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Nutritional And Field Ecology Of Stink Bugs On Tomato And Cowpea Under Two Insecticide Regimens

Akamu Jude Ewunkem
North Carolina Agricultural and Technical State University

Nutritional and Field Ecology of Stink Bugs on Tomato and Cowpea under Two Insecticide Regimens

Akamu Jude Ewunkem

North Carolina A&T State University

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This is to certify that the Master's Thesis of

Akamu Jude Ewunkem

has met the thesis requirements of
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Approved by:

Dr. Louis E.N. Jackai Major Professor	Dr. Charles Raczkowsi Committee Member
Dr. Muchha Reddy Committee Member	Dr. Louis E.N. Jackai Department Chairperson

Dr. Sanjiv Savin
Associate Vice Chancellor for Research and Graduate Dean

Biographical Sketch

Akamu Jude Ewunkem was born in Cameroon. He received the Bachelor of Science and Master of Science in Biochemistry and Zoology, respectively, from University of Buea, Cameroon, in West Africa. He enrolled at Tuskegee University Alabama for a Master Degree in Plant Science where he stayed for a year and later transferred to North Carolina A and T State University for a Master Degree in Plant, Soil and Environmental Science. During his study he conducted research was on Integrated Pest Management of pests of Cowpea and Tomato and Developmental biology of Southern Green Stink bugs, *Nezara viridula* under the supervision of Dr. Louis E.N. Jackai. Mr. Akamu Jude Ewunkem has also served as Arachnologist for Delmonte Cameroon and Research Assistant in the Department of Natural Resources and Environmental Design. He received the Graduate Merit scholarship award which honors academic excellence (2010). His research findings were presented at two meetings including the International Education Week Luncheon at North Carolina A & T State University and Association of Research Directors Symposium (ARD) Atlanta, Georgia. After graduating he plans to pursue a doctoral degree in Entomology or Environmental Science.

Dedication

This thesis is dedicated to my beloved daughter Shiloh Margaret Ebongken Ewunkem.

Acknowledgments

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CAG .... Cowpea treated with Agroneem®

CAI .... Cowpea treated with Imidacloprid

CAT .... Cowpea treated with Thiamethoxam

CON .... Control Plots

DAP .... Day after planting

GJ .... German Johnson

IPM .... Integrated Pest Management

Kg/ha .... Kilogram/Hectare

MAR .... Mariana

MS .... Mississippi Silver

PPH .... Pinkeye Purple Hull

TAI .... Tomato treated with Imidacloprid

TAT .... Tomato treated with Thiamethoxam

Abstract

A laboratory study was conducted to compare food utilization and suitability of *Nezara viridula* on selected varieties of tomato and cowpea. A two-year field study was performed to evaluate the effectiveness of biorational pesticides (Agroneem®) and conventional pesticides (Imidacloprid or Thiamethoxam) to suppress and enhance the population of insect pests and beneficial, respectively, on both crops. In the first year both pesticide groups were applied following manufacturer's recommendation (10-14 d cycles), and in the second year the application of the pesticides was driven by monitored thresholds of insect pests. In the laboratory study conducted on the feeding behavior, nymphs performed better on cowpea than on tomato. Although the nymphs required comparable duration to complete development, and attained similar weights at adult emergence, mortality was higher on the seeds of Pinkeye purple hull (PPH) than those of Mississippi Silver (MS). Mortality on both varieties of tomato was comparable. Consumption index and growth rate were higher on cowpea than tomato which indicates cowpea as a preferred host. In the field study the most predominant species of insects recorded on both crops were in the families: Chrysomelidae, Pentatomidae, Cicadellidae, Vespidae, Sarcophagidae, Thripidae and Sphingidae. In both years the number of insects on cowpea was higher than on tomato. The number of insects on these crops was higher in the second year compared to the first. However, there was no significant difference (P>0.05) in pest number between varieties in the treated plots. The yield of cowpea and tomato was comparable in all sprayed plots.

CHAPTER 1

Introduction

Cowpea (*Vigna unguiculata* L. Walp) and tomato (*Lycopersicon esculentum L. Karst*) are two important vegetable crops cultivated worldwide. Insect pests and diseases are a constraint in the cultivation of these crops resulting in severe economic damage (Caswell, 1981; Lange & Bronson, 1981).

Cowpea is an important food crop to millions of people and it is also a major component in cropping systems which include monocropping, relay cropping, and mix intercropping (Inaizumi *et al.,* 1999; Lattanzio *et al.,* 2005). It is a source of protein and carbohydrates and provides rural families with food, animal feed, as well as cash income a (Inaizumi *et al.*, 1999). The mature cowpea seeds have about 25% protein and 64% carbohydrate, and play a major role in alleviating malnutrition among the poor (Inaizumi *et al.,* 1999, Davis *et al.,* 2006). Cowpea can also be fed to animals as fodder or used to replenish soil nitrogen when used as a green manure crop (Inaizumi *et al*., 1999).

On a global scale annual cowpea production is estimated at 3-7.6 million tons grown on 13 million hectares annually. Africa produces about 68%, Brazil (17%), Asia (3%), the United States 2% and the rest of the world 10% (Singh *et al.,* 2002). In the United States cowpea is grown on about 78,800 hectares each year and harvested either as fresh vegetable crops or dry bean in the southern states; California accounts for 90% of the dried cowpea grown in the United States (Quinn, 1999). North Carolina ranks fifth in the production of cowpea, with a production of about 5,469 bushels of fresh pods per annum (Farmer Express, 2010).

Cowpeas are susceptible to a wide range of insect pests and diseases that attack the crop at all stages of growth which lower yield substantially (Jackai & Daoust, 1986). In the tropics, the most important insect pests during cowpea production are aphids (*Aphis cracciroca* Koch) which generally feed near the tips of infested stems, cowpea curculio (*Chalcodermus aeneus* Boheman) and the coreid pod-sucking bug (*Clavigralla tomentosicollis* Stal) attack developing seeds, thrips (*Megalurothrips sjostedti* Trybom) attack cowpea flowers resulting in necrosis and or/abscission of flower (Singh & Allen, 1980; Rusoke and Rubaihayo,1994; Edema and Adipala,1996), the pod borer (*Maruca vitrata* Fabricius) feeds inside developing pods and the southern green stink bug (*Nezera viridula* Linnaeus) which feeds on fresh seeds and pods (Lattanzio *et al*., 2005).

Tomato is the second most important vegetable crop in the world next to potato (FAOSTAT Database, 2004). World production is about 100 million tons of fresh fruit produced on 3.7 million hectares. The top five tomato fruit-producing countries in order are the United States, China, Turkey, Italy, and India (FAOSTAT Database, 2004). In the United States tomatoes are grown either to process or for the fresh market. California accounts for 90% of U.S. production and North Carolina ranks seventh (Farmer Express, 2010). Tomato is rich in lycopene, vitamins and antioxidants which are beneficial to the heart and also can reduce the risk of developing prostate cancer (Yilmaz, 2001).

Tomato is host to wide range of insect pests which include Colorado potato beetle (*Leptinotarsa decemlineata* Say), corn earworm (*Helicoverpa zea* Boddie), potato flea beetle (*Epitrix cucumeris* Harris), aphids (*Macrosiphum euphorbiae* Thomas), and (*Myzus persicae* Sulzer), cutworms (*Agrotis ipsilon* Rottemburg) and (*Peridroma saucia* Hubner), fall armyworm, (*Spodoptera frugiperda* Smith), whiteflies (*Trialeurodes vaporariorum* Westwood), fruit flies, (*Drosophila melanogaster* Meigen), and stink bugs (*Acrosternum hilare* Say and *Nezara viridula* Linnaeus) (Hofmaster, 1977).

The southern green stink bug, *Nezara viridula* is a highly polyphagous pentatomid pest of crops such as soybeans, cotton, macadamia, pecan and other fruits and vegetables including tomatoes and cowpeas (Todd, 1989, Panizzi, 1997, Zalom *et al.,* 1997). In the United States it is an important pest in the southern states (Todd & Herzog, 1980; Pedigo, 2002). It feeds on seeds, pods and on immature fruits but sometimes feeds on tender plant tissues. Direct plant damage occurs when it inserts its stylets and feeds (Drake, 1920). Damage is exacerbated when enzymes are secreted during feeding leading to premature fruit drop, delay in crop maturity and reduced seed quality or quantity (Mitchell & Mau, 1971). The insect transmits a strain of plant opportunistic bacterium, *Pantoea agglomerans*, which occurs on the surface of fruit and causes boll rot in cotton (Medrano and Bell, 2007; Enrique *et al.,* 2009).

Insect pest management on cowpea and tomato can be achieved through the use of resistant varieties, ecological manipulation and insecticides (Brun, 1981; Kennedy *et al*., 1983; Jackai *et al*., 1985; Hamilton and Toffolon 1987; Walgenbach *et al*., 1989). Conventional insecticides which are the option of choice due to convenience are rather expensive and may also have adverse effects on the environment. Alternate substitutes are plant-based insecticides, which are both user- and environment-friendly, are desirable (Isubikalu *et al.,* 1999) or resistant varieties.

In the selection of insect resistant crop varieties a useful index would be insect nutritional ecology. Insect ecology is a complex interconnected relationship between insects and the environment which entails the dynamics of insect number in time and space as affected by the environment including its food (Pedigo, 2002). The crop attributes leading to consumption, utilization and insect performance are a primary focus and this provides the logical basis for host plant resistance. Studies have been conducted on the nutritional ecology of stink bugs on both seeds and pods of soybean (Panizzi & Slansky, 1985). Therefore it is important to generate information on the nutritional and field ecology of the southern green stink bug on cowpea and tomato, and to evaluate the effectiveness of biorational and conventional pesticides on pests and beneficial insects associated with these crops. This will serve as a prelude to develop small farm IPM strategies for vegetable crops, and to screen cultivars for resistance to stink bugs.

1.1. Objectives

The objectives of the study were to:

1) Study the population dynamics of the southern green stink bug and other insects on cowpea and tomato grown in two crop protection regimens;
2) Evaluate the yield of cowpea and tomato in the two management systems; and
3) Compare food utilization indices for stink bugs on cowpea pods and tomato fruit as an index of food suitability.

CHAPTER 2

Literature Review

2.1. Crop Origin and Importance

2.1.1. Cowpea. Cowpea *Vigna unguiculata* (L.) is a dicotyledonous plant belonging to the family Fabaceae. Verdcourt (1970) subdivided the species into 3 subspecies: *unguiculata*, *catjang* and *sesquipedalis*. However, Marechal *et al*. (1978) reclassified the subspecies as cultigroups: *Unguiculata*, *Biflora*, and *Sesquipedalis*, and lumped these cultigroups under *V. unguiculata* subsp *unguiculata*. Most cowpea breeders seem to have adopted Marechal *et al*. (1978) cultigroup scheme for classification of cultivated *V. unguiculata* taxa.

Cowpea is a native of Central Africa and the name "cowpea" originated from the fact that the plant was an important source of hay for cows in the southeastern United States and in other parts of the world. The precise origin of cowpea remains debatable however, it is reported that it has been cultivated since 6000 BC (www.world-foodhistory.com/2010/06/history-of-cowpea.html*)*. Cowpea was introduced from the West Indies to the United States in 1700 and was first cultivated successfully in North Carolina and Virginia (Ehlers and Hall, 1997).

2.1.1.1. Production of cowpea in the world and the United States. Worldwide area of production of cowpeas is approximately 10 million hectares and annual global cowpea grain production is approximately 5 million tons (FAO, 2008). The largest production is in Africa, with Nigeria and Niger predominating, while Brazil, Haiti, India, Myanmar, Sri Lanka, Australia, the U.S., Bosnia, and Herzegovina all have significant production (FAO, 2008). Annual production of cowpea in the United States is about 80,000 hectares (Fery, 2002). Tennessee and California are leaders in cowpea processing and also producers of dry and fresh cowpea, respectively (Fery, 2002). North Carolina ranks sixth and produces 5,469 bushels (Farmer Express, 2010).

2.1.1.2. Importance of cowpea. Cowpeas have been consumed by humans since the earliest practice of agriculture due to its nutritional and medicinal properties (Phillips and McWatters, 1991). Cowpea contains about 24% protein, 62% soluble carbohydrates, and other nutrients (Nielsen et al., 1993). Cowpea provides excellent grazing and high feed value for dairy cattle and it is also suitable for other livestock due to its high protein and fiber contents (Singh, 2005). The leaves and seeds are applied as poultice to treat swellings and skin infections. The root is used as an antidote for snake bites and to treat epilepsy, chest pain constipation and dysmenorrhoea（Grubben, 2004). Cowpea is valued in the southern US as a vegetable crop and is supplied as fresh, canned, frozen, and dry-pack products that are marketed nationwide (Fery, 1990).

Cowpea enhances soil quality by fixing nitrogen without the addition of rhizobium. It is compatible with intercropping systems, particularly with cereals such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench), pearl millet (*Pennisetum glaucum* L. R. Br.), cassava (*Manihot esculenta* Crantz), and cotton (*Gossypium barbodense* L.) (Singh, 2005).

2.1.1.3. Diseases and insect pests of cowpea. Cowpeas are susceptible to a wide range of pests and pathogens that attack the crop at all stages of growth. Major diseases and causative agents include phytophthora stem rot *(Phytophthora vignae);* wilt *(Fusarium oxysporum)* which results in discoloration of the vascular tissue inside the stem; tan spot *(Curtobacterium flaccumfaciens)* which causes broad irregular yellow areas starting from the leaf margin and extending inwards followed by a tan discoloration; cowpea mosaic virus which results in severe yellow mottling of the leaves, and southern blight, a stem disease caused by *Sclerotium rolfsii* (Aycock *et al*., 1966; Queensland Goverment, 2010).

Insect pests reported on cowpea that cause yield reduction includes the cowpea aphid, *Aphis craccivora* Koch, flower bud thrips, *Megalurothrips sjostedti* Trybom, the legume pod borer, *Maruca vitrata* Fab, and a complex of pod sucking bugs: *Aspavia armigera* Fab, *Clavigralla spp*, *Anoplocnemis spp*, *Riptortus spp, Mirperus spp* and *Nezera viridula* L (Olatunde *et al*., 1991). A primary insect pest that causes losses to stored cowpeas is the cowpea weevil, *Callosobruchus maculatus* Fab. (Ntoukam *et al*., 2000).

2.1.1.4. Management of cowpea pests. Management tools for cowpea pests include host plant resistance, the use of cultural control, biological control and application of pesticides. Mechanisms of resistance involve the combination of antibiosis and antixenosis (Singh, 1980; Ezueh, 1981). Factors contributing to resistance include the elevation of trypsin inhibitors, seed texture, high protein content and pod wall (Caswell, 1980; Bosque-Perez, 1982). Cultural control is among the oldest control practices used by small cowpea growers (Okigbo, 1978). Most studies on cultural control focus on intercropping (Monyo *et al.,* 1976; Jackai *et al.,* 1985) which usually involves intercrops of sorghum or maize alternated with cowpea. Some studies have shown a reduction in the population density of post-flowering pests *Maruca vitrata* and the flower pest, *Megalurothrips sjostedti* (Mensah, 1997; Oso & Falade, 2010).

In spite of the outstanding amount of research that has been conducted on insect pests of cowpea very little has been done on their natural enemies (Jackai & Daoust, 1986). Parasitoids and entomopathogenic fungi have successfully been used to control *Megalurothrip*s *sjostedti* Trybom (Tamb *et al*., 1997; Ekesi *et al.,* 1998). Parasitization of flower thrips, lepidopteran and coleopteran pests have been reported (Ennis & Chambliss, 1976; Matteson, 1982; Don-Pedro, 1983).

Control of insect pests of cowpea relies heavily on the use of synthetic insecticides which remains the most popular tactic. Toxic insecticides pose a threat to human and environmental health as well as being expensive (Isubikalu *et al*., 1999). Insecticides such as endosulfan®, dimethoate®, monocrotphos® (now banned in the US, Indonesia) (FAO, 1990), thimeton®, phorate® and carbofuran® have been used against beanfly, aphids, leafhoppers and foliage beetles. (Singh & Allen, 1980; Akingbohungbe, 1982). The most efficacious insecticides against storage pests include pirimiphos-methyl (Actellic®), cypermethrin (SH-1479®), carbon disulfide, chlorpyrifos®, and phosphine® (Abdel *et al.*, 1975; Caswell and Akibu, 1980; Abbassy and Abdel-Rahim, 1981; Fondohan ,1982). Botanical pesticides with low toxicities have been used in the control of pod and storage pests. To enhance their effectiveness some of these botanicals are combined with synthetic insecticides (Agona *et al.,* 2001, 2002).

2.1.2. Tomato. Tomato (*Lycopersicon esculentum L. Karst*) belongs to the family Solanaceae, is believed to have originated in the coastal strip of western south America and was transported to Europe in 1519 (Papadopoulos, 1991). From Europe it was transported to the United States and was first grown and cultivated in South Carolina more as ornamental plants than for food in 1710 (Smith,1994).

2.1.2.1. Tomato production in the world and the United States. Tomato is the second most important vegetable crop next to potato. The world production is about 130 million tons and the major producers are China, United States and Turkey (FAOSTAT Database, 2004). More than 160,000 hectares of tomatoes are cultivated in the United States with a yearly production exceeding 14 million tons. More than 12 million tons are processed into various products such as soup, catsup, sauce, salsa and prepared foods. Another 1.8 million tons are produced for the fresh market (Farmer Express, 2010). California is the leading producer of both processing tomatoes and fresh market tomato in the United States (Farmer Express, 2010). North Carolina ranks seventh in the production of fresh market tomato where more than 400,000kg are produced annually (Farmer Express, 2010).

