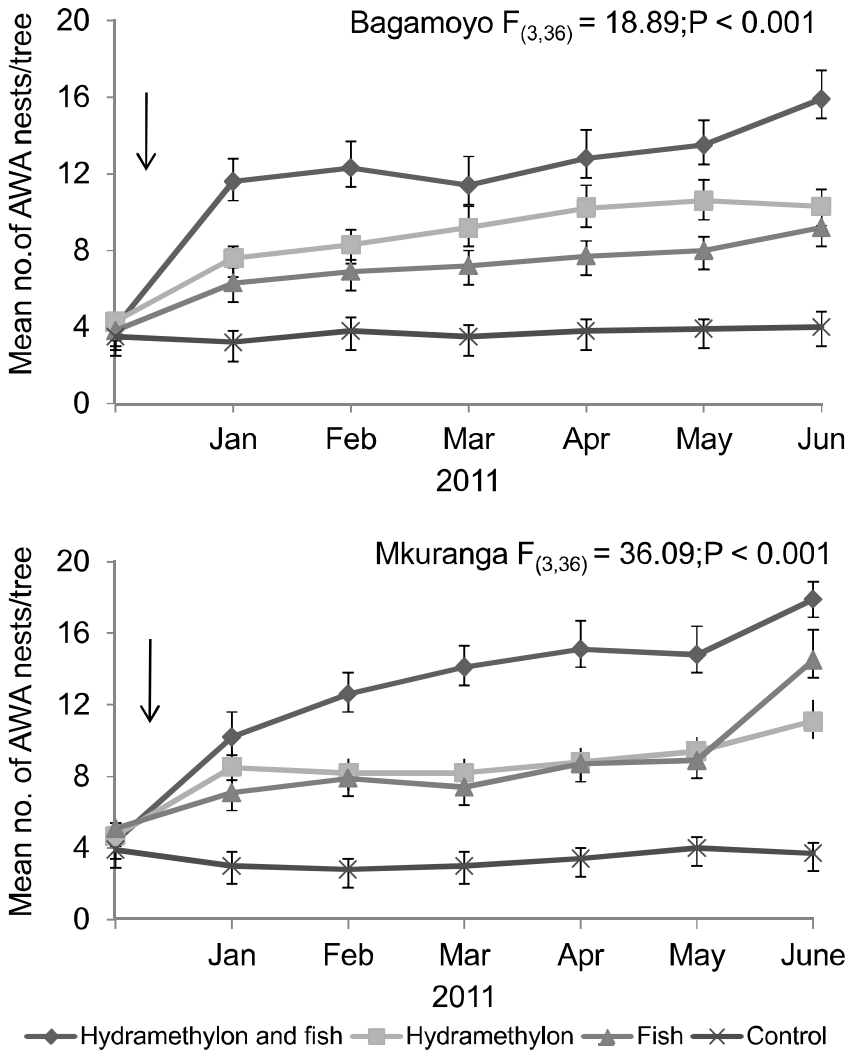


Figure 6.1 Mean number of AWA leaf nests in the trees baited with hydramethylon and fish, hydramethylon alone, fish alone and control in the cashew fields at Bagamoyo and Mkuranga in 2011. The arrow denotes the beginning of the baiting. Bars indicate SE.

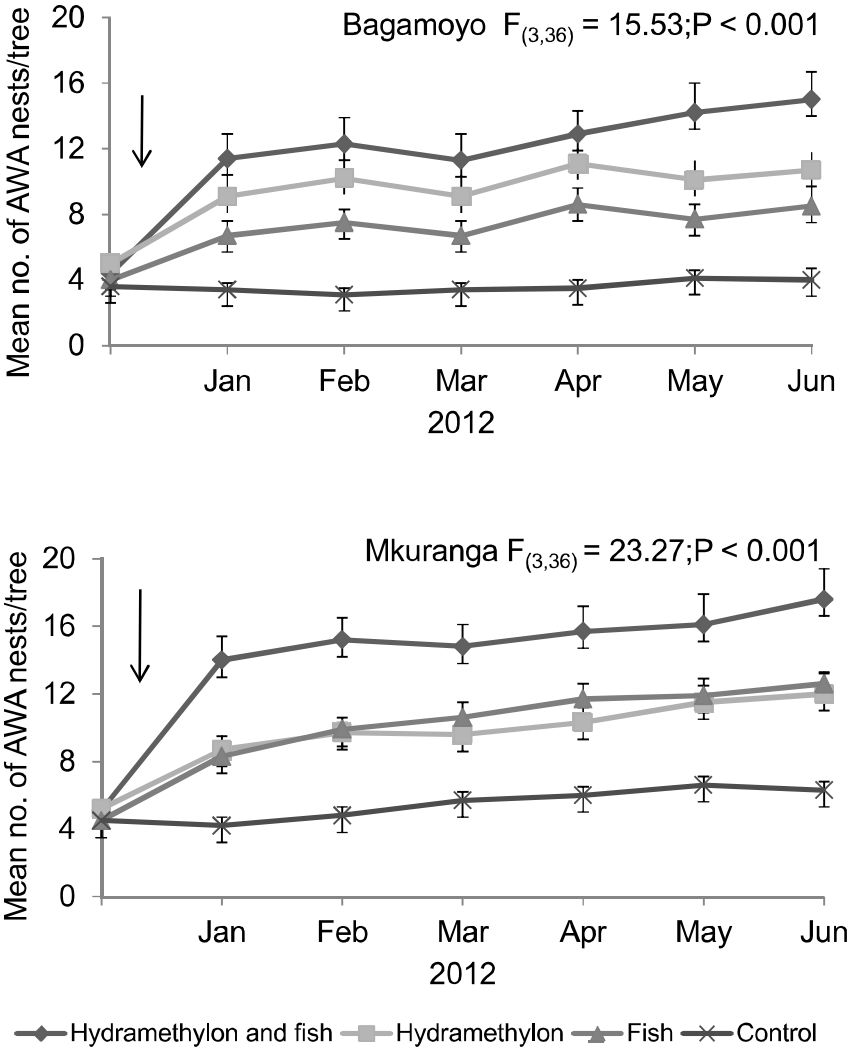


Figure 6.2 Mean number of AWA leaf nests in the trees baited with hydramethylon and fish, hydramethylon alone, fish alone and control in the cashew fields at Bagamoyo and Mkuranga in 2012. The arrow denotes the beginning of the baiting. Bars indicate SE.

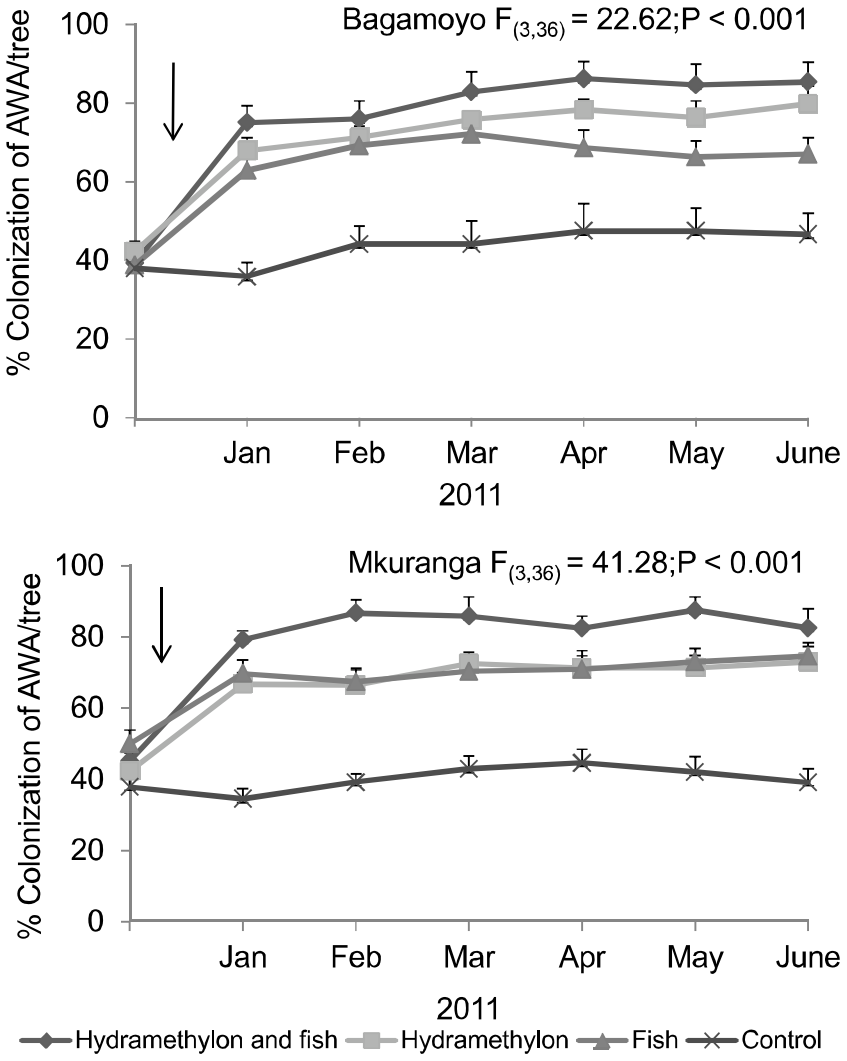


Figure 6.3 Percentage AWA trails colonization in the trees baited with hydramethylon and fish, hydramethylon alone, fish alone and control in the cashew fields at Bagamoyo and Mkuranga in 2011. The arrow denotes the beginning of the baiting. Bars indicate SE.

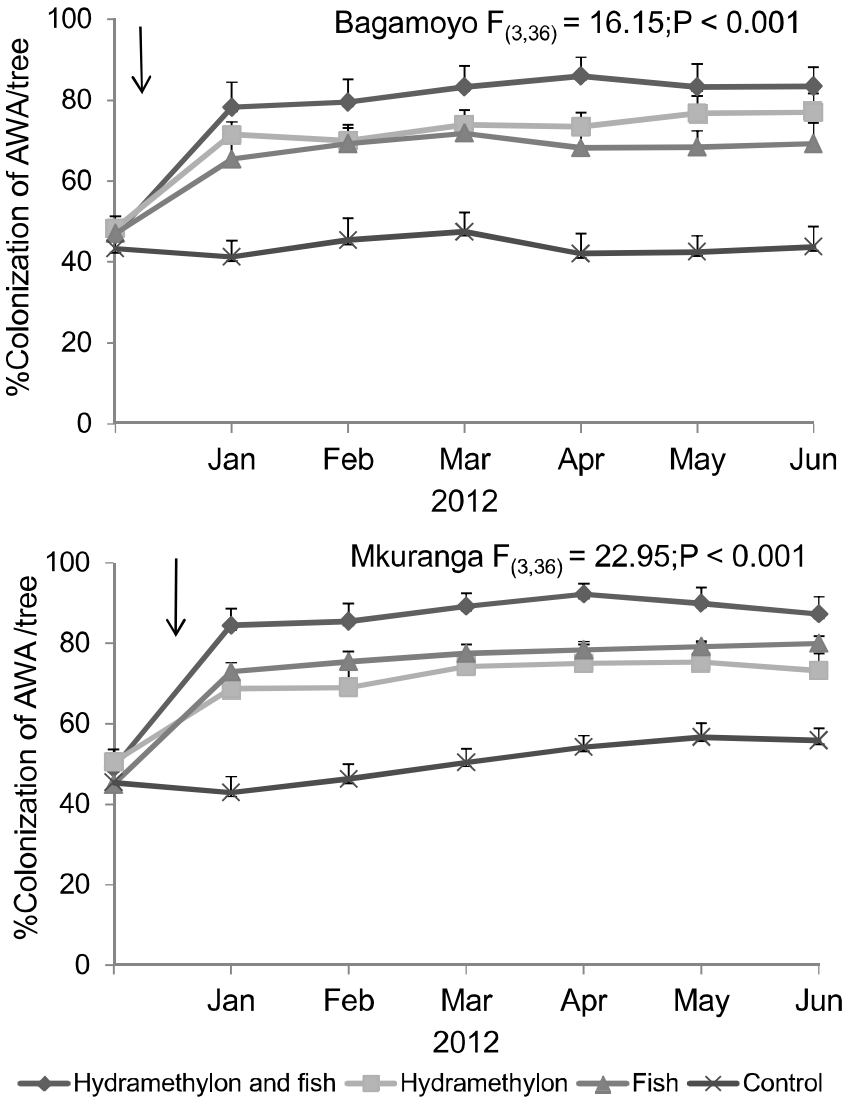


Figure 6.4 Percentage colonization AWA trails in the trees baited with hydramethylon and fish, hydramethylon alone, fish alone and control in the cashew fields at Bagamoyo and Mkuranga in 2012. The arrow denotes the beginning of the baiting. Bars indicate SE.