2.1.2.2. Importance of tomato. Tomato is used in diverse ways, including as raw in salads, or processed into ketchup or tomato soup. Unripe green tomatoes can also be breaded and fried, used to make salsa, or pickled. Tomato juice is sold as a drink, and it is used in cocktails. Tomatoes have significant nutritional value. In recent years, they have become known as an important source of lycopene, which is a powerful antioxidant that acts as an anticarcinogen (Yilmaz, 2001). Tomato also provides vitamins (A, B and C) and minerals such as potassium, iron and calcium (Farmer Express, 2010). Tomato consumption has been associated with decreased risk of breast, head and neck cancers (Freedman *et al*., 2008; Zhang *et al*., 2009).

2.1.2.3. Diseases and insect pests of tomato. Tomato crops are attacked by diseases and insect pests whose status may differ among regions (Lange & Bronson, 1981; Zalom *et al*., 1997). Major diseases include septoria leaf spot, caused by the fungus *Septoria lycopersici*, early blight, caused by the fungus *Alternaria solani*, anthracnose caused by the fungus *Colletotrichum coccodes* which attacks the fruits, late blight caused by the fungus *Phytophthora infestans*, and bacterial spot caused by the bacterium *Xanthomonas campestris* (Mark & Brooke, 2006). These diseases can be the most important limiting factor in tomato production in North Carolina. The most prominent diseases in North Carolina are early blight which causes about 50% yield losses. Late blight has the potential to be the most destructive disease, capable of causing complete loss in unprotected crops. Gray mold caused by *Botrytis cinerea* can be very damaging, causing blighting and fruit rot (Crop Profile for tomato in North Carolina, 2005).

Insects attack tomatoes from the time the seed is planted until the fruit is harvested (Harry & Lorin, 1981). Insect pests that mine leaves or bore into fruits and/or buds include tobacco budworm, (Heliothis virescens Fabricius), tomato fruitworm (Helicoverpa zea Boddie), tomato pinworm (Keiferia lycopersicella Walshingham) and vegetable leafminer (Liriomyza sativae Blanchard). (Crop Profile for tomato in North Carolina, 2005). Chewing pests that make holes in leaves include blister beetle (*Epicauta pennsylvanica* De Geer), cabbage looper (*Trichoplusia ni* Hübner), Colorado potato beetle (*Leptinotarsa decemlineata* Say), potato flea beetle (*Epitrix cucumeris* Harris) and the hornworm (*Manduca sexta* Linnaues). Sap-sucking pests which cause leaf discoloration, leaf or fruit deformation, or defoliation include green peach aphid (*Myzus persicae* [Sulzer]), potato aphid *Macrosiphum euphorbiae* (Thomas), whiteflies (*Trialeurodes vaporariorum* Westwood), Western flower thrips, (*Frankliniella occidentalis* Pergande) and stink bugs, eg *Acrosternum hilare* Say. Pests that feed on roots or lower stems are cutworms (*Agrotis ipsilon* Rottemburg) and southern potato wireworm (*Conoderus falli* Lane) (Crop Profile for tomato in North Carolina, 2005). The most common insects seen in North Carolina are tomato fruit worm, stink bugs, thrips, aphids, and flea beetles (Crop Profile for tomato in North Carolina, 2005).

2.1.2.4. Management of tomato insect pest. Tomato pest management systems utilize multiple resources, including host plant resistance, cultural controls, natural and applied biological controls, and chemical controls (California Department of Food and Agriculture, 1978; Office of Technology Assessment 1979). Host plant resistance is receiving considerable attention as a management tool (Kennedy, 1976). The mode of resistance in tomato involves antibiosis, preference, phenological development (such as flowering time and time of fruiting), morphological characteristics, presence or absence of foliage pigments, foliage volatiles, and physiological incompatibility (Harry and Lorin, 1981).

The presence of α-Tomatine and plant polyphenol oxidases found in the stems, leaves, and fruit are associated with resistance against many pathogenic microorganisms and some insect pests such as phloem-feeding and leaf-chewers (Courtney & Lambeth, 1977; Ryan & Gregory, 1982; Stout *et al.,* 1989). Studies have shown that some varieties are resistant to the tomato fruitworm, *Heliothis zea,* leaf miners, *Liriomyza spp* (Wolfenbarger, 1966); tomato pinworm, *Keiferia iycopersicella* and hornworms, *Manduca spp* (Kennedy & Henderson,1978).

The mechanized growing and harvesting of processing tomatoes reduces pests such as Vinegar flies, *Drosophila spp* as fruit is moved rapidly out of the fields (Mason & Dorst, 1962). Spacing of plants is also important management tool for some insect pests. Beet leafhopper, *Eutettix tenellus,* prefers widely spaced plants and plants under stress to closely spaced and healthy plants. Other approaches such as irrigation, seeding, transplanting, fertilization, rotation, and weed control all play an important role in determining pest population levels (Long & Cantliffe, 1975). Biological control has not been fully exploited in tomato IPM. However, in California and Florida mass releases of about 200,000 to 300,000 *Trichogramma pretiosum* per acre has shown to reduce damage by *Heliothis zea* and increased egg parasitism of the cabbage looper, *Trichoplusia ni,* and horn worms, *Manduca spp* (Oatman & Platner, 1971).

2.2. Insecticides

The use of insecticide is an essential component of most crop protection strategies in agriculture, albeit over reliance on insecticides has been reported to result in resistance problems, ecological disturbance, and higher cost to the growers (Denney, 2001). There are two broad categories of insecticides namely conventional and biorational. Conventional insecticides are generally synthetic pesticides with broad spectrum activity, many acting as “nerve poisons” both on pests and non-targets including beneficial insects (Dennehy, 2001). These insecticides are expensive and also cause harm to the environment (Isubikalu *et al*., 1990). Examples of conventional insecticides include organophosphates, cabamates, organochloine and neonicotinoid (George *et al*., 2002). Biorationals on the other hand are normally very selective, targeting just the pest, do not usually persist in the environment, and are much safer to handle and apply. Biorationals tend to preserve beneficial organisms and also have less concern on the environment. Some of the more commonly used and effective bio-rational pesticides are formulated as Insect (Mite) Growth Regulators (IGR’s), microbial spores, horticultural oils, insecticidal soaps, entomopathogenic nematodes, and plant extracts or derivatives (George *et al*., 2002).

2.2.1. Neonicotinoid insecticides. Neonicotinoids, or chloronicotinyls, are a new class of synthetic insecticides that are analogs of the natural product nicotine. It is one of the most important new classes of synthetic insecticides of the past three decades, are used to control sucking insects both on plants and animals. Imidacloprid, nitenpyram, acetamiprid, tiacloprid, thiamethoxam, and others act as agonists at the insect nicotine acetylcholine receptors (Tomizawa & Casida 2003).

Imidacloprid [N-(6-chloropyridin-3-ylmethyl)-2-nitroiminoimidazolidine] is one of the most widely used neonicotinoids (Pedigo, 2002). The insecticide was discovered in 1984 at Nihon Bayer Agrochem, Japan (Kagabu, 1997). It is widely used for the management of pests on a wide range of crops where it is effective against sucking insects and several species of beetles, flies, and moths but not toxic to plant-feeding mites. Studies have reported that imidacloprid is less toxic to natural enemies like predatory beetles and some predatory bugs (James, 1997; Elzen, 2001). Imidacloprid shares structural similarity and a common mode of action with the tobacco toxin, nicotine. Its toxicity is based on the interference of neurotransmission in the nicotinic cholinergic nervous system. Imidacloprid binds to the nicotinic acetylcholine receptor (nAChR). The receptor normally exists in a closed state; however, upon ACh binding, the complex opens a pore and becomes permeable to cations. The channel openings occur in short bursts, which represent the lifetime of the receptor-ligand complex. ACh is then rapidly degraded by the enzyme acetylcholinesterse (AChE). In contrast, imidacloprid bound to the nAChR is inactivated very slowly (Matsuda *et al*., 2005). Sustained activation of the nAChR by imidacloprid causes desensitization and blocks the receptor leading to paralysis and death (Matsuda *et al*., 2005). The most common clinical signs associated with exposure to imdacloprid include rash, breathing difficulty, headache, tearing eyes, nausea, itching, dizziness, increased salivation, vomiting, numbness and dry mouth (Wu *et al*., 2001).

Actara® is a foliar- applied insecticide containing the active ingredient thiamethoxam with the chemical name 3-[(2-chloro-5-thiazolyl) methyl] tetrahydro-5-methyl-N-nitro-4H-1, 3, 5-oxadiazin-4-imine. Thiamethoxam is a neonicotinoid insecticide that acts through contact and ingestion. Its mode of action involves interference with or binding to nicotinic acetylcholine receptors (Maienfisch *et al*., 2001). Thiamethoxam exhibits minimal effects on non target such as beneficial insects, low toxicity toward mammals, and does not produce any teratogenic or mutagenic effects (Lawson *et al.*, 1999).

2.2.2. NEEM. Plant products and their analogues are an important source of agrochemicals used for the control of insect pests (Cardellina, 1988). One widely studied plant in this context is the neem tree, *Azadirachta indica* (A) Juss (Meliaceae) (Agona *et al.,* 2001).

Originally from south and Southeast Asia, neem was one of the earliest used botanical pest control agents (Ahmed & Koppel, 1987, BAIF, 1988). Today, the tree grows in Asia, Africa, the Americas, Australia, and other areas with a tropical or subtropical climate. In recent years, neem has attracted interest because of its pesticidal products.

The biorational insecticide, Agroneem® contains 168 compounds that are chemically diverse and structurally complex. Besides Azadirachtin the compounds include meliantriol, salanin, deacetyl-azadirachtinol, vepaol, isovepaol, nimbidin, 7-deacetyl, 17-hydroxy azadiradione, nimosone, nimbosone, methyl nimbiol and methyl nimbion (Schmutterer, 1990; www.agrologistic.com/content/agriculture).

Azadirachtin, a very complex tetranortriterpenoid, has been effectively used against more than 400 species of insect pests, and has proved to be one of the most promising plant candidates for integrated pest management (Jacobson, 1989; Rembold, 1989; Schmutterer, 1990; Isman, 1999; Walter, 1999). Azadirachtin exhibits an array of effects on insects such as oviposition deterrent, repellent, antifeedant, growth retardant, molting inhibitor, sterilant, and preventing insect larvae from developing into adults (Schmutterer, 1990; Mordue & Blackwell, 1993; Schmutterer, 1995). Formulations based on neem plant parts have been recommended to control cotton bollworms (Gupta & Sharma, 1997; Gahukar, 2000). Moreover, azadirachtin-based insecticides have negligible effects on natural beneficial insects and have a low environmental impact (Schmutterer, 1990 & 1995). Because the neem-based insecticides are not toxic to human and many beneficial arthropods and the fact that pests are unlikely to become resistant, these insecticides have become more sensible materials to use in most pest management programs (Feng and Isman, 1995; Immaraju, 1998; Walter, 1999).

2.3. Southern Green Sting Bug *Nezara viridula* (Linnaeus)

2.3.1. History, background, identification and distribution of *Nezara viridula*. The southern green stink bug, *Nezera viridula* (Linnaeus), is in the order Hemiptera or "true bugs" suborder Heteroptera. They occur in the superfamily Pentatomoidea with five representative families in North America: Scutellaridae (shiledbacked bugs), Corimelaenidae (negro bugs), Cydnidae (burrower bugs) Acanthosomatidae (acanthosomatids) and Pentatomidae (stink bugs) (McPherson *et al*., 1994).

The Pentatomidae are found all over the world with about 760 genera and 4100 species known thus making it the fourth largest family of Heteroptera (Schuh & Slater, 1995). Pentatomids are recognized by their ovoid shape, five segmented antennae and their malodorous scent (Pedigo, 2002). Other important species in this family include: *Nezera hilaris*, *Acrosternum hilare*, *Podisus maculiventria* (Pedigo, 2002), *Halyomorpha halys and Murgantia histrionica*.

The southern green stink bug is believed to have originated in Ethiopia (Todd, 1989). Its distribution now includes Europe, Asia, Africa, and North and South America. In the United States it is found in the southern states including Virginia, Florida, Louisiana, Alabama, Mississippi, Georgia, and Texas (Pedigo, 2002).

2.3.2. Developmental biology. Pre-mating and mating behavior of hemipterans may involve several cues including production of odors and sounds. Males of *N. viridula* produce sex pheromones, which are important for mate finding (Mitchell & Mau, 1971; Harris & Todd, 1980; Borges *et al*., 1987; Borges, 1995). Duration of copulation may last from 1 to 165 hours (Harris and Todd, 1980) and both male and female may feed during copulation (Mclain, 1981; Caroll, 1988). Egg production by hemipterans is variable and depends on the quality of food ingested (Pannizi, 2000). Females mate and lay eggs repeatedly in masses with increasing size and decreasing intervals between successive oviposition. Unmated females produce unfertilized eggs, and live longer than mated females (Pannizi, 2000). Reduced longevity of females may be due to the strain of egg laying which may divert energy away from the maintenance of the females (Pannizi, 2000).

Stink bug eggs are deposited on host plants in polygonal clusters (Todd, 1989). Each cluster may contain several to greater than 70 barrel-shaped eggs that are tightly packed in rows (Esselbaugh, 1946; Bundy & McPherson, 2000). *N.viridula* uses tactile stimuli to stay aggregated near the egg cluster without feeding during the first two days of the first stadium (Lockwood & Story, 1986; Todd, 1989). Beyond this period, chemical cues (n-tridecane) are used to maintain the individuals together, however, depending on the concentration; this chemical may also act as a dispersant of colony (Lockwood & Story, 1985).

The first instar nymphs do not feed. It has been speculated that they ingest egg shell residues, microorganisms and water (Todd & Herzog, 1980). Subsequently second instars disperse slightly and begin feeding (Todd & Herzog, 1980). Stink bugs develop through five nymphal instars (Dercoursey & Esselbaugh, 1982, Todd, 1989). The duration of immature development may range from 3 to 5 weeks depending on the temperature (Todd, 1989). During the third instar nymphs may split into smaller groups while feeding. Fourth and fifth instar nymphs are the major nypmhal ages involved in colonization (Panizzi *et al*., 1980; Dercoursey & Esselbaugh, 1982). The fifth instar nymphs feed on highly nutritional food in order to molt into an adult with maximum reproductive potential (Panizzi, 1997).

2.3.3 Stink bug feeding on cowpea and tomato. Injury is the effect of pest activities on host physiology that is usually deleterious (Pedigo, 2002). Abudulai and Shepard (2001) reported that early pod-fill is the most susceptible stage to damage by pod-sucking bugs in cowpea. Adult and nymphal stages of stink bugs generally feed by puncturing plant tissues with their piercing sucking mouth parts and removing the cell contents (McPherson *et al*., 1994, Panizzi, 1997). Feeding on pods results in seed damage and ultimately distorted development of pods (Payne & Wells, 1984). The damage on fruit from the puncture results in a hard brownish or black spots. Secondary damage occurs when phytotoxic microorganisms are transmitted during feeding (Payne & Wells, 1984).

In tomato stink bug feeding causes cloudy spots. The insect removes sap from the fruit which is replaced with air. These air pockets are soft and spongy and appear white when the fruit is green and yellow as the fruit turns red (www.mdvegetables.umd.edu/sting bug). In addition to the visual damage caused by stink bug feeding, the mechanical transmission of tomato bacterial spot may also result. Stink bugs also carry fungi and other pathogens on the stylets that may cause decay when introduced into fruit. Tomato fields that have been significantly damaged by introduced fungi from stink bugs are often said to be "moldy" by graders (www.mdvegetables.umd.edu/sting bug).

2.3.4. Nutritional ecology of stink bugs. Plant attributes such as nutrients, non-nutrients, and morphological features dictate the effect of food on the biology of insect. The impact may result in death of immature insects, reduced growth rates, increased mortality of pupae, small adults with reduced fecundity, shortened adult life span and morphological malformations (Pedigo, 2002). Physical and structural characteristics of seeds or pods affect nymphal development. In soybean the hardness of seed coat favors nymphal mortality of *N. viridula* (Panizzi, 1987).

Nutrition regulates growth, development and reproduction. Insect nutritional ecology involves the integration of biochemical, physiological, and behavioral information, within the context of ecology and evolution (Panizzi & Slansky, 1985). In the past most studies of nutritional ecology have been done in association with soybean (Todd & Herzog, 1980; Panizzi

& Slansky, 1985). In those studies both pods and seeds were used to evaluate the performance of *N. viridula* and the total developmental time was 23.2d and 35.1d on seeds and pods respectively (Panizzi & Slansky unpublished data).

Quantitative nutritional approach consist of measuring the amount o food consumed, digested and assimilated, excreted metabolized, and converted into biomass (Slansky & Panizzi, 1987). Analysis of these measurements reveals the responses of organisms to different foods and how the growth of the organism is affected. Accurate measurements are made on consumption, utilization, and allocation of food using gravimetric methods. Meanwhile quantitative food utilization studies are not common among members of the Pentatomidae family (Slansky & Panizzi, 1987).

2.3.5. Field ecology of stink bugs. Field ecology explains the dynamics of insect numbers in time and space which provides an understanding of the physiology and behavior of insects as affected by their environment (Pedigo, 2002). Stink bugs over-winter in the adult stage beneath leaf litter, bark, wood piles and within other objects that offer protection from environmental extremes (Todd & Herzog, 1980; McPherson *et al*., 1994). Adult stink bugs become active in the spring (Rolston & Kendrick, 1961). Generally the first generation of stink bugs can be found in clovers, early vegetables, small grains, corn fields and in weeds (Todd, 1976; Todd & Herzog, 1980; McPherson *et al*., 1994). As the season progresses the subsequent generations of stink bugs migrate to cultivated hosts with corns and soybeans suggested to be the common hosts (Todd, 1976).

Stink bug movement from wild host plants to cultivated field crops coincides with seed development stages of the hosts (Rolston & Kendrick, 1961; Todd & Herzog, 1980). As spring plant hosts senesce and become unattractive for feeding and oviposition, adults migrate to hosts that are more acceptable for nutrition and reproduction (Todd & Herzog, 1980; Panizzi & Meneguim, 1989).

2.3.6. Control of stink bugs. Many control methods have been shown to lower the population of stink bugs.

2.3.6.1. Cultural control. Cultural control consists of the use of trap-boarders such as crotalaria which attract and hold stink bug population (Clausen, 1978; Mcpherson *et al*., 1994) and destruction of weeds (legumes, blackberries, Russian thistle, mustards, and little mallow) around the field that serve as good over wintering host and lowers the population of stink bugs (UC IPM Pest Management Guidelines, 2009).

2.3.6.2. Biological control. Several biological programs have been highly successful in the control of stink bugs (DeBach, 1962; Clausen, 1978; Caltagirone, 1981). The introduced parasites *Trissolcus basalis*, *Trichopoda pilipes* and *Trichopoda pennipes* are generally effective in controlling the bugs (Noble, 1937; Clarke, 1990). *T. pennip*es is highly attracted by an aggregation pheromone produced by male southern green stink bugs, which results in the males being parasitized at a consistently higher rate than females (Mitchell & Mau, 1971; Gerald, 2009). Each parasitoid lays an average of 100 eggs and the young larva that hatches from the egg bores directly into the host body. The maggot feeds on the body fluids of the host thus killing it (Gerald, 2009). The big head ant *Pheidole megacephala* prey on eggs and nymphs of stink bugs (Nishida, 1966).

2.3.6.3. Chemical control. Chemical insecticides are not generally required. However they are recommended when the population of stink bug is very high. Stink bugs have chemically been controlled by the use of carbamates and organophosphate compounds (Hills, 1983). Thiodan®, Lannate®, monocrotophos®, and methyl parathion® have been used to control

N. viridula in soybean (Orr *et al*., 1989). In Washington for example, stink bug management on pomes and stone fruits rely on delay sprays of endosulfan®, dimethoate® and formetanate hydrochloride in spring (Orr *et al*., 1989).

2.3.6.4. IPM. Integrated pest management (IPM), the integration of methods to control pest population has been utilized in the management of *N. viridula* (Kogan, 1989). On soybean in Brazil the following management tools were employed: pest monitoring; management decision based on established economic injury level and the used highly selective products on *Anticarsia gemmatalis* to preserve natural enemies; mass release of *T. basalis* and the application of reduced dose of insecticide mixed with cooking salt when necessary (Correa-Ferreira *et al*., 2000).

CHAPTER 3

Materials and Methods

3.1. Origin and Maintenance of Insect Culture

3.1.1. Source of insects. Feral *N. viridula* adults were collected from the Research farm at Tuskegee University in 2010 to start a culture that served as the source of insects for the laboratory experiments. The culture was maintained in cages measuring 30.2cm x 30.2cm x 30.2cm (BioQuip Product, Rancho Dominguez, California) (Figure 1). Paper towels were suspended along the inside of the cages to serve as oviposition substrate and moist cotton balls were placed in Petri-dishes on the floor of the cage to provide water especially by first and second nymphal stages. Egg masses were collected when laid and allowed to hatch in 500ml cups under laboratory conditions (27.5±1ºC, 60 ± 10% RH 12L: 12D photoperiod). Moist cotton wool was always provided in the cups with egg masses to maintain high humidity. The adults and their progeny were reared on a mixture of fresh green beans peanuts and other fruits as described by Harris & Todd (1981), Brewer & Jones (1985) and Jones (1985). The food source was replaced every 2 days or earlier if desiccated or became moldy.

3.1.2. Tested plant varieties. Two varieties each of cowpea (Mississippi silver [MS] and Pink eye purple hull [PPH]) and tomato (Mariana [MAR] and German Johnson [GJ]) were used for this study. MS had brown smooth seed coat and the pods are silvery-green which produces large brown smooth seeds. MS seeds are resistant to fusarium wilt and root knot nematodes (Thomason and Mckinney, 1960). PPH had cream wrinkled seed coat whose hull is distinctively purple. These cowpea varieties are among the popular varieties in the southern states. MAR has a uniform shape with large internal locules. Studies have shown that MAR is resistant to the fungus *Verticillium dahliae* and *Fusarium oxysporum (*SAKATA, 2010). GJ is an heirloom and an indeterminate with large fruits with a rough surface and is fairly disease resistance. The seeds of each variety of both crops were planted in the greenhouse and newly formed fruiting structures of cowpea and tomato were labeled to indicate the dates of formation. These served as the source of food substrate (10-12 day old pods and ripen tomato fruits) for experiments.

(a) (b)

Figure 1. Rearing cages for stink bugs: (a) inside the cage with stink bugs feeding (b) external view of the cage.

3.2. Laboratory Studies

3.2.1. Food consumption and utilization. Food consumption and utilization by stink bug using third instar nymphs from the laboratory culture described in 3.1, immature pods (10-12d) of the two cowpea varieties and ripened fruits of the two tomato varieties. Twenty insects were used for each variety. The weight of the insects and the food substrates were taken using a Mettler Toledo scale with sensitivity 0.0001g. The insects were weighed daily. A set of 20 insects and each food substrate were weighed and dried at 75^{o}C to constant weight. Food consumption was calculated on both dry food basis (using dry weight of food eaten and fresh weight of insects) and a wet food basis (using fresh weight of food eaten and fresh weight of insect) using the method described by Waldbauer (1968) and as modified by Candy and Baker (2002)

The following indices were calculated:

- Consumption index (CI), the consumption rate corrected for final body weight: CI = F/TA, where F is dry weight of food ingested, T –Duration of feeding period (in days). A = mean dry weight of insect
- Growth Rate (GR),biomass gained per day =WT/TA, where WT=dry weight gained
- Efficiency of conversion of ingested food to body mass Conversion of Ingested food (ECI), a measure of the ability to convert ingested food into biomass: ECI= (WT/F) X100
- Relative growth rate(RGR), the amount of growth attained (mg dry matter) per unit body weight(mg dry matter) per unit time = (Insect wet weight gain)(Insect wet weight at the beginning of the trail) (Time)
- Relative Consumption rate (RCR), food ingested per unit nymphal mass per day: (Dry weight of food eaten) (Insect weight at the beginning of the trail) (Time).
- Growth Index (G I) = no surviving nymphs/initial no of nymphs (Carlos et al., 2004)

3.2.2. Nymphal development on immature cowpea pods and tomato fruit. Egg masses were collected on the day of oviposition and placed in plastic containers as described in the previous section (Figure 2). On the first day of the second stadium (first instar does not feed) (second instar (N2)) nymphs were removed and placed individually in Petri-dishes (9.0 x 1.5cm) with paper towel and moistened cotton ball. Immature pods (12-14 day old) of cowpea were placed individually in the Petri-dishes. Forty nymphs replicates were used for each food substrate or variety. The insects were weighed after each molt, and nymphal survival as well as developmental time recorded. The Petri-dishes were cleaned when necessary and replenished with appropriate food source. A Similar experiment was conducted using ripened tomato fruits.

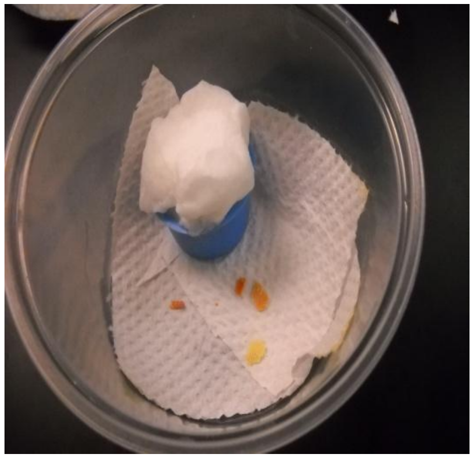

Figure 2. Plastic container with stink bug eggs.

3.2.3. Nymphal development on dry cowpea seeds. Twenty, 1-day old neonates in four replicates were reared singly on dry seeds of each of the two varieties of cowpea. Daily records were taken of molting, nymphal weight, nymphal survival and developmental period time through adult stage.

3.3. Field Study

3.3.1. Population dynamics of insects of tomato and cowpea. In 2010 and 2011, identical experiments were carried out at the same location (North Carolina A&T State University Teaching and Research Farm, Guilford County, Greensboro NC). Planting in the first year was done on May 27, 2010. The total size experimental area was 64 x 41m (Figure 3). Land preparation was carried out by four furrow reversible plough. The experiment was set up using a split -splot design with 4 replications. Insecticides (Agroneem® and Imidacloprid) were randomly assigned to main plots and crop types (MS, PPH, MAR and GJ) were randomly assigned to sub plots (Figure 3). The dimension of each subplot was 8 x 6m In each cowpea subplot there were 7 rows and 4 rows in each tomato plot.

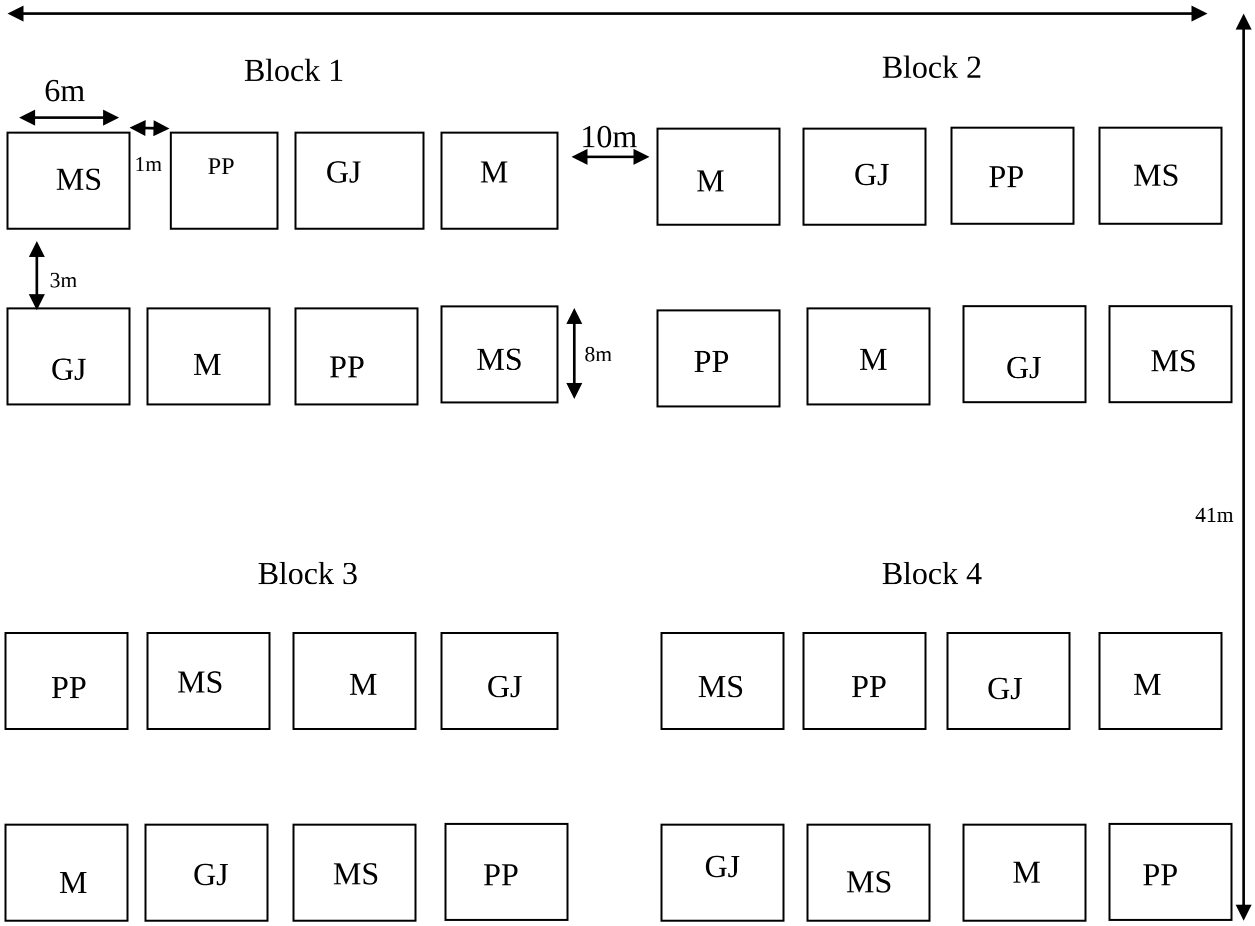

Figure 3. Experimental layout 2010.

These crops were planted/transplanted manually. Mechanical plastic mulch layers were used to lay plastic mulch on the tomato on all rows in the tomato plot and secured to control weeds and retain moisture. The two insecticides: Neem derived Agroneem® and conventional Imidacloprid (Provado®) were sprayed in a 10-14 day cycle following manufacturer's recommendation from June to August 2010. Insecticides were randomly assigned to subplots within each main plot. The insecticides were applied using a 4-gallon Solo® backpack sprayer (Figure 4).

Figure 4. Spraying of insecticide on cowpea.

During the 2011 cropping season one variety of each crop was used (MS and MAR). A randomize complete block design was used with 6 treatments combination replicated 4 times. Agroneem® and a different neonicotinoid, Thiamethoxam (Actara®) was used because of the lengthy PHI (21 days) of Imidacloprid on cowpea and tomato. Thiamethoxam is also a much safer insecticide (acute oral LD_{50}=1563mg/kg in rats) than Imidacloprid (acute oral LD_{50}=450mg/kg in rats) and. Insecticides were applied on a need-only (threshold-driven) basis for damage/ infestation. The control plots were sprayed with water. Each experimental plot measured 5m x 3m with inter-plot space of 1.5m (Figure 5) and each plot consisted of 4 rows. Wheat straw was laid on the plot to prevent weeds and to conserve moisture. A total of 8 bales of straw were spread out (2" thick) on the plots each bales weighing 540 kg. It took about 8 man hours to cover the entire experimental unit. Cowpea was planted manually at 1.0-1.5 cm soil depth at a spacing of 45cm within rows given plant density of 84 plants/15m^2 plots making a total of 1008 plants/108m^2. Tomato plants were transplanted at a spacing of 65cm within rows giving a plant density of 24 plants/15m^2 with a total of 295/108m^2 plants. General agronomic practices such as weed control, irrigation and staking were done when necessary.

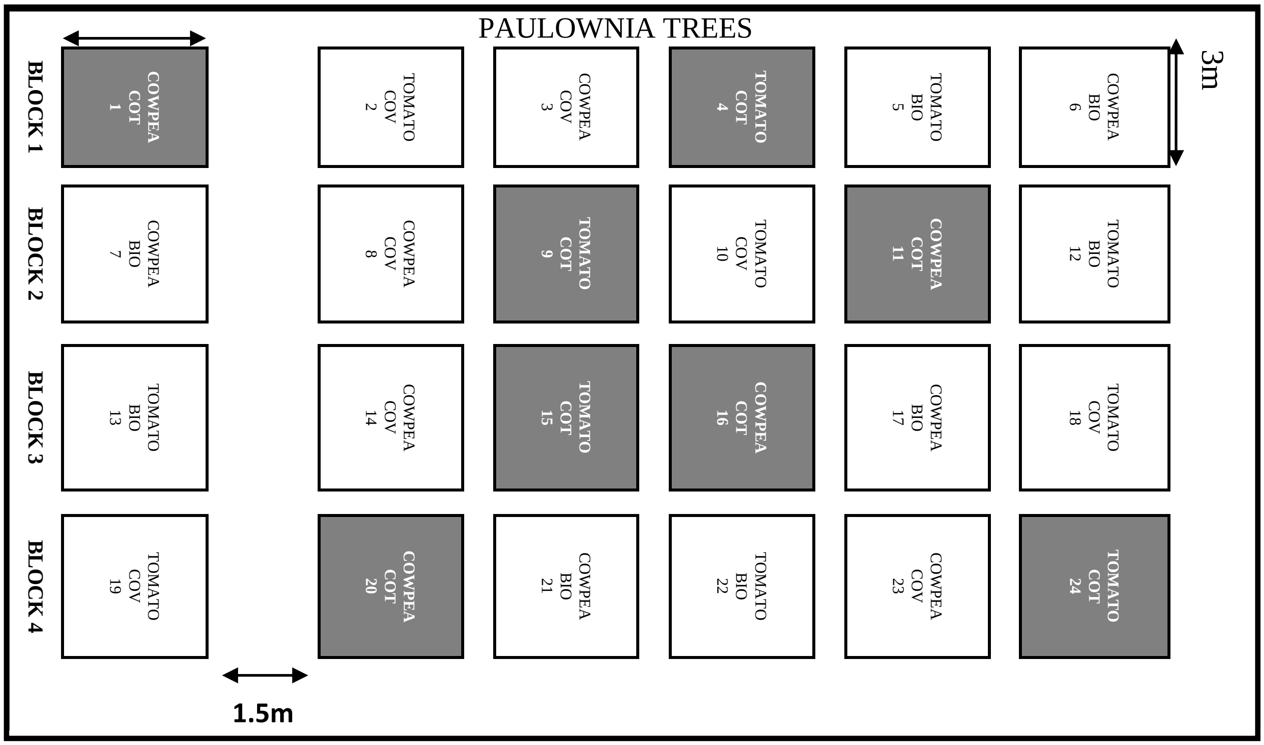

Figure 5. Experimental layout 2011.