6.5 Discussion

High mean number of AWA leaf nests per tree and stable AWA trails colonization were recorded after provision of different baits at the two sites during the 2011 and 2012 cashew off-seasons. It can be ascribed to the efficacy of these baits in promoting conservation of AWA. Provision of fish alone was as effective as hydramethylon alone. The provision of fish-based bait is therefore considered as an alternative source of food, which supplemented the diet of AWA during cashew off-seasons. The use of fish-based bait was also used for conservation of AWA in forests (Van Mele & Cuc 2007) and the green ant, *Oecophylla smaragdina* Fabricius (Hymenoptera: Formicidae) (Peng *et al.,* 2009). In Malaysia, the provision of food has been proved to augment *O. smaragdina* populations in a mahogany plantation (Lim, 2007). Supplementing the diet of AWA with fish-based bait contribute to maintaining and strengthening of AWA colonies within the cashew fields which should otherwise have moved out of the fields in search for food resources.

Apart from supplementing the diet of AWA with fish-based bait, application of hydramethylon ant bait contributed to the high number of AWA leaf nests per tree and stable colonization of AWA trails during cashew off-seasons. The use of hydramethylon bait has been proved effective for control of *P. megacephala* in coconut groves (Varela, 1992; Seguni, 1997) and in cashew groves (Olotu *et al.,* 2012). AWA workers were observed foraging on other host plants in the absence of *P. megacephala* and can also co-exist with *P. megacephala* under suitable ground vegetation in citrus groves (Seguni *et al*., 2011).

It can be concluded that the provision of fish and hydramethylon-based baits can effectively contribute to conservation of AWA during cashew off-seasons. Of the two conservation baits, fish-based bait is cheaper and more affordable by local farmers and can therefore be used as an alternative diet for AWA during cashew off-season.

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CHAPTER SEVEN

Abundance and diversity of ground-dwelling ant species in cashew agro-ecosystems in Tanzania

7.1 Abstract

Ants are well-known to play significant ecological roles in agro-ecosystems. Yet, information on their abundance and diversity in cashew agro-ecosystems is scanty. The abundance, diversity and richness of ant species occurring in cashew fields was determined using pitfall traps. A total of 14001 ants were trapped belonging to six subfamilies, 18 genera and 32 species. Their abundance, diversity and richness varied according to sampling sites and seasons. However, more ants were trapped in trees without the African weaver ant (AWA) and buffer zones than in trees colonized with AWA. A total of 2011, 673, 1131 and 3866 ants were recorded in cashew fields at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B, respectively in 2011. Similarly, there were 1252, 641, 1287 and 3140 ants at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B, respectively in 2012. The common pugnacious ant (CPA), *Anoplolepis custodiens* Smith was the most abundant ants in the pitfall traps. Similarly, two genera, *Pheidole* sp.3 and *Tapinoma* sp. did not appear in the second year of sampling. Although CPA was abundant and probably responsible for structuring the ant community, further experimentation is needed to elucidate this interaction.

7.2 Introduction

Ants are ubiquitous, abundant and diverse, and constitute an important fraction of animal biomass in terrestrial ecosystems (Hölldobler & Wilson 1990). They are most abundant in the tropics and represent up to 85% of animal biomass in forest canopies (Hölldobler & Wilson, 1990; Davidson *et al.,* 2003). Ants are very susceptible to environmental disturbances as they are fixed to the same location; this enables ants to be used as bioindicators and for environmental monitoring programmes (Andersen, 1993; Wang *et al.,* 2000). They perform essential ecological functions such as nutrient cycling, seed dispersal and regulating populations of other insects, especially insect pests (Hölldobler & Wilson, 1990; Folgarait, 1998).

Ants are a useful focal taxon in agro-ecological research also (Philpott & Armbrecht, 2006), and are considered as typical dominant predators and scavengers (Fellers, 1987). One to the efficiency of ants as predators they can play an important role in limiting damage caused by insect pests in agro-ecosystems (Philpott & Armbrecht, 2006; Armbrecht & Gallego, 2007). *Oecophylla* species are good candidates for biocontrol agents because they are vigilant and territorial predators of living creatures in their arboreal domain (Hölldobler & Wilson, 1990). The African weaver ant (AWA), *Oecophylla longinoda* Latreille (Hymenoptera: Formicidae) has successfully been used to control sap-sucking pests in Africa (Van Mele, 2008, Dwomoh *et al.,* 2009; Olotu *et al.,* 2012). Similarly, *O. smaragdina* Fabricius (Hymenoptera: Formicidae) was reported to control over 50 species of insect pests on many tropical tree crops and forest trees in Australia and Asia (Peng *et al.,* 2005; Peng *et al.,* 2010; Peng *et al.,* 2011).

Agricultural intensification such as pruning can reduce canopy complexity which causes a decrease in ant species richness and abundance (Philpott *et al.,* 2008). Some agricultural land-use types, however, can conserve biodiversity (Bhagwat *et al.,* 2008), resulting in better pest regulation. Ants also are important for the protection of species and their habitats outside

formally protected areas, because they maintain heterogeneity at local habitat and landscape scales (Rizali *et al.,* 2012).

The abundance and diversity of ants have been studied in cashew agro-ecosystems in Sri Lanka, India and Malaysia (Rickson & Rickson, 1998) and in coconut agro-ecosystems in Tanzania (Varela, 1992). However, there is little information about their abundance, diversity and richness in cashew agro-ecosystems in Tanzania. This study aimed therefore to determine the abundance and diversity of ant species in Tanzanian cashew agro-ecosystems.

7.3 Materials and methods

7.3.1 Experimental sites

Sampling of ants were conducted in cashew fields at Bagamoyo(S 06° 49.3', E 38° 54.8', 53.43 m.a.s.l), Kibaha (S 06° 33.4', E 38° 54.7', 150.57 m.a.s.l), Mkuranga A (S 07° 3.5', E 39° 15', 90.53 m.a.s.l) and Mkuranga B (S 7° 3.50', E 39° 14.92', 120.70 m.a.s.l), Coast region of Tanzania. The average annual rainfall of the region is 1000mm. Cashew trees at the Bagamoyo and Kibaha sites were planted in a monoculture system and ground vegetation was rich because no weed control was done. The cashew trees at Mkuranga A and Mkuranga B were irregularly intercropped with mango, coconut and citrus trees. Regular weeding at Mkuranga B resulted in little ground cover vegetation.

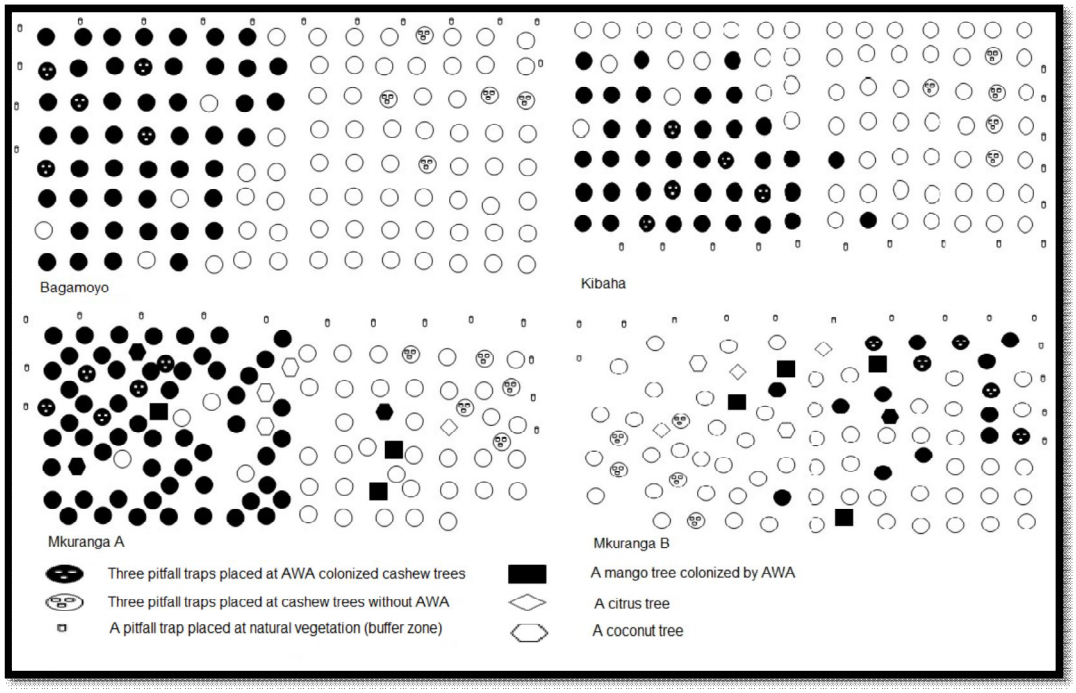


Figure 7.1 Schematic presentation of the placing of pitfall traps at the four experimental sites.

7.3.2 Pitfall trapping of ant communities

The ants at each site were sampled with 45 pitfall traps. In each site, 15 pitfall traps were placed under five cashew trees colonized by AWA and 15 traps were placed under five trees not colonized by AWA. These traps were placed in sets of three pitfall traps per tree, forming a triangle from the tree base. In addition, 15 pitfall traps were placed along the border of the cashew field with natural vegetation (buffer zone) to form a transect of 150m at 10m intervals (Figure 7.1). This transect was parallel to cashew trees colonized by AWA and uncolonized cashew trees. The trials were carried once in each of the three months, from September to November 2011 and 2012. Pitfall traps were constructed with PVC tubing with an internal bore of 2.5 cm and length of 20 cm which was sunken into the soil with one end flush with the soil surface. These tubes were sealed when not in use. During sampling, specimen tubes (2.3 x 15 cm) were inserted into the plastic tubing to fit flush with the soil surface.

Pitfall trapping was done for six consecutive days per sampling event. Seven milliliters solution containing 70% ethanol and 5% glycerol was added into each pitfall trap to preserve the trapped specimens in the field. After six days, the pitfall traps were removed from the fields and taken to a pest control section at Mikocheni Agricultural Research Institute (MARI) laboratory, Dar-es-Salaam for sorting and identification. Overall, pitfall trapping was done for 144 days during the cashew seasons of 2011 and 2012.

7.3.3 Sorting of the ant specimens

The contents of each pitfall trap was rinsed with distilled water and sieved with a 250-µm mesh. Ant specimens were separated from other arthropods and then sorted to morphospecies using a dissecting microscope at 7x magnification. All specimens were stored in a solution of 70% ethanol and 5% glycerol. Ant specimens were identified to genus levels and were sent to AfriBugs laboratory, Pretoria, South Africa, for further identification.

7.3.4 Data analysis

Data were analysed separately for each site and season to compare diversity and abundance under cashew trees colonized by AWA, under trees not colonized by AWA and that of the natural vegetation bordering the orchard. The Shannon diversity index (*H'*) (equations i and ii) describes species diversity, whereas the Margalef richness index (D_{mg}) (equation iii) describes species richness. The Shannon diversity and Margalef richness indices were calculated using the R Biodiversity statistical package 10.2 (Kindt & Coe, 2005). Rank abundance graphs were also compiled to compare ant species sampled per season. Statistical analysis was done with STATISTICA version 11 (Stasoft, Inc., Tulsa, Oklahoma, USA). Data was not normally distributed and the non-parametric Mann-Whitney-U-test and Kruskal-Wallis tests were therefore used. Since the latter test uses a rank of numbers from high to low, a median and not a mean value was calculated to indicate abundance and numbers. The Shannon and Margalef indices, the total number of species, as well as the total number of individuals were compared between localities,

between seasons and under cashew trees colonized by AWA, under trees not colonized by AWA and that of the natural vegetation bordering the orchard. Equation (i) $pi = \frac{ni}{N}$ and equation (ii) $H' = -\sum_{i=1}^{s} pi(\ln(pi))$.

Where: n*i* = number of individuals of species "*i*", N = total number of individual of all species, *pi* = relative abundance of species "*i*" (see equation i), *s* = total number of species and *H'* = the Shannon diversity index (see equation ii).