3.3.1.2. Sampling techniques. Sampling was done at weekly intervals. Insect sampling techniques used included visual sampling, sticky traps and sweep nets.

3.3.1.2.1. In-situ counts. The number of insects present in each plot was determined through visual counts. Both sides of all the leaves were examined for insects and damage. Sampling consisted of counting *in situ* of major insect pests: *Disonycha glabrata*, *Halyomorpha halys*, *Lygus sp* and *Empoasca sp* and their damage. Sampling was made weekly between at 9am and 10am. In 2010 sampling on cowpea was on the third and fifth rows in each plot of seven rows while in 2011 sampling was done on the two middle rows in each plot of four rows. Ten plants in each row were randomly chosen for sampling. In both years sampling on tomato was on plants in the two middle rows of the four –row plot.

3.3.1.2.2. Assessment of flower thrips. Twenty flowers (i.e. 10 flowers per row) from randomly selected plants in the two middle rows of each plot were harvested and kept in vials. The vials were placed in zip lock bags and taken to the laboratory where they were kept in soapy water in vials (Cockfield et al., 2003). After two hours the number of flower thrips was carefully counted in each vial.

3.3.1.2.3. Assessment of spider mites. Ten upper (closer to the tip) and ten lower (closer to the base) leaves of tomato were examined for mites by holding a clean white sheet of paper underneath a leaf and was struck twice with the index finger. The number of mites that dropped on the paper was counted and recorded. Mite identification was carried out in the laboratory with the aid of a microscope.

3.3.1.2.4. Sticky card sampling. Disposable yellow dual sticky traps (7.6 x13cm) (Bioquip Product, Rancho Dominguez, California) were mounted on a metal stake secured 20cm above the ground. The traps were used as passive traps for small flying insects. The traps were placed in the inner rows of each cowpea (3rd and 5th rows in 2010; 2nd and 3rd rows in 2011) or tomato (2nd and 3rd rows in both years) plots. Traps were left for 24 hours and then removed and placed in a Ziploc® plastic bag. The bags were transported to the laboratory and the insects on each card counted and identified down to identifiable taxa (order, family genus and species) with an aid of published keys.

3.3.1.2.5 Sweep net sampling. Sweep- net samples were made once weekly between 9am and 10am. Ten sweeps were made over the canopy in each cowpea plot on the two inner rows. The sweeps were made in a straight line without repetition. Thereafter, the samples were immobilized with a killing agent (ethyl acetate). The specimens were subsequently identified to species where possible.

3.3.1.2.6. Yield assessment of cowpea and tomato. Yield was obtained from two inner rows of each cultivar of tomato, and from all cowpea rows. In the first year cowpea was harvested as dry pods and tomatoes at the ripened fruit stage. Matured pods were harvested manually and placed in brown paper bags transported to the laboratory where they were weighed and shelled. The seeds were used as the yield indicator. In 2011 fresh pods were harvested and weighed. Fresh pods were harvested in lieu of dry pods to prevent further damage by wild deer as experienced in the previous season.

3.4. Statistical Analysis

Data on insect pest and beneficial insects in the treated plots were analyzed with one way analysis of variance (ANOVA) using statistical software package (SAS 9.2) to determine the differences. Statistical differences among the means were evaluated using the least significant difference (LSD) test at $\alpha=0.05$. Data on Fresh body weight at adult emergence and developmental time were analyzed and compared using student's *t*-test ($P<0.05$)

CHAPTER 4

Results

4.1. Section A: Developmental Biology of *Nezara viridula* on Two Cultivars of Cowpea and Tomato

4.1.1. Cowpea. The total developmental time of *N. viridula* was longer in females (22.0-32.0 days) than males (19.3-27.6 days) regardless of the variety. The total developmental time of nymphs that fed on Mississippi Silver (MS) (21.8-23.3d) was not significantly longer (P>0.05) than those that fed on Pinkeye Purple Hull (PPH) (19.3-22.0d) (Table 1). On all the varieties mortality was greatest in the fourth instar. Nymphal mortality was higher on PPH (70%) than MS (40%) (Table 1). Weight gained by females (n=12) fed on fresh seeds or pods (n=4) of MS (129.0-158.7mg) was not significantly greater (P>0.05) than those that were fed on PPH (fresh seeds n=6; pods n=8) (69.3-155.7mg) (P>0.05) (Table 2). However weight gained by males (n=12) was significantly (P<0.05) greater on MS (129.0mg) than males (n=4) on PPH (69.3mg). The results on developmental time of dry seeds (Table 3) were similar to those on fresh seeds (Table 1). Regardless of the cowpea variety the total development time (TDT) of females (27.1 - 28.1d) that fed on dry seeds was longer than those of males (26d) (Table 3). Total developmental time of nymphs that fed on MS (26-28.1d) was not significantly longer (P>0.05) than those on PPH (26-27.1d). Also, developmental time of nymphs was longer on dry seeds than on fresh seeds (Tables 1 and 3). Greatest mortality of nymphs occurred at the fourth instar regardless of variety. Also, mortality tended to be greater on PPH (ca. 78 %) than MS (ca. 60%) (Table 3). Mortality was greater on dry seeds compared to fresh seeds (Table 1 and 3).Weight gain of females on MS was significantly higher (P<0.05) than those on PPH (Table 4). However, the weight gain of males on MS (136mg) was not significantly (*P*>0.05) greater than those on PPH (131.8mg) (Table 4).

Table 1

Mean (±SE) developmental time and mortality of Nezara viridula fed on fresh seeds of cowpea in the laboratory

Cowpea variety	Stadium duration, d				Total Developmental Time		GI	TM (%)
	2nd	3rd	4th	5th	Male	Female		
MS	5.3±0.18[a] (36)	4.8±.16[a] (32)	3.9±0.39[a] (32)	9.1±0.29[a] (24)	21.8±0.43[a] (12)	23.3±0.37[a] (12)	0.6	40
PPH	5.9±0.2[a] (40)	3.7±0.33[a] (26)	3.9±0.42[a] (22)	7.5±1.15[a] (12)	19.3±1.2[a] (6)	22.0±3.0[a] (6)	0.3	70

Note. Means in each column followed by the same letter are not significantly different (*P*>0.05; t-test). Initial number of nymphs n=40 on each food; MS=Mississippi silver; PPH=Pinkeye purple hull; TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

Table 2

Mean (±SE) body weight of Nezara viridula fed on fresh cowpea seeds in the laboratory

Cowpea variety	Nymphal weight				Adult weights		GI	TM
	2nd	3rd	4th	5th	Male	Female		
MS	0.5 (36)	6.7±0.54[a] (32)	27.7±2.6[a] (32)	67.3±5.9[a] (24)	129.0±10.85[a] (12)	158.7±10.0[a] (12)	0.6	40
PPH	0.5 (40)	8.3±0.72[a] (26)	22.9± 3.6[a] (22)	56.6± 5.8[a] (12)	69.3± 9.23[a] (6)	155.7± 27.4[a] (6)	0.3	70

Note. Means in each column followed by the same letter are not significantly different (*P*>0.05; t-test). Initial number of nymphs n=40 on each food; MS=Mississippi silver; PPH=Pinkeye purple hull; TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

Table 3

Mean (±SE) developmental time and mortality of Nezara viridula fed on dry seeds of cowpea in the laboratory

Cowpea variety	**Stadium duration, d**				**Total Developmental Time**			
	2nd	**3rd**	**4th**	**5th**	**Male**	**Female**	**GI**	**TM**
MS	4.8±0.23[a] (32)	5.5±0.35[a] (26)	6.3±0.53[a] (19)	10.9±0.5[a] (18)	26.0±0.70[a] (6)	28.1±1.0[a] (10)	0.4	60
PPH	4.6±0.24[a] (30)	5.0±0.28[a] (24)	5.9±0.38[a] (19)	11.2±1.1[a] (9)	26.0±4.1[a] (3)	27.1±1.72[a] (6)	0.2	77.5

Note. Means in each column followed by the same letter are not significantly different (P>0.05; *t*-test). Initial number of nymphs n=40 on each food; MS=Mississippi silver; PPH=Pinkeye purple hull; TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

Table 4

Mean (±SE) body weight of Nezara viridula fed on dry cowpea seeds in the laboratory

Cowpea variety	**Nymphal weight**				**Adult weights**		**GI**	**TM**
	2nd	**3rd**	**4th**	**5th**	**Male**	**Female**		
MS	0.5 (32)	6.6±0.46[a] (26)	18.5±1.7[a] (19)	66.3±4.1[a] (18)	136.0±4.38[a] (6)	157.9±5.87[a] (10)	0.4	60
PPH	0.5 (30)	7.3±1.29[a] (24)	21.5± 2.3[a](19)	83.6± 14.0[a](9)	131.8± 10.0[a](3)	149.8± 10.0[b] (6)	0.2	77.5

Note. Means in each column followed by the same letter are not significantly different (P>0.05; t-test). Initial number of nymphs n=40 on each food; MS=Mississippi silver; PPH=Pinkeye purple hull. TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

Nymphal development took longer on the pods (27.3-32.0d) than both fresh and dry seeds (19.3-28.1d) (Tables 1, 3, and 5). Both males and females that fed on MS (29-30d) took slightly longer to develop compared to those that fed on PPH (27.6-27.3d) (Table 5). The difference was not significant (P>0.05). Nymphal mortality was greatest in the third instar and fifth instar on the pods of MS and PPH, respectively (Table 5). In contrast to the seeds, mortality was greater on MS (90%) than PPH (45%) (Table 5). Growth index (GI), which measures survival of *N. viridula* on food substrate, was higher on fresh seeds (0.6) than dry seeds (0.4) and pods (0.4) (Tables 1, 3, and 5). Higher values were recorded on MS (0.4-0.6) than PPH (0.2-0.3) (Tables 1, 3, and 5).The result on nymphal weight gain was similar to those of seeds (Table 4).Weight gain of females that fed on PPH (173.5mg) was significantly greater ($P<0.05$) than those that fed on MS (115.5mg) (Table 6).The weight of males that fed on MS pods was not significantly greater than those that fed on PPH (Table 6).

Table 5

Mean (±SE) developmental time and mortality of Nezara viridula fed on young cowpea pods (12-14days old) in the laboratory

	Stadium duration, d				Total Developmental time			
Cowpea variety	**2nd**	**3rd**	**4th**	**5th**	**Male**	**Female**	**GI**	**TM**
MS	4.2±0.70[a] (18)	6.4±0.82[a] (10)	6.8±0.79[a] (12)	13.0±1.7 (8)	29.0±7.0[a] (4)	32.0±6.31[a] (4)	0.2	90
PPH	2.9±0.07[b] (40)	6.3±0.32[a] (40)	5.7±0.32[a] (40)	11.9±0.4 (28)	27.6±0.98[a] (14)	27.3±1.95[a] (8)	0.7	45

Note. Means in each column followed by the same letter are not significantly different ($P>0.05$; *t*-test). Initial number of nymphs $n=40$ on each food; MS=Mississippi silver; PPH=Pinkeye purple hull. TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

Table 6

Mean (±SE) body weight of Nezara viridula fed on young cowpea pod (12-14days) in the laboratory

	Nymphal weight				Adult weights			
Cowpea variety	**2nd**	**3rd**	**4th**	**5th**	**Male**	**Female**	**GI**	**TM**
MS	0.5 (18)	4.1±0.91[a] (10)	36.4±4.7[a] (12)	58.8±3.5[a] (8)	110.0±0.51[a] (4)	115.5±0.51[a] (4)	0.2	90
PPH	0.5 (40)	2.4±0.26[a] (40)	18.2± 1.52[a] (40)	67.6± 27.3[a] (28)	102.3± 8.25[a] (14)	173.5± 47.8[b] (8)	0.7	45

Note. Means in each column followed by the same letter are not significantly different ($P>0.05$; *t*-test). Initial number of nymphs $n=40$ on each food; MS=Mississippi silver; PPH=Pinkeye purple hull. TM=Total mortality (%); GI=Growth index. Numbers surviving each stadium are given in parentheses.

4.1.2. Tomato. Development time was generally longer on ripe tomato (41.3-44.3d) (Table 7) than on cowpea (29-32d) (Tables 1, 3, and 5) and males took 44.3-47.7d compared to females who took 41.3-46.7d. Total developmental time of adult *N. viridula* on German Johnson (GJ) was not significantly (*P*>0.05) longer than those on Mariana (MAR) (Table 7). High nymphal mortality was observed as early as the second instar and was greater on MAR (85%) than GJ (82.5%). Growth index (GI) was less lower on tomato (0.2) compared to cowpea (0.2-0.6) (Tables 1, 3, 5, and 7). The weight of nymphs that fed on tomato (56.8-62mg) was much less than those that fed on cowpea (69.3-157.8mg). Newly emerged adult females on GJ weighed 62.0mg and those on MAR 56.8mg (P<0.05) (Tables 2, 4, 6, and 8).

Table 7

Mean (±SE) developmental time and mortality of Nezara viridula fed on ripe tomato fruit in the laboratory

Tomato variety	Stadium duration, d				Total Developmental time		GI	TM
	2nd	3rd	4th	5th	Male	Female		
MAR	9.2±0.72[a] (11)	9.2±0.54[a] (11)	8.7±0.81[a] (6)	16.1±0.89[a] (6)	44.3±7.0[a] (3)	41.3±6.31[a] (3)	0.2	85
GJ	8.9±0.53[a] (9)	8.9±0.96[a] (8)	7.3±0.65[a] (7)	14.2±1.1[a] (7)	47.7±1.3[a] (3)	46.7±0.88[a] (4)	0.2.	82.5

Note. Means in each column followed by the same letter are not significantly different (*P*>0.05; *t*-test). Initial number of nymphs *n*=40 on each food; MAR=Mariana; GJ=German Johnson. TM=Total mortality (%); Numbers surviving each stadium are given in parentheses.

Table 8

Mean (±SE) body weight of Nezara viridula fed on ripe tomato fruit in the laboratory

Tomato Variety	Nymphal weight				Adult weight		GI	TM
	2nd	3rd	4th	5th	Male	Female		
MAR	0.5[a] (11)	3.1±0.63[a] (11)	21.8±0.55[a] (6)	34.0±1.44[a] (6)	55.3±1.75[a] (3)	56.8±3.28[a] (3)	0.2	85

Table 8 *(cont)*

Tomato Variety	Nymphal Weight				Adult Weight		GI	TM
	2nd	3rd	4th	5th	Male	Female		
GJ	0.5[a] (9)	2.8±0.13[a] (8)	22.1±0.71[a] (7)	24.6±1.03[a] (7)	58.3±1.20[a] (3)	62.0±3.67[b] (4)	0.2	82.5

Note. Means in each column followed by the same letter are not significantly different (*P*>0.05; *t*-test). Initial number of nymphs *n*=40 on each food; MAR=Mariana; GJ=German Johnson. TM=Total mortality (%); Numbers surviving each stadium are given in parentheses.

4.1.3. Measurement of nutritional indices. Nutritional indices are employed to assess food suitability. Indices measured include Consumption index (CI) which give an idea of consumption rate; efficiency of conversion of ingested food (ECI) measures the ability to convert ingested food into biomass; growth rate (GR) measures biomass gained per day; relative growth rate (RGR) the amount of growth attained per unit body and relative consumption rate (RCR) which measures food ingested per unit nymphal mass per day. CI was higher on cowpea (12.4-32.7) when compared to tomato (7.1-9.9) (Table 9). A higher value was recorded on PPH than MS. On tomato the CI was higher on MAR than GJ. The nymphs were able to digest MS (ECI 15.5) and MAR (ECI 14.4) more efficiently compared to GJ (ECI 6.1) and PPH (ECI 5.9). Growth rate (GR) was generally higher on cowpea (1.9) than tomato (0.4-1.4). Similar GR was recorded on PPH and MS.

Table 9

Consumption indices of third instar Nezara viridula on varieties of cowpea and tomato

Variety	CI	ECI	GR	RGR
MS	12.4	15.5	1.9	61.6
PPH	32.7	5.9	1.9	89.6
MAR	9.9	14.4	1.4	14.4

Table 9 *(cont)*

Variety	CI	ECI	GR	RGR
GJ	7.1	6.1	0.4	18.1

Note. CI=consumption index, ECI=efficiency of conversion of ingested food, GR=growth rate, RGR=relative growth rate. MAR=Mariana; GJ=German Johnson; MS=Mississippi silver; PPH=Pinkeye purple hull. The indices were not replicated.