Equation (iii) $D_{mg} = \frac{S-1}{\ln N}$.

Where: D_{mg}= Margalef's index of richness, S = total number of species and N = total number of individuals.



Plate 7.1 (a) A pitfall trap was placed under cashew tree and (b) Scientist sorting ant specimens to morphospecies at MARI laboratory.

7.4 Results

7.4.1 Abundance of ant species

A total of 14001 ants, belonging to six subfamilies, 18 genera and 32 species were collected from the four cashew fields for both seasons (Appendix 7.1). Of these, 7684 and 6320 ants were trapped in 2011 and 2012, respectively. The total abundance of ants trapped per site was 2011, 673, 1131 and 3866 at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B, respectively, during 2011, and 1252, 641, 1287 and 3140 at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B, respectively, during 2012. Higher numbers of individuals were

recorded in trees without AWA and buffer zones than in trees with AWA at Bagamoyo (P = 0.01), Mkuranga A (P = 0.08) and Mkuranga B (P = 0.02) (Tables 7.1a and 7.1b). The same trend was observed in season 1 (2011) and season 2 (2012), except in season 2 at Bagamoyo where the difference was not significant (P = 0.29) (Tables 7.1a and 7.1b). The abundance of ants was not significantly different between the sampled zones and seasons at Kibaha (Table 7.1a). The common pugnacious ant (CPA), *Anoplolepis custodiens* Smith (Formicidae: Formicinae) was the most abundant ant species in pitfall traps, followed by *Myrmicaria* sp. (Formicidae: Myrmicinae), big-headed ant (BHA), Pheidole *megacephala* Fabricius (Formicidae: Myrmicinae), the African weaver ant (AWA), *Oecophylla longinoda* Latreille (Formicidae: Formicinae) and *Pheidole* sp1 (Formicidae: Myrmicinae) (Figures 7.2 and 7.3).

7.4.2 Species richness and diversity

Total number of ant species richness trapped in all sites was 32 and 30 in 2011 and 2012, respectively. The number of species was similar at Bagamoyo at all three zones samples during both seasons (Table 7.1a). The diversity and species richness did, however, differ during season 1 (P = 0.05 and P = 0.04, respectively) at this site (Table 7.1a). At Kibaha no difference was observed between zones during both seasons in terms of number of species, diversity and species richness (Table 7.1a). At Mkuranga A and Mkuranga B, all indices differed significantly during season 1, season 2 which indicated a stable diversity and species richness over a long period (Table 7.1b).

The number of ant species sampled was similar at all the sites but varied significantly between seasons (P < 0.03) (Tables 7.2 and 7.3). The number of individuals sampled during the two seasons differed significantly, except at Kibaha (P= 0.5) (Table 7.2). Diversity, species richness as well as number of individuals differed significantly between the sites over two seasons (P < 0.0001) (Table 7.3).

Two genera, *Pheidole* sp.3 and *Tapinoma* sp. did not appear in the second season of sampling at Mkuranga B. A list of ant species sampled at the different sites of the Coast region of Tanzania is provided in Appendix 7.1. In addition to ground-dwelling ants, arboreal ants such as AWA, *Tetraponera ambigua* Emery, *T. natalensis* Smith (Formicidae: Pseudomyrmecinae) and *Cataulacus intrudens* Smith (Formicidae: Myrmicinae) were also collected in the pitfall traps (Appendix 7.1).

Table 7.1a Descriptive statistics and p-values for diversity index values, abundance and number of ant species under AWA colonized trees, trees without AWA and in the natural vegetation (buffer zones) at Bagamoyo and Kibaha

Bagamoyo	Combined data Median				Season 1 Median				Season 2 Median			
Diversity indices	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value
Shannon index	0.69	0.52	0.81	P=0.01	0.69	0.42	0.80	P=0.06	0.69	0.51	0.87	P=0.18
Margalef index	1.12	0.66	1.12	P=0.01	1.00	0.64	0.91	P=0.04	1.24	0.71	1.28	P=0.18
No. of species	3	3	3	P=0.29	3	3	3	P=0.78	3	3	3	P=0.30
No. of individuals	5	10	5.5	P=0.01	8	15	6	P=0.01	5	9	5	P=0.29

Kibaha	Combined data Median				Season 1 Median				Season 2 Median			
Diversity indices	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value
Shannon index	0.69	0.79	0.69	P=0.52	0.69	0.69	0.64	P=0.26	0.69	0.94	0.72	P=0.74
Margalef index	1.25	1.24	1.12	P=0.14	1.25	0.96	0.81	P=0.24	1.12	1.24	1.25	P=0.51
No. of species	2	3	2	P=0.11	3	3	2	P=0.08	2	3	3	P=0.07
No. of individuals	3	4	3	P=0.16	4	5	3	P=0.38	3	4	4	P=0.11

Table 7.1b Descriptive statistics and p-values for diversity index values, abundance and number of ant species under AWA colonized trees, trees without AWA and in the natural vegetation (buffer zone) at Mkuranga A and Mkuranga B

Mkuranga A	Combined data Median				Season 1 Median				Season 2 Median			
Diversity indices	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value
Shannon index	1.29	1.32	1.30	P=0.79	0.97	0.97	1.15	P=0.94	1.54	1.35	1.26	P=0.74
Margalef index	1.44	1.44	1.44	P=0.89	1.03	1.12	1.36	P=0.39	1.54	1.82	1.44	P=0.71
No. of species	3	4	4	P=0.09	3	3	4	P=0.12	4	5	4	P=0.20
No. of individuals	6	8	8	P=0.08	5.5	6	8	P=0.07	8	8	9	P=0.08

Mkuranga B	Combined data Median				Season 1 Median				Season 2 Median			
Diversity indices	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value	Trees colonized AWA	Trees without AWA	Buffer zones	P-value
Shannon index	0.40	0	0.28	P<0.0001	0.36	0	0.23	P=0.002	0.46	0	0.33	P=0.01
Margalef index	0.62	0	0.39	P<0.0001	0.54	0	0.31	P=0.01	0.72	0	0.53	P<0.0001
No. of species	3	1	2	P<0.0001	3	1	2	P<0.0001	3	1	2	P<0.0001
No. of individuals	13	21	17	P=0.02	23	34	23	P=0.08	12	21	18	P=0.04

Table 7.2 Descriptive statistics and p-values for diversity index values, abundance and number of ant species in two cashew production seasons at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B

	Combined data			Bagamoyo			Kibaha			Mkuranga A			Mkuranga B		
Diversity indices	Median		P value	Median		P value	Median		P value	Median		P value	Median		P value
	Season 1	Season 2		Season 1	Season 2		Season 1	Season 2		Season 1	Season 2		Season 1	Season 2	
Shannon index	0.64	0.69	P=0.001	0.69	0.69	P=0.13	0.69	0.69	P=0.81	1.11	1.40	P<0.0001	0.19	0.29	P=0.03
Margalef index	0.75	1.11	P<0.0001	0.81	0.81	P=0.01	0.96	1.25	P=0.88	1.24	1.44	P<0.0001	0.27	0.39	P=0.01
No. of species	3	3	P=0.90	3	3	P=0.90	2	2	P=0.60	3	4	P<0.0001	2	2	P=0.07
No. of individuals	7	6	P=0.19	7	7	P=0.01	4	3	P=0.50	6	8	P<0.15	23	15	P=0.03

Table 7.3 Descriptive statistics and p-value for diversity index values, abundance and number of ant species at Bagamoyo, Kibaha, Mkuranga A and Mkuranga B over two seasons

Diversity indices	Combined data					Season 1					Season 2				
	Median				P-value	Median				P-value	Median				P-value
	Site[1]	Site [2]	Site [3]	Site [4]		Site[1]	Site [2]	Site [3]	Site [4]		Site[1]	Site [2]	Site [3]	Site [4]	
Shannon index	0.69	0.69	1.30	0.25	P<0.0001	0.69	0.69	1.11	0.19	P<0.0001	0.69	0.69	1.40	0.29	P<0.0001
Margalef index	0.91	1.21	1.82	0.32	P<0.0001	0.81	0.96	1.82	0.27	P<0.0001	1.12	1.24	1.44	0.39	P<0.0001
No. of species	3	2	4	2	P<0.03	3	2	3	2	P<0.03	3	2	4	2	P<0.03
No. of individuals	6	3	4	18	P<0.0001	7	4	7	23	P<0.0001	5	3	8	15	P<0.0001

[1]denotes experimental site at Bagamoyo

[2]denotes experimental site at Kibaha

[3]denotes experimental siteat Mkuranga A

[4]denotes experimental site atMkuranga B

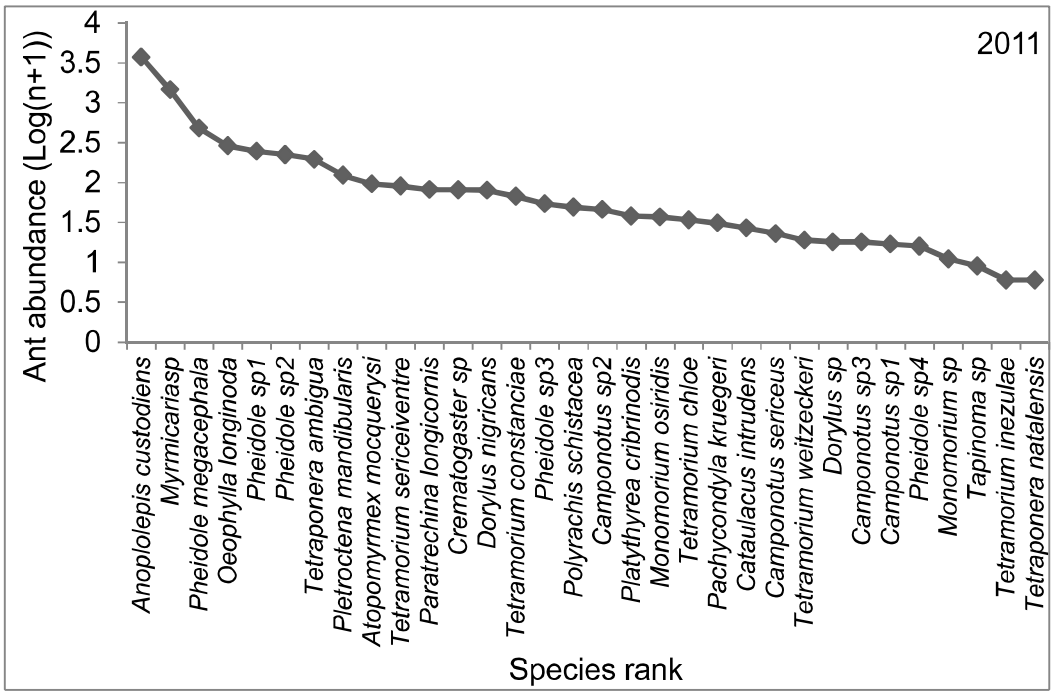


Figure 7.2 The abundance diversity curves of ants from pitfall traps during 2011. Species rank is given from the most abundant to the least abundant species.