4.2. Section B: Sweep net, Sticky Cards and in-situ Counts (2010 and 2011)

One of the objectives of this study was to determine population dynamics of southern green stink bug (*Nezera viridula*) and record other insects that occur on tomato and cowpea, and to evaluate the efficacy of a selected botanical pesticide, Agroneem® and a widely used synthetic conventional pesticide, Imidacloprid in managing these insects. In the second year of the study (2011) thiamethoxam replaced imidacloprid. Also due to logical reasons beyond our control, wheat straw was used in place of black plastic mulch.

In this study nine orders of arthropods were observed: Coleoptera, Hemiptera, Diptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera, Neuroptera and Acari. These were further classified into functional groups, as either pest or beneficial arthropods. Generally more insects were sampled in all the pesticide treated plots treated in 2011 than 2010 for which multiple reasons are discussed.

4.2.1. Sweep net sampling (2010 and 2011). Five orders of insects were captured during the sampling period in 2010. The orders were Coleoptera, Lepidoptera, Hymenoptera, Diptera and Hemiptera (Table 10 and 11). The most predominant order was Hemiptera; 4 families in this order were captured (Pentatomidae, Cicadellidae, Membracidae and Miridae) (Tables 10 and 11). The most predominant species were *Disonycha glabrata* (Coleoptera: Chrysomelidae) and *Empoasca sp* (Hemiptera:Cicadillidae) which were frequently observed on leaves. The number of insects in plot treated with Agroneem was not significantly greater than those in plot treated with Imdacloprid (P>0.05) (Table 10). However, plots that were sprayed with Agrooneen® supported more beneficial insects than those that received Imidacloprid, regardless of crop cultivar. The difference however was not statistically significant (Table 11). The diversity index (H`) in the two cultivars was comparable where higher values were recorded in plots treated with Imidacloprid (Figure 6).

Table 10

Weekly number of insect pests captured over 11 sweep net sampling periods in PPH and MS in 2 management systems (2010)

Insect Order	**Taxonomic group**		**Treatment**			
			MS		**PPH**	
	Families	**Scientific name**	**CAG**	**CAI**	**CAG**	**CAI**
Coleoptera	Chrysomelidae	*Disonycha glabrata*	1.9	1.5	2.8	3.6
		Diabrotica sp	0.9	1.1	2.1	1.5
	Buprestidae	*Bupresta sp*	0.1	0.2	0	0.2
Hemiptera	Pentatomidae	*Halyomorpha halys*	4.3	4.7	6.9	8.3
	Coreidae	*Leptoglossus spp*	0.2	0.3	0.5	0.4
	Cicadellidae	*Empoasca* sp	11.0	9.8	8.6	5.6
	Membracidae	*Ceresa sp*	5.1	3.2	2.5	0.8
	Miridae	*Lygus sp*	1.2	2.1	1.6	1.0
Lepidoptera						
	Noctuidae	*Heliothis zea*	2.4	1.1	3.5	2.3
		Spodoptera sp	1.2	1.2	2.1	3.2
Mean number			28.5±3.5	20.8±1.6	25.3±2.2	24.1±2.3

Note. Mean (±SE) number of insects per 10 sweeps on cowpea. CAG=Plots treated with Agroneem®; CAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at significant (P>0.05). MS=Mississippi Silver; PPH=Pink eye Purple Hull.

Table 11

Weekly number of beneficial insects captured over 11 sweep net sampling periods in PPH and MS in 2 management systems (2010)

Insect Order	**Taxonomic group**		**Treatment**			
			MS		**PPH**	
	Families	**Scientific name**	**CAG**	**CAI**	**CAG**	**CAI**
Diptera	Lonchaeidae	*Lonchaea sp*	15.8	10.4	10.9	10.7
	Sarcophagidae	*Sarcophaga sp*	1.2	0.9	1.3	1.2
Hemiptera	Lygaeidae	*Geocoris sp*	0.3	0.1	0.2	0.2
Hymenoptera	Apidae	*Apis sp*	1.2	1.1	2.1	**1**
	Vespidae	*Polistes sp*				
		Vespula sp				
Mean number			17.5±2.2	12.5±2.0	14.5±0.6	13.1±1.9

Note. Mean number of insects per 10 sweeps on cowpea. CAG=Plots treated with Agroneem; CAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at significant (*P*>0.05). MS=Mississippi Silver; PPH=Pink eye Purple Hull.

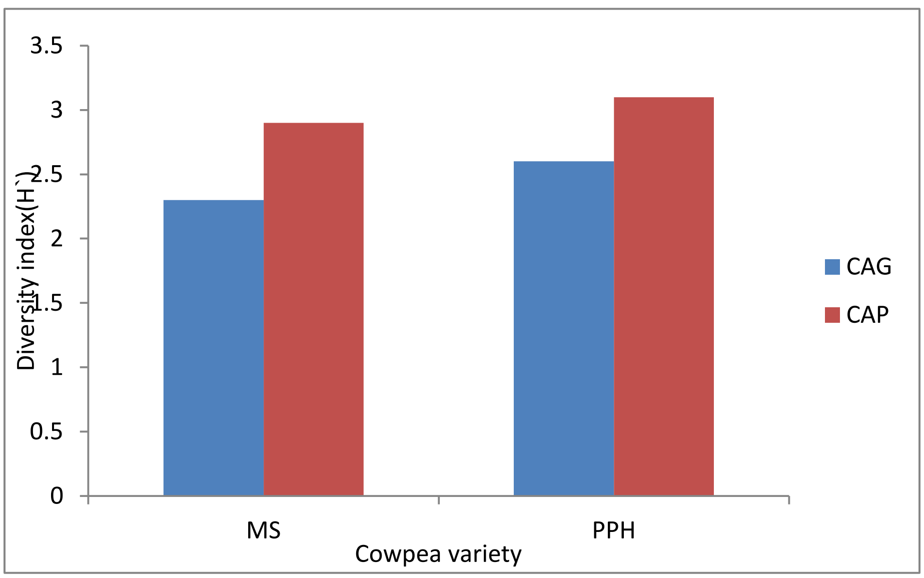

Figure 6. Insect Diversity Index (H`) of cowpea treated with Imidacloprid (CAP) and Agroneem® (CAG).

In 2011 there was a reduction in the number of insect pests captured (Table 12); however the number of beneficial insects captured was greater compared to those captured in the previous year (Table 13). Some species [*D. glabrata* (Coleoptera: Chrysomelidae) and *Diabrotica sp* (Coleoptera: Chrysomelidae)] that were captured in 2010 were not captured in 2011.

The most predominant beneficial insects that was specific to 2011 was *Condylostylus sp* (Diptera: Dolichopodidae) (Table 13) which was often seen on the foliage of cowpea. Similar to 2010 there was no significant difference (*P*>0.05) in the number of pests recorded between the two treatments (Table 12). The number of pests in plots treated with thiamethoxam was less than those in the other treatment (Table 12). In contrast there was a significant difference (*P*<0.05) in the number of beneficial insects between the treated plots with a higher number in plots treated with Agroneem® (Table 13). Insect diversity was lower in 2011 compared to 2010 (Figure 6 and 7). Between treatments insect diversity was higher in plots treated with Agroneem® (Figure 7).

Table 12

Weekly number of insect pests captured over 9 sweep net sampling periods in cowpea in 2 management systems (2011)

Insect Order	**Taxonomic group Famalies**	**Scientific name**	**Treatment CON**	**CAG**	**CAT**
Hemiptera	Pentatomidae	Halyomorpha halys	0.8	0.9	0.9
	Coreidae	*Leptoglossus* sp.,	0	0	0.03
	Cicadellidae	*Empoasca* sp.	0.7	0.6	0.3
	Acanaloniidae	*Acanalonia* sp.	0.1	0.2	0.1
	Membracidae	*Ceresa* sp.	0.3	0.4	0.1
Lepidoptera	Pyralidae	*Chrysoteuchia* sp.	0.1	0.1	0.1
Coleoptera		*Curculio* sp.	0	0.04	0.04
Diptera	Tephritidae	*Zonosemata* sp.	0	0	0.04

Table 12 *(cont)*

Insect Order	Taxonomic group Famalies	Scientific name	Treatment CON	CAG	CAT
Total number of insects			17.3±2.1	17.0±2.0	11.0±1.6
LSD(5%)					
CV(36.4)					

Note. Mean number of insects per 10 sweeps on cowpea. CAG=Plots treated with Agroneem; CAT=Plot treated with Thiamethoxam; CON=Control (Plots treated with water). Mean followed by the same letter within rows are not significant (*P*>0.05).

Table 13

Weekly number of beneficial insects captured over 9 sweep net sampling periods in cowpea in 2 management systems (2011)

	Taxonomic group		Treatment		
INSECT ORDER	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Neuroptera	Chrysopidae	*Nothancyla* sp.	0	0.03	0.03
Diptera	Dolichopodidae	*Condylostylus* sp.	1	1.1	1.1
	Lonchaeidae	*Lonchaea* sp.	15.8	19.1	11.8
	Sarcophagidae	*Sarcophaga* sp.	1.6	1.1	0.9
	Ichneumonidae	*Terilochinae* sp.	0	0	0.04
	Calliphoridae	*Lucilia* sp.	0	0.1	0
Hemiptera	Reduviidae	*Zelus* sp.	0.3	0.2	0.2
Coleoptera	Coccinellidae	*Coccinella* sp.	0.9	0.9	0.8
	Cantharidae	*Chauliognathus* sp.	0.4	1.2	0
Hymenoptera	Torymidae	*Torymus* sp.	0	0.04	0
	Halictidae	*Agapostermon* sp.	0	0.04	0
	Vespidae	*Polistes* sp.	0.3	0.6	0.5
		Vespula sp.	0.3	0.5	0.6
Total number of Beneficials			20±2.6[ab]	25.5±2.3[a]	16.4±2.0[b]
LSD(5%)	8.6				
CV(%)	23.9				

Note. Mean (±SE) number of insects 10 sweeps plant on cowpea. CAG=Plots treated with Agroneem®; CAT=Plot treated with Thiamethoxam; CON=Control (Plots treated with water). Mean followed by the same letter within rows are not significant (*P*>0.05).

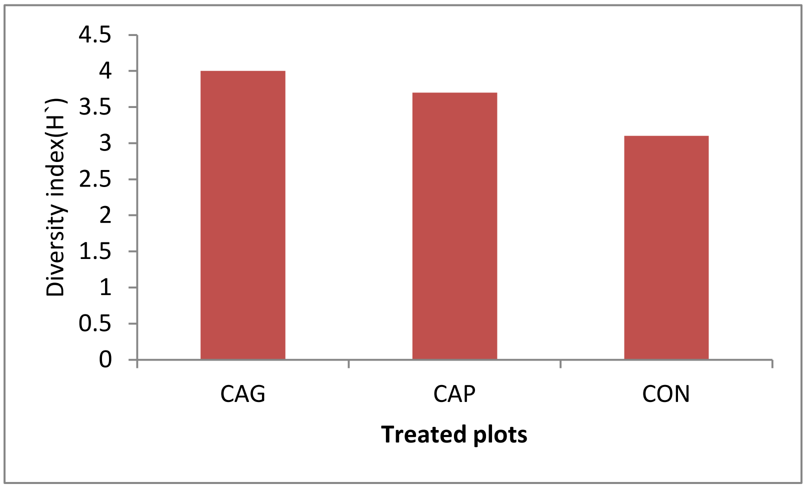

Figure 7. Insect Diversity Index (H`) of cowpea treated with Thiamethoxam (CAT) and Agroneem® (CAG).

4.2.2. Sticky trap sampling (2010 and 2011). In 2010 the most predominant insect orders with were Hemiptera (*Empoasca* sp, *Orosius sp.*, *Graphocephala* sp.) and Thysanoptera (*Frankleniella* sp.). There was an interaction between management practice and crop type (*P*<0.05) (Table 14). Plots treated with Agroneem® supported more beneficial insects than those treated with imidacloprid pesticides (Table 14). The most dominant beneficial insects were Diptera (*Lonchaea* sp) and Hymenopterans (*Vespula* sp., *Polistes fuscatus* and *Ceratina* sp.) (Table 15). Regardless of the cultivar the difference in the number of beneficial insects between the treated plots was similar (*P*>0.05) plots (Table 15).

Table 14

Mean population of insect pests on cowpea under two management systems captured over 11 sampling periods on yellow sticky cards (7.6x13cm) (2010)

Insect Order	Taxonomic group Families	Scientific name	Treatment MS CAG	CAI	PPH CAG	CAI
Coleoptera	Chysomellidae	*Disonycha glarata*	3	1.6	3.2	**2.5**

Table 14 *(cont)*

Insect Order	Taxonomic group Families	Scientific name	Treatment MS CAG	CAI	PPH CAG	CAI
		Diabrotica sp.	1.9	0.2	2.1	1.2
	Buprestidae	*Bupresita* sp.	0.1	0.1	0	0
Thysanoptera	Thripidae	*Frankliniella* sp.	91.5	65.5	72.9	83.3
Hemiptera	Cicadellidae	*Empoasca* sp.	10.2	6	9.6	11.3
		Orosius sp.	3.4	2.1	2.5	3.4
	Membracidae	*Atymna* sp.	0.6	1.5	0.1	0
Mean number of pests			116.7±11.1[b]	99.3±8.7[b]	105.5±3.8[b]	137.2±9.6[a]
LSD (5%)	34.5					
CV (%)	24.3					

Note. Mean number of insects on sticky card in cowpea.CAG=Plots treated with Agroneem; CAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05). MS=Mississippi Silver; PPH=Pink eye Purple Hull.

Table 15

Mean population of beneficial insects on cowpea under two management systems captured over 11 sampling periods on sticky cards (7.6x13cm) (2010)

Insect Order	Taxonomic group Families	Scientific name	Treatment MS CAG	CAI	PPH CAG	CAI
Diptera	Lonchaeidae	*Lonchaea* sp.	124.6	153.2	130.9	112.2
	Sarcophagidae	*Sarcophaga* sp.	6.7	5.6	10.2	6.2
Hymenoptera	Vespidae	*Vespula* sp.	2.5	2.1	3.4	3.2
		Polistes sp.	1.3	1.2	2.1	1
		Ceratina sp.	2.6	1.2	9.1	2.1

Table 15 *(cont)*

Insect Order	Taxonomic group Families	Scientific name	Treatment MS CAG	CAI	PPH CAG	CAI
Hemiptera	Lygaeidae	*Geocoris* sp.	2	3.2	4.1	1.2
Total number of Beneficials			186.7±9.2	163.3±31.5	159.8±19.5	125.6±24.1
LSD(5%)	28.0					
CV(%)	36.8					

Note. Mean (±SE) number of insects on sticky card on cowpea.CAG=Plots treated with Agroneem; CAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (P>0.05). MS=Mississippi Silver; PPH=Pink eye Purple Hull.

Fewer insects were recorded on tomato than cowpea. The insects captured on the sticky traps were Thysanoptera, Coleoptera, Diptera and Hemiptera. The order of beneficial insects captured were Diptera and Hymenoptera (Table 16). The number of pests on MAR was significantly greater (P<0.05) than on GJ (Table 16). An interaction was seen between management practice and crop type (P<0.05) with a greater number of beneficial insects in plots treated with Agroneem® (Table 17). Cowpea (1.3-1.4) generally had higher insect diversity compared to tomato (1.2-1.3) with higher values in plots treated with Imidacloprid (Figure 8).

Table 16

Mean population of insect pest on tomato under two management systems captured over 11 sampling periods on sticky cards (7.6x13cm) (2010)

Insect Order	Taxonomic classification Families	Scientific name	Treatment MAR TAG	TAI	GJ TAG	TAI
Thysanoptera	Thripidae	*Frankliniella* sp.	59.8	45.2	26.5	27.5
Coleoptera	Chysomellidae	*Disonycha glabrata*	0.8	0.3	0.1	0.3

Table 16 *(cont)*

Insect Order	Taxonomic classification: Families	Scientific name	Treatment: MAR TAG	MAR TAI	GJ TAG	GJ TAI
Hemiptera	Cicadellidae	*Empoasca* sp.	3.2	2	1.2	1.1
		Orosius sp.	0.4	0	0	0.2
Total number of insects						
LSD 9.2			55.1±3.4		32.2±2.5	
CV(%) 35.1						

Note. Mean number of insects on sticky card on tomato. TAG=Plots treated with Agroneem® TAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (P>0.05). MAR=Mariana; GJ=German Johnson.

Table 17

Mean population of beneficial insects on tomato under two management systems captured over 11 sampling periods on sticky cards (7.6x13cm) (2010)

Insect Order	Taxonomic classification: Families	Scientific name	Treatment: MAR TAG	MAR TAI	GJ TAG	GJ TAI
Diptera	Lonchaeidae	*Lonchaea* sp.	81.5	54.8	36.4	43.8
	Sarcophagidae	*Sarcophaga* sp.	0.9	3	19.2	6.2
Total number of insects			82.4±7.0[a]	51.8±16.7[ab]	56.7±2.1[ab]	50±10.9[b]
LSD	30.8					
CV(%)	27.3					

Note. Mean number of insects sticky card on tomato. TAG=Plots treated with Agroneem®; TAI=Plot treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (P>0.05). MAR=Mariana; GJ=German Johnson.

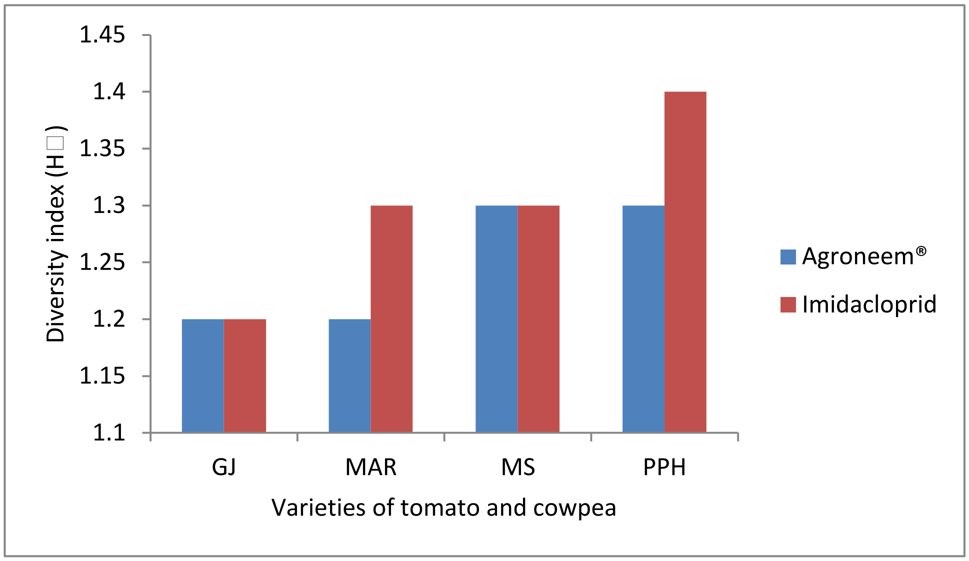

Figure 8. Insect Diversity Index (H`) of cowpea and tomato plots treated with Imidacloprid and Agroneem®. GJ=German Johnson, MAR=Mariana; MS=Mississippi Silver; PPH=Pinkeye Purple Hull.

In 2011 the population of both insect pests and beneficial insects captured on sticky traps on cowpea was greater than we observed in 2010. The number of insect pests in plots treated with thiamethoxam was not significantly lower (P>0.05) than those in any of the three treatments (Table 18). Insects in the control plots were greater than any of the other plots (Table 18). Two beneficial insects *Condylostylus* sp. (Diptera: Dolichopodidae) and *Hexacola* sp. (Hymenoptera: Eucoilidae) prominent in 2011 were not seen in the previous year. The population of the beneficial insects in plots treated with Agroneem® was not significantly (P>0.05) greater than any of the other plots (Table 19).

The population of pests captured on sticky traps on tomato was less on cowpea. The number of insects on plots treated with thiamethoxam was not significantly lower (P>0.05) than those on any other treatments (Table 20). The insect population in the control plots was greater than in the insecticide treated plots (Table 20). Beneficial insects seen in 2011 but not in 2010 were *Condylostylus* sp. (Diptera: Dolichopodidae), *Chauliognathus* sp. (Coleoptera: Cantharidae) and *Hexacola* sp. (Hymenoptera: Eucoilidae) (Table 21). The number of insects in plots treated with thiamethoxam was not significantly lower (*P*>0.05) than those on any of the other treated plots (Table 21). The diversity (H´) index was generally greater in tomato than cowpea with higher values in control plots followed by plots treated with Agroneem® (Figure 9).

Table 18

Mean population of insect pests on cowpea under two management systems captured over 9 sampling periods on sticky cards (7.6x13cm) (2011)

Taxonomic classification			**Treatment**		
Insect Order	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Thysanoptera	Thripidae	*Frankliniella* sp.	17.6	11.2	14.1
Hemiptera	Cicadellidae	*Empoasca* sp.	3.5	1.1	3.7
		Balclutha sp.	0.7	0.4	0.2
	Membracidae	*Ceresa* sp.	0.4	0.2	0.2
Total number of insects			113±3.6	122.1±3.4	98.1±2.1
LSD	62.2				
CV(%)	30.5				

Note. Mean number of insects on sticky card on cowpea. CAG=Plots treated with Agroneem®; CAT=Plot treated with Thiamethoxam. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05).

Table 19

Mean population of beneficial insects on cowpea under two management systems captured over 9 sampling periods on sticky cards (7.6x13cm) (2011)

Taxonomic group			**Treatment**		
Insect Order	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Diptera	Dolichopodidae	Condylostylus sp.	0.9	1.1	3.9
	Lonchaeidae	*Lonchaea* sp.	50.9	74.9	43.4
	Sarcophagidae	*Sarcophaga* sp.	1.5	2	1.4

Table 19 *(cont)*

	Taxonomic group		Treatment		
Insect Order	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Hymenoptera	Eucoilidae	*Hexacola* sp.	6.5	7.3	4.6
Total number of Beneficials			516.2±7.1	602±8.2	463.9±6.5
LSD	127.9				
CV(%)	14				

Note. Mean number of insects on sticky card on cowpea. CAG=Plots treated with Agroneem®; CAT=Plot treated with Thiamethoxam. CON=Control Plots. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05).

Table 20

Mean population of insect pests on tomato under two management systems captured over 9 sampling periods on sticky cards (7.6x13cm) (2011)

	Taxonomic group		Treatment		
Insect Order	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Thysanoptera	Thripidae	*Frankliniella* sp	11.8	13.9	10.3
Hemiptera	Cicadellidae	*Empoasca* sp.	0.1	0.2	0.07
	Membracidae	*Ceresa* sp.	1.9	2	1.6
	Aleyroididae	*Trialeurodes* sp.	0.04	0.1	0.04
	Aphididae	*Myzus* sp.	0.06	0	0.6
Total number of insects			84±3.6	85.9±5.2	68±5.5
LSD	37.5				
CV(%)	27.3				

Note. Mean number of insects on sticky card on cowpea. TAG=Plots treated with Agroneem®; TAT=Plot treated with Thiamethoxam. CON=Control Plot. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05).

Table 21

Mean population of beneficial insects on tomato under two management systems captured over 9 sampling periods on sticky cards (7.6x13cm) (2011)

	Taxonomic group		Treatment		
Insect Order	**Families**	**Scientific name**	**CON**	**TAG**	**TAT**
Diptera	Dolichopodidaa	Condylostylus sp.	1.7	2.3	2.9
	Lonchaeidae	*Lonchaea* sp.	27.2	33.4	31.1
	Sarcophagidae	*Sarcophaga* sp.	0.6	1.9	0.7
	Sciaridae	*Lycoriella* sp.	0.2	0.3	0.2
Hymenoptera	Eucoilidae	*Hexacola* sp.	5	6.2	5.6
Coleoptera	Cantharidae	Chauliognathus sp.	0.07	0.04	0.04
Total number of Beneficials			217.5	251.4	250.4
LSD	127.9				
CV (%)	14				

Note. Mean number of insects on sticky card on cowpea. TAG=Plots treated with Agroneem; TAT=Plot treated with Thiamethoxam. CON=Control Plot. Means followed by the same letter(s) within the same row are not significantly different (*P*>0.05).

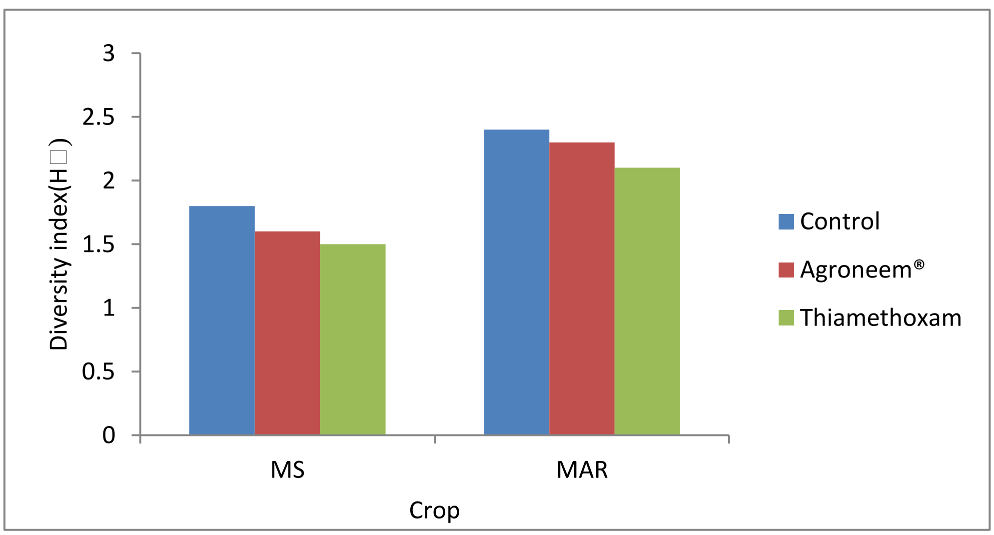

Figure 9. Insect Diversity Index (H`) of cowpea and tomato plots treated with Thiamethoxam and Agroneem®. GJ=German Johnson, MAR=Mariana; MS=Mississippi Silver; PPH=Pinkeye Purple Hull.

4.2.3. In situ counts of insects on cowpea and tomato (2010 and 2011). In 2010 more insects were seen on the cowpea compared to tomato. On cowpea the following insect orders were recorded: Coleoptera (*Disonycha glabrata*) *and Hemiptera (Halyomorpha halys, Empoasca sp and Lygus* sp.*)* (Table 22). *Disonycha glabrata*, *Empoasca* sp. and *Lygus* sp. were often seen underneath the leaves while *Halyomorpha halys* was mostly seen feeding on the pods and sometimes on the leaves of cowpea. Irrespective of cultivar there was no difference (*P*>0.05) in the number of insect between treatments (Table 22).

Table 22

Weekly number of insects per plant counted over 11 sampling periods in cowpea in 2 management systems (2010)

Taxonomic classification			**Treatment**			
			MS		**PPH**	
Pest Order	**Families**	**Scientific name**	**CAG**	**CAI**	**CAG**	**CAI**
Hemiptera	Pentatomida	*Halyomorpha halys*	5.9	1.4	1.3	0.8
	Cicadellidae	*Empoasca* sp.	0.3	1.2	0.1	0.2
	Miridae	*Lygus* sp.	0.1	0.2	1.2	0.1
Coleoptera	Chrysomellidae	*Disonycha glabrata*	0.9	0.5	1.5	0.5
Total number of insects			6.9	3.3	4.1	1.6

Note. Mean number of insects per plant on cowpea. CAG=Plots treated with Agroneem®; CAI=Plots treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05). MS=Mississippi Silver; PPH=Pink eye Purple Hull.

Arthropod orders seen on tomato included Hemiptera (*Halyomorpha halys* and *Macrosiphum* sp.), Lepidoptera (*Manduca* sp.), Broconidae (*Cotesia* sp.) and Acari (*Tetranychus urticae*), the two spotted mites (Table 23). All the*Manduca* sp.recorded were parasitized by *Cotesia* sp. Regardless of cultivar type there was no significant difference in insect number between the two management practices (*P*>0.05). *H halys* was seen feeding on mature fruits of tomato, but the population gradually decreased overtime following the formation of cowpea pods on adjacent plots. Insect diversity index (H´) was higher on cowpea (4.3-5.6) than tomato (1.7-2.4) with higher values recorded on plots treated with Agroneem® than imidacloprid (Figure 10).

Table 23

Weekly number of insect per plant counted over 11 sampling periods in tomato in 2 management systems (2010)

	Taxonomic classification		Treatment			
			MAR		GJ	
Pest Order	**Families**	**Scientific name**	**TAG**	**TAI**	**TAG**	**TAI**
Hemiptera	Pentatomida	*Halyomorpha halys*	1.2	1.2	4.1	1.2
	Aphididae	*Macrosiphum* sp.	9.8	10.5	12.2	14.3
Lepidoptera	Sphingidae	*Manduca* sp.	6.3	2.8	2.6	1.1
Total number of insects			4.2	3.7	3.6	2.3

Note. Mean number of insects per plant on cowpea. TAG=Plots treated with Agroneem; TAI=Plots treated with Imidacloprid. Means followed by the same letter(s) within the same row are not significantly different at (P>0.05). MAR=Mariana; GJ=German Johnson.

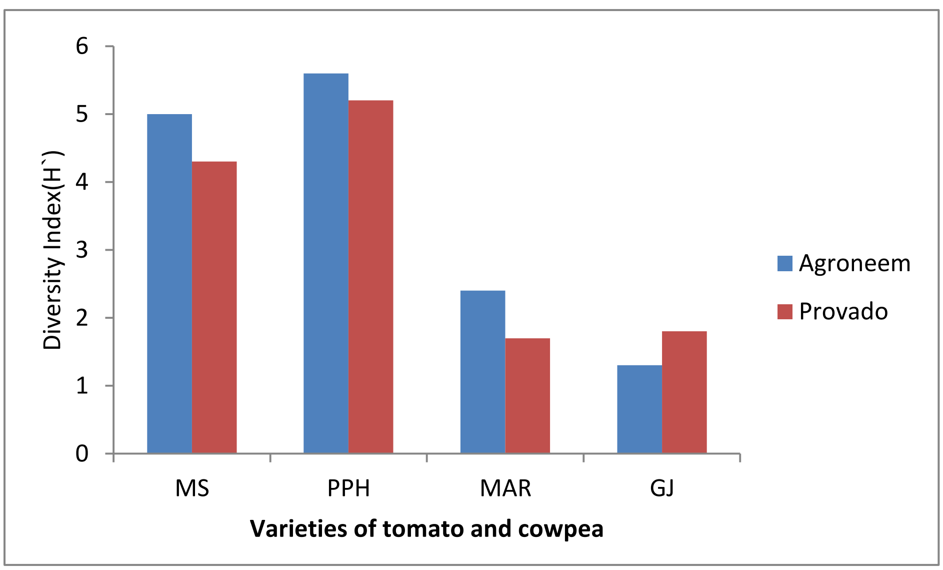

Figure 10. Insect Diversity Index (H`) of cowpea and tomato plots treated with Imidacloprid and Agroneem®. GJ=German Johnson, MAR=Mariana; MS=Mississippi Silver; PPH=Pinkeye Purple Hull.

In 2011 *Disonycha glabrata* (Coleoptera:Chrysomellidae and *Lygus sp* (Hemiptera: Miridae) were not observed on cowpea (Table 24). *Leptoglossus* sp. (Hemiptera: Coreidae) *Helicoverpa* sp. (Lepidoptera: Noctuidae) were recorded. The number of insects in plots treated with thiamethoxam was not significantly greater than those in any of the other treatments (*P*>0.05) (Table 24). Though Coleopterans were not seen on the leaves during the actual sampling activity there was an increase in the number of holes in the leaves of cowpea at 18 DAP. The number of these holes per plant and leaf miner tunnels per leaf in all the plots had exceeded action thresholds (6 holes per plant; 0.7 tunnels per leaf) (Figure 11 and 12). Following the application of pesticides there was a reduction in the number of this damaged leaves/plant with time (Figure 11 and 12). The number of shot holes in plants in the control plots were greater than in the other treatments (Figure 11).

Table 24

Weekly number of insects counted over 10 sampling periods on cowpea in 2 management systems (2011)

	Taxonomic group		**Treatments**		
Pest Order	**Families**	**Scientific name**	**CON**	**CAG**	**CAT**
Hemiptera	Pentatomidae	*Halyomorpha halys*	0.2	0.2	0.2
	Coriedae	*Leptoglossus* sp.	0.0085	0.03	0.1
	Cicadellidae	*Empoasca* sp.	0.03	0.003	0.009
	Aphididae	*Myzus* sp.	0.4	0.9	0.4
Lepidoptera	Noctuidae	*Helicoverpa* sp.	0.1	0.1	0.2
Total number of insects			3.4[a]	5.2[a]	7[a]
LSD					
CV (%)	*46.1*				

Note. Mean number of insects per plant on cowpea. TAG=Plots treated with Agroneem®; TAT=Plots treated with Thiamethoxam. CON=Control Plot. Means followed by the same letter(s) within the same row are not significantly different at (*P*>0.05).

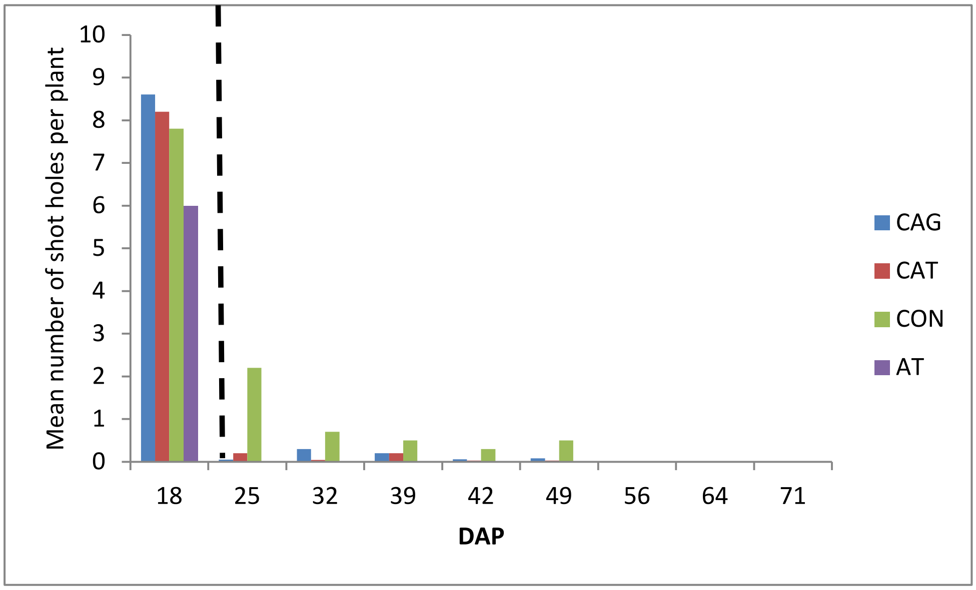

Figure 11. Mean number of shot holes per leaf on cowpea. CAG=Plots treated with Agroneem®; CAT=Plots treated with Thiamethoxam; CON=Control (Plots treated with water); AT=Action threshold. Broken lines indicate when pesticides were applied. DAP=Days after planting.