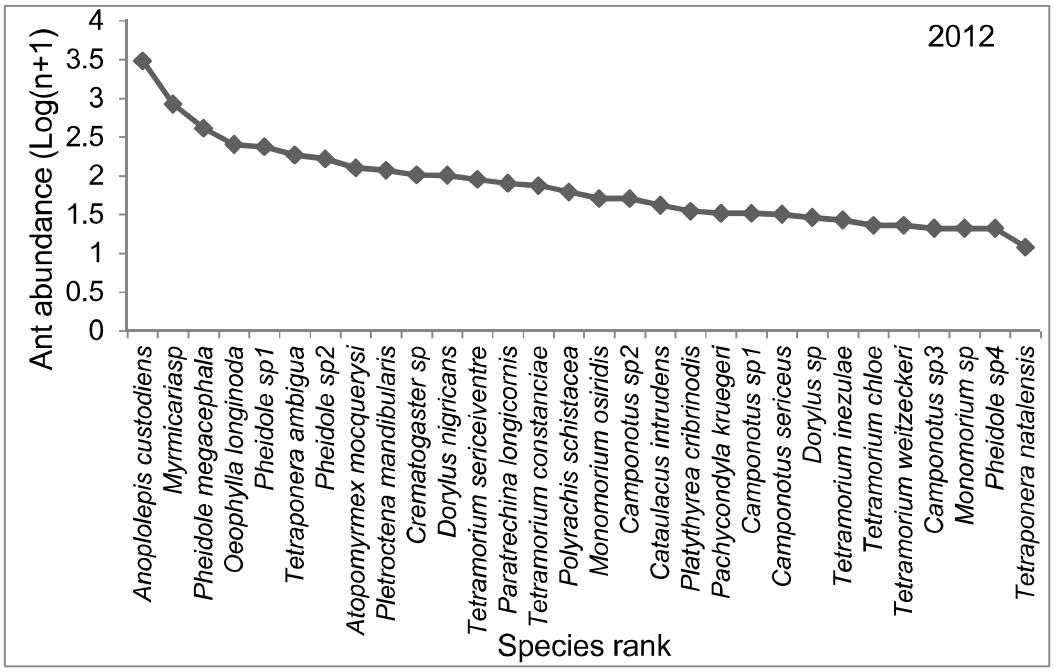


Figure 7.3 The abundance diversity curves of ants from pitfall traps during 2012 sampling periods. Species rank is given from the most abundant to the least abundant species.

7.5 Discussion

The abundance of ants was generally high in trees not-colonized by AWA and buffer zones than in trees colonized by AWA, implying an antagonistic effect between AWA and other ant species. Similar results have been reported in the study of the interaction between AWA and two dominant ant species (see chapter 4). Interestingly, the diversity and species richness was highest in trees colonized by AWA, followed by the buffer zone with natural vegetation and trees without AWA. This could possibly be ascribed to one or a combination of plant associated factors such as richness, biomass and percentage of cover that affect ant diversity. The cultivation practices of the cashew field at Mkuranga B could have contributed to the ant diversity at this site. The fields were intercropped with cashew, mango, coconut and citrus trees. , which changed the ground cover vegetation also An example of the influence of disturbed areas on an ant assemblage is in the arid southern Karoo of South Africa where the plant composition is mainly annual plants, and the ant fauna is dominated by *Anoplolepis steingroeveri* Forel (Hymenoptera: Formicidae), (Dean & Milton, 1995). The common pugnacious ant (CPA), *A. custodiens* was the most abundant ant species in the pitfall traps at Mkuranga B and it can therefore also be as a result of regular weeding of ground vegetation. CPA is known to confine to sandy soils with relatively sparse ground vegetation and it seems to be an exclusively ground nesting ant species (Varela, 1992). The species is highly aggressive and is known to exhibit extreme dominance over other ant species in agricultural landscapes (Samways, 1990). Its dominance possibly played a critical ecological role in structuring other ant's assemblages in cashew agro-ecosystems. The lack of intra-specific competition between ant speciesamong colonies could explain their invasive expansions. Low abundances of ants in the cashew field at Kibaha could be attributed to frequent fire. Fire has also been reported to reduce the abundance of ants elsewhere (Farji-Brener *et al.,* 2002).

Sampling of arboreal ants (i.e. AWA, *T. ambigua*, *T. natalensis* and *C. intrudens*) in the pitfall traps should be attributed to their extensive foraging behaviours. Arboreal ants, namely AWA, *T. aculeatum* and *C guineensis* were also sampled in pitfall traps at Dja Biosphere Reserve, Southeast Cameroon (Deblauwe & Dekoninck 2007).

The species composition (diversity and richness) of ant colonies in crop fields should be investigated and the impact should be determined what these interactions may have on the efficacy of AWA as biocontrol agent of hemipteran pests.

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Appendix 1Appendix 7.1Ant species collected from pitfall trapping in the different cashew fields of the Coast region during 2011-2012

Subfamily	Species names	Experimental sites			
		Bagamoyo	Kibaha	Mkuranga A	Mkuranga B
Dolichoderinae	*Tapinoma* sp.	-	-	+	-
Dorylinae	*Dorylus nigricans*(Gerstaecker)	+	+	-	-
Dorylinae	*Dorylus* sp.	-	+	-	-
Formicinae	*Anoplolepis custodiens* (Smith)	+	+	+	+
Formicinae	*Camponotus sericeus* (Fabricius)	+	-	+	+
Formicinae	*Camponotus* sp.1	+	+	+	+
Formicinae	*Camponotus* sp.2	+	+	+	+
Formicinae	*Camponotus* sp.3	+	+	+	-
Formicinae	*Oecophylla longinoda* (Latreille)	+	+	+	+
Formicinae	*Paratrechina longicornis* (Latreille)	+	+	+	+
Formicinae	*Polyrhachis schistacea* (Gerstaecker)	+	+	+	+
Myrmicinae	*Atopomyrmex mocquerysi* (André)	-	-	+	+
Myrmicinae	*Cataulacus intrudens* (Smith)	+	+	+	+
Myrmicinae	*Crematogaster* sp.	+	+	+	+
Myrmicinae	*Monomorium osiridis* (Santschi)	+	+	+	+
Myrmicinae	*Monomorium* sp.	+	+	+	-

Myrmicinae	*Myrmicaria* sp.	+	+	+	-
Myrmicinae	*Pachycondyla kruegeri* (Forel)	+	+	+	+
Myrmicinae	*Pheidole megacephala* (Fabricius)	+	+	+	+
Myrmicinae	*Pheidole* sp.1	+	+	+	+
Myrmicinae	*Pheidole* sp.2	+	+	+	+
Myrmicinae	*Pheidole* sp.3	+	+	+	+
Myrmicinae	*Pheidole* sp.4	+	+	+	-
Myrmicinae	*Tetramorium chloe* (Santschi)	+	+	+	+
Myrmicinae	*Tetramorium constanciae* (Arnold)	+	+	+	+
Myrmicinae	*Tetramorium inezulae* (Forel)	+	-	+	+
Myrmicinae	*Tetramorium sericeiventre* (Emery)	+	-	+	+
Myrmicinae	*Tetramorium weitzeckeri* (Emery)	+	+	+	-
Ponerinae	*Platythyrea cribrinodis* (Gerstaecker)	+	+	+	+
Ponerinae	*Plectroctena mandibularis* (Smith)	+	+	+	+
Pseudomyrmecinae	*Tetraponera ambigua* (Emery)	+	+	+	+
Pseudomyrmecinae	*Tetraponera natalensis* (Smith)	+	-	+	-

+denotes presence of a species at a given experimental site

- denotes absence of a species at a given experimental site

CHAPTER EIGHT

General discussion, conclusion and future research

8.1 General discussion

The results presented in this thesis confirm seasonal variation of the African weaver ant (AWA) abundance expressed as mean number of leaf nests and percentage colonization of trails. The abundance of AWA was high and more stable during cashew on-seasons than during off-seasons. This could be explained by food resource availability since plants provide nectar only during cashew on-seasons (Gottlieb *et al.,* 2005; Stone *et al.,* 1999). During flowering, the nectaries have been reported to attract other insect fauna such as homopteran insects, *Coccus hesperidum* Linnaeus (Homoptera: Coccidae) and *Hilda patruelis* Stål (Homoptera: Tettigometridae) (Stathers, unpublished). This provides additional food since AWA tended the homopteran insects for honey dew in cashew orchards (Dwomoh *et al.,* 2009). High abundance of AWA during cashew on-seasons could also be attributed to occurrence of the sap-sucking pests, *Helopeltis anacardii* Miller, and *H. schoutedeni* Reuter and *Pseudotheraptus wayi* Brown which acted as prey.

The study also demonstrates that AWA was effective in controlling the sap-sucking pests (*Helopeltis* spp. and *P. wayi*) in Tanzanian cashew orchards. The observed reduction in flushing shoot and nut damage on AWA-colonized trees might be due to the ability of AWA to prey on sap-sucking pests on cashew. Similar behaviour was also observed in coconuts in East Africa (Varela, 1992; Seguni, 1997) and in cashew in West Africa (Dwomoh *et al.,* 2009).The aggressive behaviour of AWA experienced by farmers, as a nuisance during harvesting, should not be a serious matter since farmers collect cashew that have naturally dropped to the ground (Stathers, unpublished; Dwomoh *et al.,* 2009).

The interaction between AWA and the two dominant ants, the big-headed ant (BHA) and the common pugnacious ant (CPA) can be described as antagonistic. The reduction of AWA abundance indicated by a negative

correlation was attributed to the numerical dominance of the inimical ants, BHA and CPA. Previous studies have also reported that individuals of the genus *Oecophylla* can retreat and recruit nest-mates to the location of the encounter (Hölldobler & Wilson, 1978; Way & Khoo, 1992). There was also a reduction in AWA abundance due to other ants foraging at the sugar baits. In another study, *Crematogaster* sp have been observed excluding *Oecophylla* by recruiting substantial numbers of workers to exploit the food resources (Majer, 1976).

The use of powdery mildew fungicides (sulphur dust, triadimenol and triadimefon) did not affect the abundance of AWA in the two cashew fields at Bagamoyo and Kibaha, in northern Tanzania. Similar results were reported with the same powdery mildew fungicides in southern Tanzania (Sijaona, personal communication). Application of triadimenol and sulphur fungicides for PMD control in grapevine in South Africa did also not affect the abundance of the predaceous mite, *Ambyseius addoensis* Van der Merwe and Ryke (Acari: Phytoseiidae) (Schwartz, 1993).

The efficacy of fish intestines and hydramethylon-based baits for conservation of AWA during cashew off-season was evaluated in the field. High mean number of AWA leaf nests per tree and stable colonization levels of AWA trails were recorded after provision of the two baits. Fish-based bait was also recommended for conservation of AWA in West Africa (Van Mele & Cuc 2007) and the green ant, *Oecophylla smaragdina* Fabricius in Australia (Peng *et al.,* 2009).

The study shows that CPA was most abundant in the cashew field at Mkuranga B probably due to regular weeding of ground vegetation. CPA isknown to be confined to sandy soils with relatively sparse ground vegetation and it seems to be an exclusively ground nesting ant species (Varela, 1992). The species is highly aggressive and is known to exhibit extreme dominance over other ant species in agro-ecosystems (Samways, 1990). Their dominance possibly played the ecological role in structuring other ant's

assemblages in cashew agro-ecosystems. Low abundance of ants in the cashew field at Kibaha could possibly be attributed to frequent fire. Fire has also been reported to reduce the abundance of ants elsewhere (Farji-Brener *et al.,* 2002).

The study also shows that regular weeding at Mkuranga B may explain the difference in all diversity and species richness indices. Interestingly the diversity and species richness was highest in trees colonized with AWA, followed by the buffer zone with natural vegetation and trees without AWA. The abundance of ants was generally high in trees not-colonized by AWA and buffer zones than in trees colonized by AWA, implying possible antagonistic effects between AWA and other ant species.

8.2 Conclusion

The abundance of AWA varies significantly between cashew seasons at the different sites of the Coast region of Tanzania. Although few leaf nests and unstable AWA colonization levels were recorded during off-seasons, the provision of fish and hydramethylon-based baits can effectively contribute to conservation of AWA. The efficacy of fish intestine was generally similar to that of hydramethylon. Since fish-based bait is a disposable waste and accessible to local farmers, it should therefore be recommended to be used as an alternative food source for AWA conservation during cashew off-season. This practice may result in effective and sustainable control of sap-sucking pests in cashew in Tanzania by AWA as it has been demonstrated in this study. The use of the three powdery mildew fungicides (triadimenol, triadimefon and sulphur) does not have detrimental effects on the abundance of AWA in cashew fields and can therefore be used together with AWA as important components of an integrated pest and disease management programme for cashew crops in Tanzania.

The abundance of AWA at sugar baits was negatively affected by the presence of the two dominant ants, namely BHA and CPA. Therefore, suppression of the two inimical ants should be emphasized for effective

control of the sap-sucking pests in cashew fields. Similarly, pitfall sampling demonstrated that abundanceof ants and their species richness varied significantly between experimental sites and seasons.

8.3 Future research

Prior to this study, no knowledge was available with regard to the potential use of AWA as a biocontrol agent of sap-sucking pests in Tanzanian cashew agro-ecosystems. Results indicated that AWA should be included as an important component of an IPM system for the control of the sap-sucking pests in cashew production. This knowledge should be disseminated to smallholder cashew growers through National Agricultural Research Institutes (NARIs) and thereafter to extension officers. The kind of training that will be most effective to achieve a sustained behavioural change in the adoption of IPM strategies in cashew agroecosystems needs to be determined. Hydramethylon ant bait controls BHA effectively. The CPA has a negative effect on AWA and control of this inimical ant in cashew agroecosystems should be investigated.

8.4 References

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