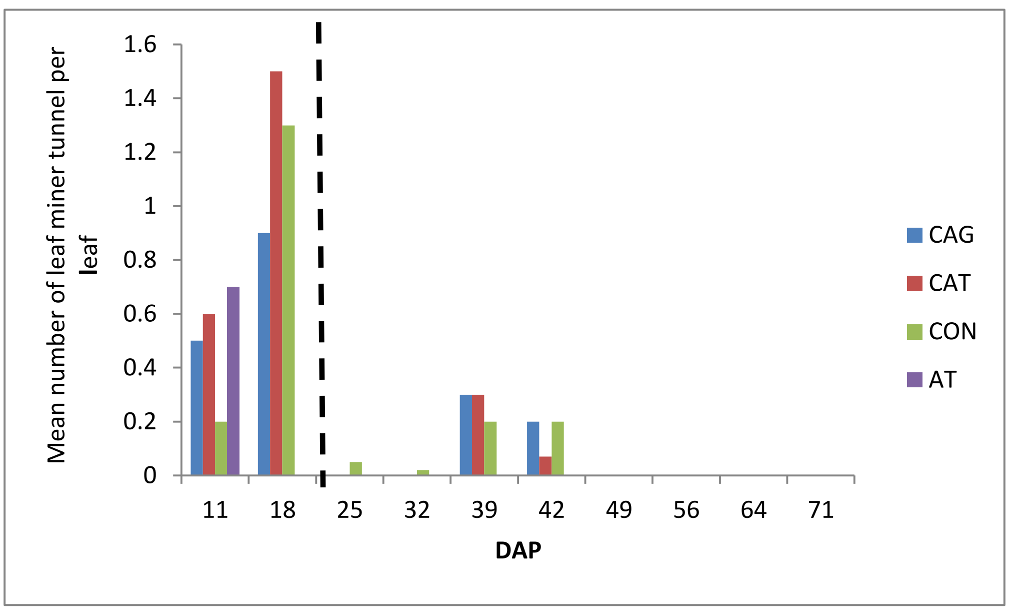

Figure 12. Mean number of leafminer tunnels per plant on cowpea. CAG=Plots treated with Agroneem®; CAT=Plot treated with Thiamethoxam; CON=Control (Plots treated with water);

AT=Action threshold. Broken lines indicate when pesticides were applied. DAP=Days after planting.

Unlike 2010 when there were a few insects of different orders, in 2011 the only insect observed on tomato leaves was *Manduca* sp. in plots where Agroneem® had been applied and also in the control plots. In 2011 there was a general increase in the number of two spotted mites, *Tetranychus urticae* (Acari: Tetranychidae) from 53 to 74 DAP (Figure 13). The number of *T. urticae* in plots treated with thiamethoxam was greater than in any of the other treated plots (Figure 13). However, the number of mites stayed below action threshold (10 mites per plant) (Fasula and Denmark, 2002). There was a gradual increase in flower thrips *Frankliniella* sp (Thysanoptera: Thripidae) at 33 DAP to 43 DAP when the number in plots treated with Agroneem® and thiamethoxam had reached action threshold (0.5 thrips per flower) (Figure 14) (Founderburk & Stavisky, 2004). Following the application of both pesticides there was a steady decrease in the number of thrips in all the treated plots (Figure 14).

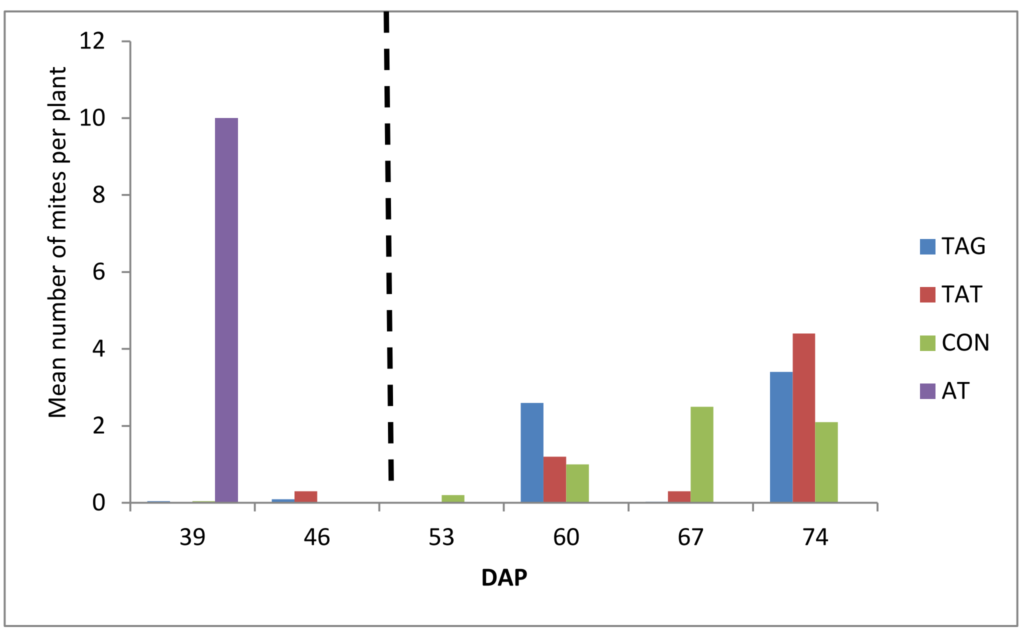

Figure 13. Mean number of mites per plant on tomato. TAG=Plots treated with Agroneem®; TAT=Plots treated with Thiamethoxam; CON=Control (Plots treated with water). Broken lines

indicate when pesticides were applied. DAP=Days after planting; AT=Action threshold. DAP=Day after planting.

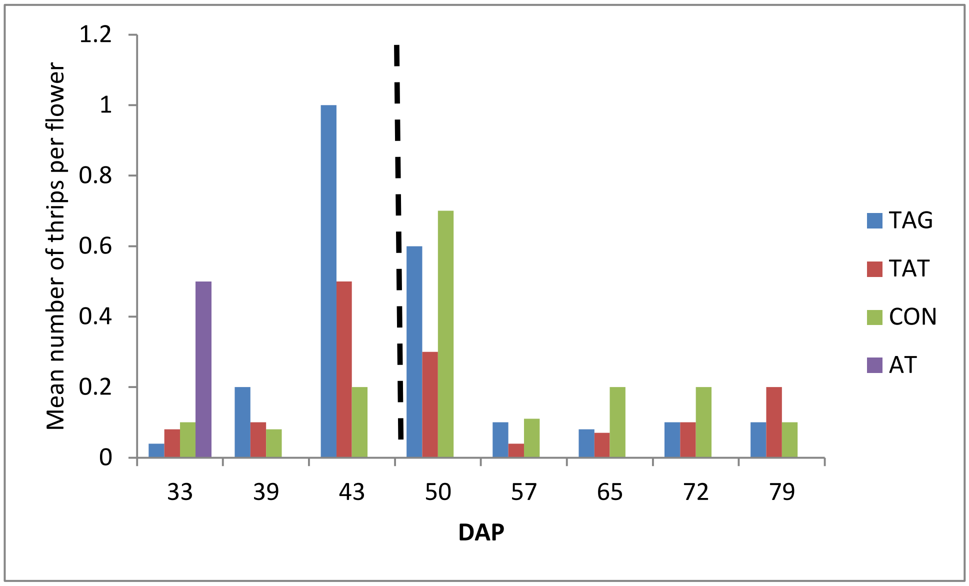

Figure 14. Mean number of flower thrips per flower on tomato. TAG=Plots treated with Agroneem®; TAT=Plots treated with Thiamethoxam; CON=Control (Plots treated with water). Broken lines indicate when pesticides were applied.

4.3. Crop Yield (2010 and 2011)

In 2010 the yield of pods and seeds of cowpea harvested were comparable in both management regimes (Figure 15). The differences between treatments were not significant (*P*>0.05). This could be due to deer damage as were seen by presence of half eaten pods. Yield of tomato harvested from plots treated with Agroneem® (1500-1600kg/ha) was higher those from plot treated with Imidacloprid (1300-1500kg/ha) (Figure 16). The two management regimens resulted in 25–53% insect damage on tomato fruit, with the hybrid (Mariana) having less damage (25-27%) than the heirloom (49-53%) (Figure 17). However, percent damage of both crops was comparable in the two management regimes (Figure 17). In 2011 the differences (*P*>0.05) between means was not significant because of a large error in the ANOVA (CV=65-72%). The large error is attributed to the unaccounted pods from deer damage. The yield of tomato harvested from plots treated with Agroneem® (6900kg/ha) was greater than those harvested from plots treated with thiamethoxam (3700kg/ha) (Figure 18).

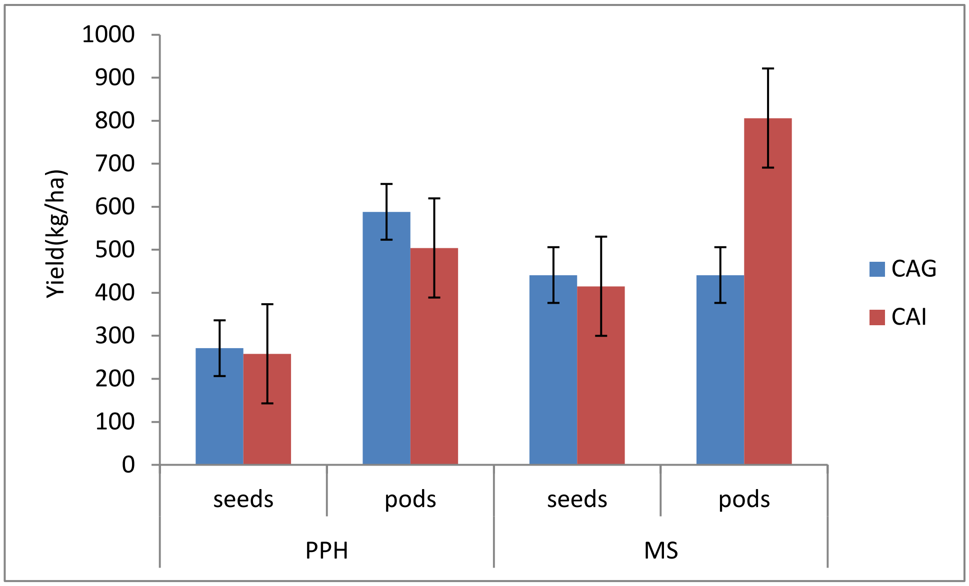

Figure 15. Average yield (kg/ha) dry pods and seeds of cowpea grown in plots treated with Imidacloprid and Agroneem® (2010). CAG=Plots treated with Agroneem®; CAI=Plots treated with Imidacloprid

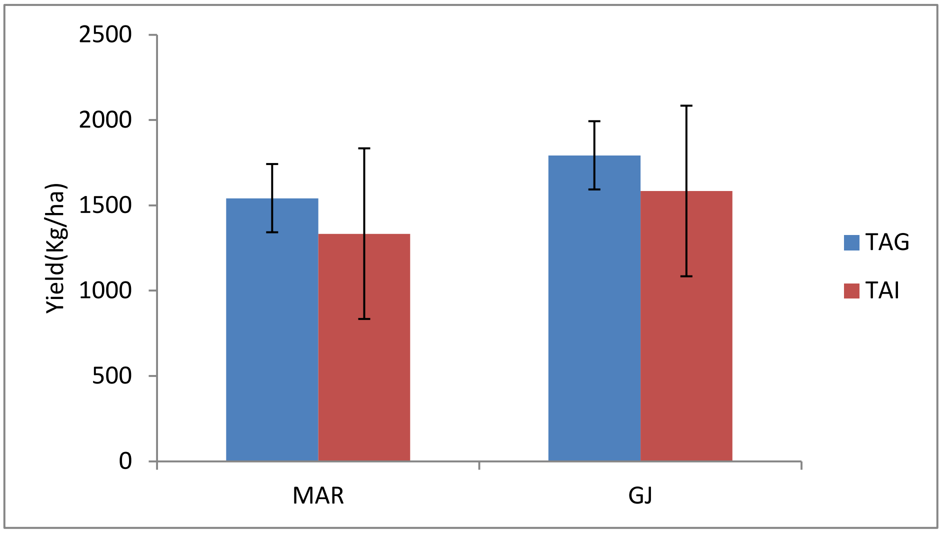

Figure 16. Average yield (kg/ha) of tomato fruits grown in two management systems (2010). TAG=Plots treated with Agroneem®; TAI=Plots treated with Imidacloprid; MAR=Mariana, GJ=German Johnson.

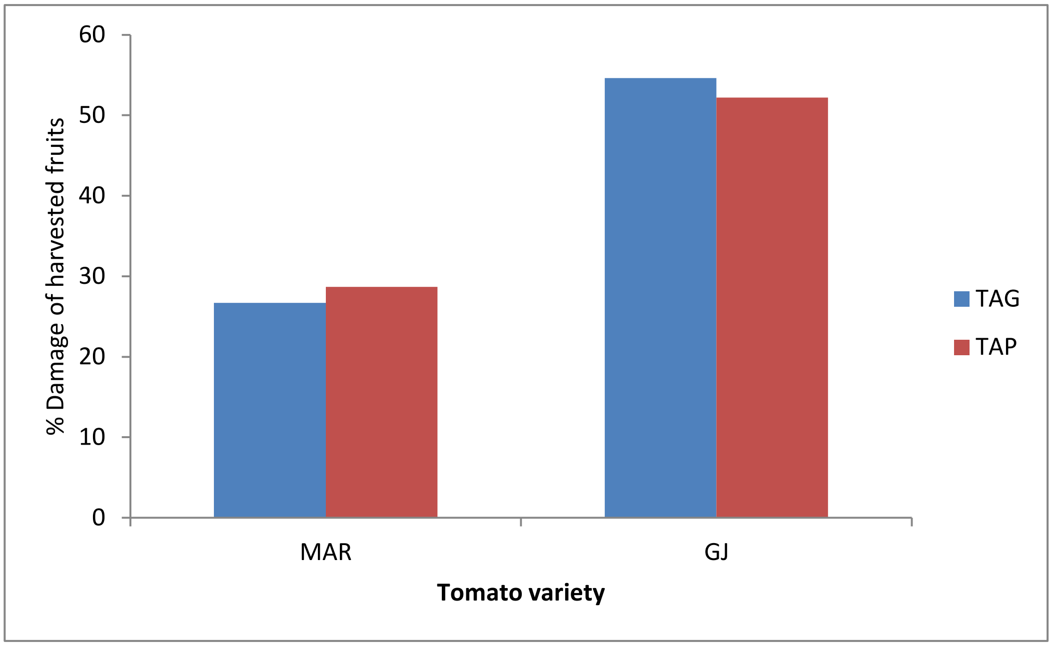

Figure 17. Damage percentage of tomato fruits grown in plots treated with Agroneem® (TAG) and Imidacloprid (TAP).

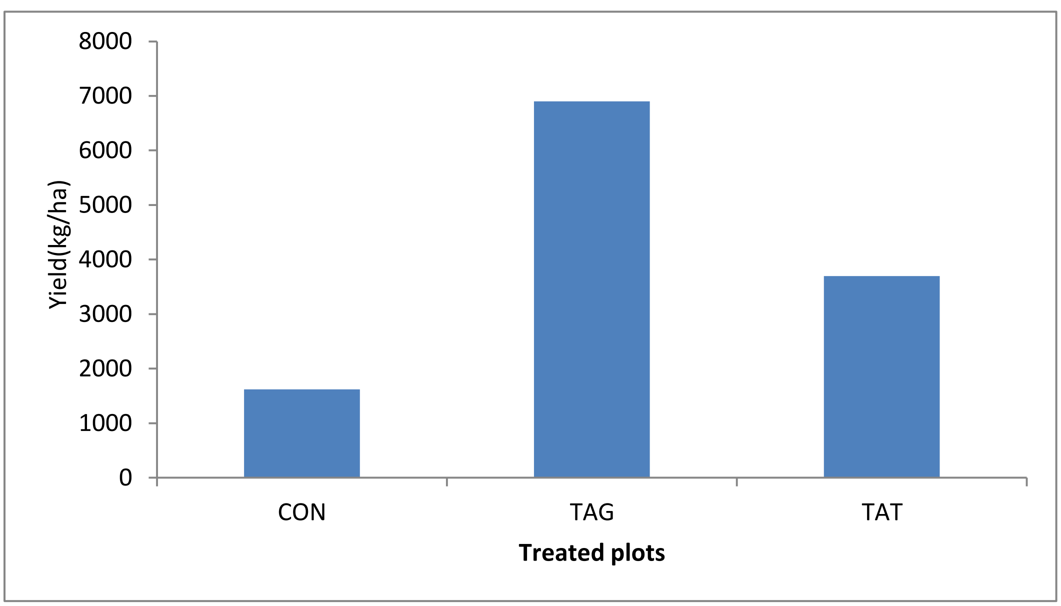

Figure 18. Yield (kg/ha) of tomato (MAR) grown in plots treated with Thiamethoxam and Agroneem® (2011). CON=Control; TAG=Agroneem® treated plots; TAT=Thiamethoxam treated plots, MAR=Mariana.

Tomato harvested from the control was less than any of the two treated plots (1620kg/ha) (Figure 18). Percent damage of fruits harvested from thiamethoxam treated plots was less than those harvested from plots to which Agroneem® was applied (Figure 19). Cowpea harvested from plots treated with Agroneem® (1600kg/ha) was greater than those harvested from plots treated with thiamethoxam (1500kg/ha) (Figure 20). Cowpeas harvested from the control (1700kg/ha) was greater than any of the treatments.

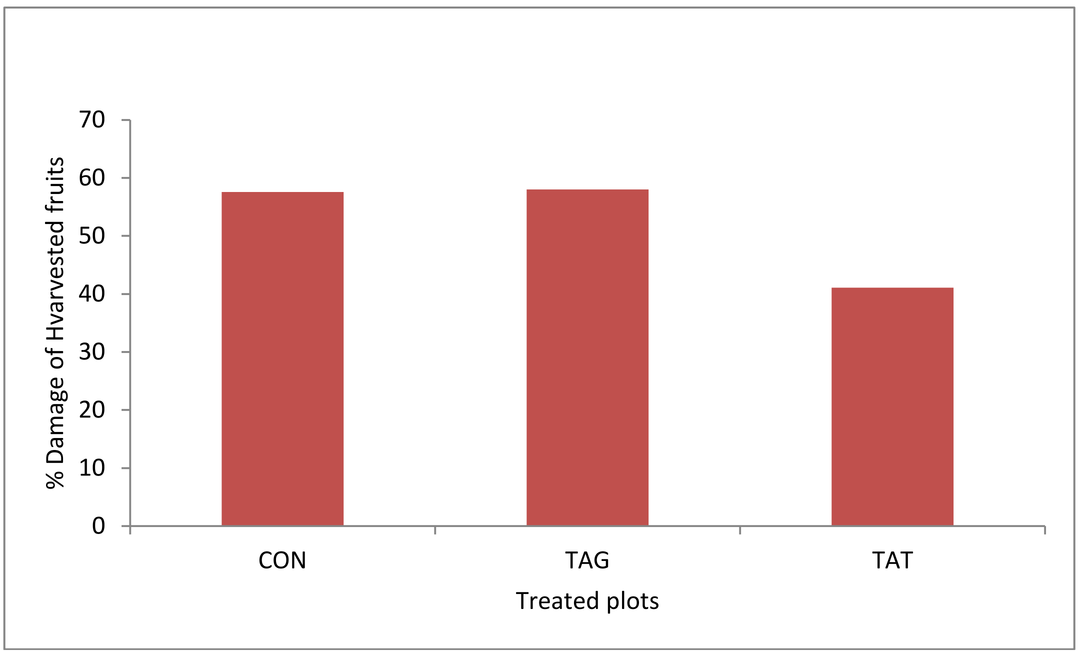

Figure 19. Damage percentage of tomato fruits grown in treated plots (2011). CON=Control; TAG=Agroneem® treated plots; TAT=Thiamethoxam treated plots.

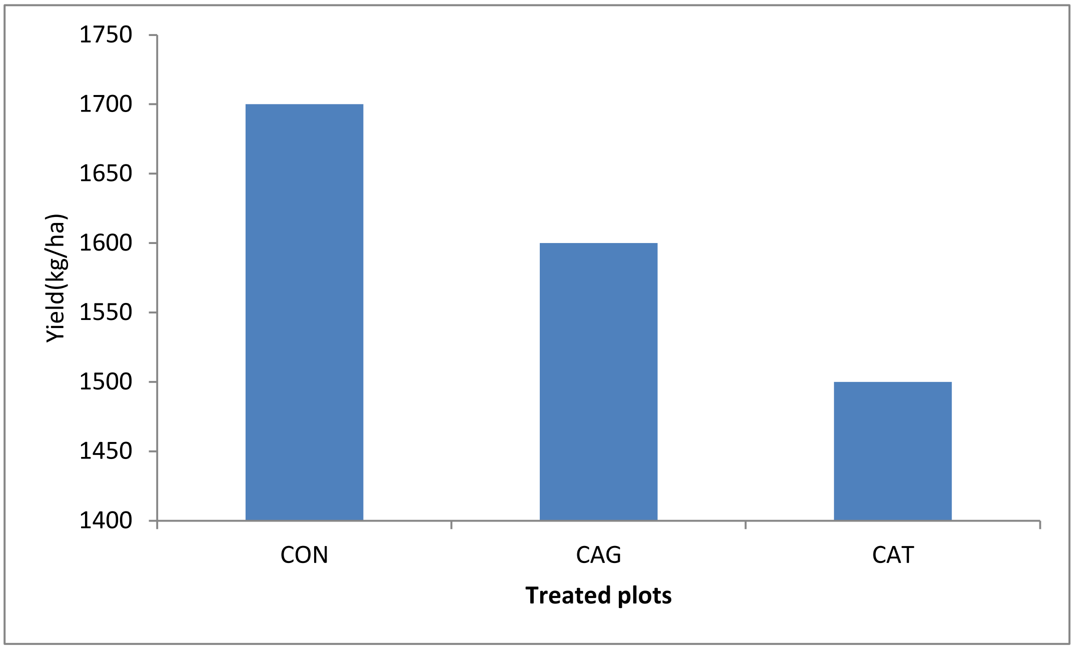

Figure 20. Yield (kg/ha) of cowpea (MS) grown in plots treated with Thiamethoxam and Agroneem® (2011). CON=Control; CAG=Agroneem® treated plots; CAT=Thiamethoxam treated plots, MS=Mississippi Silver.

CHAPTER 5

Discussion

5.1. Section A: Developmental Biology of *Nezara viridula* on Two Cultivars of Cowpea and Tomato

Developmental time of *N. viridula* on cowpea was similar to those reported in previous studies on artificial diet and soybean (25-43d) (Drake, 1920; Harris & Todd, 1980; Panizzi, 2000). The longer nymphal developmental time, lower body weight at adult emergence, higher nymphal mortality and lower growth index indicate that tomato is a less suitable food source for *N. viridula* than was cowpea suggesting that under the same environmental conditions *N. viridula* will take a longer time to complete its life cycle on tomato than on cowpea. Allelochemicals can reduce consumption, slow growth and reduce final size of insect (Paradise & Stamp 1990) Studies have shown that the presence of allelochemicals in tomato slows the growth of insects. Also, it has been reported that host plant properties influence growth, development and survival of juveniles with direct implication on adult fitness (Tikkanen et al., 2000; Coll & Yuval, 2004). . Steroidal glycoalkaloid α-tomatine, rutin, chlorogenic acid and tomatin are the major constitutive allelochemicals in tomatoes that interefere with growth and development of insect pests (Isman & Duffey 1982). This could account for the low consumption index (consumption rate corrected for final body weight of these insects) on the two varieties of tomato.

In general, nymphs required a longer time to complete development on both tomato and cowpea Results of other studies state that a longer time is required for hemipterans to complete fifth the stage compared to earlier stages (Panizzi & Slansky, 1985). The longer time to complete development suggests that the insects must feed for a longer time to have enough energy to develop structures with maximum reproductive potential. Yeargan (1977) reported that fifth instars of southern green stink bug caused a greater damage to seeds than any other stage. Females required a longer developmental time probably because they needed greater amount of nutrients for reproduction than do males (Lockwood & Story, 1986).

Nymphs on fresh cowpea seeds required less time to develop compared to those on dry seeds or immature pods. This is an indication of the suitability of fresh seeds than dry seeds for growth and development. Findings by Panizzi & Slansky (unpublished data) indicated that development of *N.viridula* was shorter on immature seeds compared to pods and dry seeds. Studies have shown that the pod walls contain sclerotic cells in addition to parenchyma and other plant tissues that hinder the nymphs of herbivorous insects from having a normal feeding activity (Oghiakhe & Jackai, 1991). A similar study showed that the mortality of young nymphs of *N.viridula* was high on pods of the legume *Sesbania vesicaria* but most survive on exposed seeds. It was suggested that the high mortality was due to the fact that young nymphs find it difficult to reach the seeds in the pods because of air space that separates the seeds from the pod wall (Panizzi and Slansky, unpublished data). An insect normally insert its stylets through the pod wall to have access to the seeds which are packages of highly concentrated nutrients (Slansky and Scriber, 1985). Longer developmental time was required on dry seeds than fresh seeds. Probably the insects took a longer time to digest dry seeds than fresh seeds. This could also account for the higher mortality on dry seeds compared to fresh seeds.

The differences in developmental time, mortality and weight gain by nymphs in the two varieties suggest differences in the level and availability of physical plant traits that make the food substrate unsuitable. It appears that the seeds of PPH meet these criteria more than MS seeds. In contrast there was a high mortality on the pods of MS compared to PPH. PPH pod walls are thin that could be penetrated more easily. Pollard (1973) suggested that tissue hardness could hinder sucking insects by preventing easy access to feeding sites. The pods walls of MS were thicker than those of PPH thus making it more difficult to penetrate. Biochemical analyses are needed to determine these factors that impede the development of *N.viridula* in these varieties.

5.2. Section B: Field Study

Findings from the field experiments showed that cowpea attracted more insects than did tomato. This might be related to the nature of the both crops. Cowpea plants have extrafloral nectarines that attract insects especially beneficials (Hector & Jody 2002). Moreover, the cowpea provides an upper canopy which serve as microhabitat for insects. The reduction in the number of insects observed on tomato could also be attributed to the physical and /or chemical protection offered by tomato that adversely affects the behavior of insect. As earlier mentioned, the presence of allelochemicals such as rutin, chlorogenic acid and tomatin in tomato interferes with growth and development of insect pests (Isman & Duffey 1982). The results on the difference in size of insect populations between cowpea and tomato suggest that cowpea could be used as a trap crop to protect common pests from damaging tomato. In the early stages of cowpea the most predominant insect pests on the foliage were *Disonycha glabrata* and *Lygus* sp. which fed on the leaves causing damage. The insects were also observed on wild *Amaranthus* sp. that was ubiquitous in the field in 2010. Studies have it that *Amaranthus sp* serve as a host plant for D. *glabrata.* in Arkansas (Hemenway and Whitcomb, 1969). *Amaranthus* sp. could be used as trap crop to divert *D. glabrata* away from cowpea.

In the second year of the study, wheat straw controlled weeds which could explain the absence of *Amaranthus* sp. that serves as primary host of *D. glabrata*, *Lygus* sp. and *Diabrotica* sp**.** Studies have demonstrated that straw mulch lowers Colorado potato beetle populations in potato, probably due to physical obstruction and reduced soil temperature where it pupates (Brust

1994; Hoy et al., 1996). The population of the leaf hopper *Empoasca* sp. and whitefly *Trialeurodes* sp. was lower in 2011 than in 2010 which could be due to the effect of mulch. It has been reported that wheat straw significantly lowers the population of whitefly, aphids and leaf hoppers (Summer et al., 2003). Other factors such as changes in temperature, relative humidity and rainfall could also account for differences in insect numbers between the two seasons.

During the two-year study *Nezara viridula* was not observed but instead two members of pentatomidae: *Halyomorpha halys* and *Acrosternum* sp. were seen on the plants. *H. halys* was the dominant species whose major host appeared to be adjacent *Paulownia* sp. from which it infested the experimental plots. *Paulownia* sp. could serve as a trap crop for farmers who are interested in growing vegetables. *Paulownia* sp. could divert *H. halys* away from the crop or vegetable thus alleviating its damage to the main crop.

Insect population on PPH was slightly greater than those on MS. The former being an early variety flowered approximately 2 weeks earlier than MS. Early flowering and pod formation could have resulted in the early colonization of insect pests. Early flowering and pod formation appears to have attracted the insects which used it.

Following the application of pesticides there was a reduction in pest infestation in all the treated plots. Plots that received imidacloprid showed a marked reduction in pest numbers, with the exception of mite populations compared to plots treated with Agrooneem®. Imidacloprid out performed Agroneem® in controlling sucking insects. This confirms results by McPherson et al., (1998) who concluded that imidacloprid was effective in controlling thrips and aphids on beans. In 2011 application of pesticides by a threshold drive was effective in the control of insect pests. Pest population in these treated plots was lower than the control plots. In most cases the number of insect pest in plots treated with thiamethoxam was lower compared to plots treated with Agroneem®.

The high effectiveness of Imidacloprid is associated with its systemicity. When applied, the products are taken up via the leaves, distributed in the plant and give consistent long lasting control of sucking insects. It has been reported that following foliar application, neonicotinoids penetrate into the leaf lamina and control pests on the lower side of the leaf due to their good translaminar activity (Alfred, 2008). Studies on aphids have shown that Imidacloprid reduces aphid feeding and may increase wing forms which could be caused by the insecticide acting on the endocrine system in a way similar to that of precocenes (Hardie, 1986). However imidacloprid was not effective against mites which corroborate with other results (James & Price, 2002). Studies show that female mites exposed to imidacloprid live longer and this pesticide stimulates the production of eggs (James & Price, 2002). Reproductive stimulation of pest or insects by sub-lethal doses of insecticides is known as hormoligosis. In contrast treatment with NEEM deters oviposition result and increased incubation time for eggs of spider mites (Dimetry et al., 1993). Reduction in the number of mites when exposed to Agroneem® suggested that Agroneem® might have disrupted the breeding cycle of the pest.

In 2011 there were more natural enemies compared to those in the previous year and this could be attributed to the presence of straw mulch. Plant mulches have been reported to be effective in augmenting the number of predatory insects by providing shelter (Johnson et al., 2004). Agroneem® was not as effective as imidacloprid in controlling pests, however; it was less harmful to beneficial insects and increased insect diversity in some of the treated plots. Earlier studies found neem-derived products to be harmless against beneficials (Schmutterer, 1990).

Yield of both crops in plots treated with Agroneem® was greater than those treated with imidacloprid. This could be due to the antifeedant activity of Agroneem®. Anitfeedant activity of Agroneem® might have prevented pests from feeding on plants to which this pesticide (Agroneem®) was applied thus causing less damage and subsequent yield increases. Studies have shown that antifeedant activity of NEEM repelled insects away from treated crops and exposes them to crops treated with synthetic pesticides .The two management regimens resulted in 25-55% insect damage differences on tomato fruits, with the hybrid (Mariana) having less damage than the heirloom (German Johnson) which is possibly attributed to the low level of pest incidence or a higher resistance in Mariana (SAKATA, 2010). In 2011 the percentage of damage of tomato harvested from plots treated with thiamethoxam was lower than those treated with Agroneem suggesting that thiamethoxam is more effective in controlling sucking insects. Fruits harvested from the control plots had the highest percentage damage suggesting that both pesticides were effective in managing the pests.

In general for both cowpea and tomato yield results are inconclusive as a measure of pesticide effectiveness because of the damage caused by deer.

CHAPTER 6

Conclusion and Recommendations

The following conclusions can be drawn from this study:

- The results from the effect of cowpea and tomato on the development of Southern Green Stink Bug (*Nezara viridula*) showed that cowpea is more suitable host plant for *N.viridula*.
- The seeds of PPH are less suitable for feeding by *N. viridula* than those of MS.
- The following nutritional induces: CI and ECI were higher on cowpea than tomato suggesting that *N.viridula* preferred cowpea to tomato
- Cowpea attracted more insect pests than tomato.
- Differences in insect pests and beneficials between 2010 and 2011 could be attributed to differences in the rate of pesticide application, differences in locations and differences in temperature, relative humidity and rainfall.
- Irrespective of the sampling method the insect species diversity based on families was higher in 2011 than 2010. In both years the values was higher for sweep-net than any other sampling technique.
- In general the number of pests in plots treated with conventional pesticides (Thiamethoxam/Imidacloprid) was less than those treated with biorational (Agroneem®).
- Plots treated with Agroneem® supported more beneficial insects than those treated with Imidacloprid or Thiamethoxam.

This study also compared the effectiveness of Agroneem® and imdacloprid/ thiamethoxam on pests of cowpea and tomato. In order to collect good and conclusive data on yield at the same site, better and more effective deer control strategies would have to be put in place.

Also, further investigation is needed on the effect of straw mulch on insect pests and beneficial arthropods.

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Appendix

Variation in temperature, rainfall and relative humidity in 2010 and 2011

	2010			**2011**		
	Rainfall (Inches)	**Temp (°F)**	**RH (%)**	**Rainfall (Inches)**	**Temp (°F)**	**RH (%)**
Jan	4.8	36.3	61.5	1.4	35.8	61.4
Feb	3.8	36.9	62.0	3.0	45.4	56.5
March	3.4	51.0	58.0	5.0	49.7	61.4
April	2.0	61.8	56.1	4.2	61.4	61.5
May	6.7	69.5	70.9	3.6	67.6	72.3
June	3.0	78.7	69.7	8.9	77.1	64.5
July	7.5	79.4	68.2	5.0	80.4	70.6
Aug	3.9	78.5	74.4	2.4	78.4	66.0
Sept	6.5	73.2	65.0	10.1	71.0	74.2
Oct	3.0	60.9	65.3	3.0	60.9	65.3
Nov	0.9	49.2	64.4	0.9	49.3	64.4
Dec	2.4	33.4	59.8	2.4	33.4	59.8