Effectiveness of Trap Crops for the Control of Stinkbugs (*Heteroptera pentatomidae*) in Edible *Cucurbitaceae* Species, in Limpopo Province, South Africa

By

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ABSTRACT

Four trap crops were tested for their ability to intercept stinkbugs (*Heteroptera pentatomidae*) in a cucurbit field crop at Waterpoort, Limpopo Province. The experimental trap crops were: Sunnhemp (*Crotolaria juncea*), okra (*Abelmoschus esculentum*), mustard mixture (*Brassica hirta* and *Brassica juncea*) and cowpea (*Vigna unguiculata)*. The surveys were based on visual counts of stinkbugs from all the trap crops. Stinkbugs were collected from trap crops in a field crop trial of cantaloupe (*Cucumis melo*). The correlation between *Brassica hirta* and *Brassica juncea* with other trap crops had a great variance. The repeated *B. hirta* and *B. juncea* inner row experiment in 2012 interestingly lured the green stinkbug (*Nezara viridula)* into the cantaloupe field.

Amongst the entire trap crops, stinkbugs recovered from *Brassica hirta* and *Bassica juncea,* exceeded the average of the other three trap crops. The number of adult *N. viridula* captured had significantly increased in March 2012 and started to drop on the *B. hirta* and *B. juncea* mixture in the first week of April. During this increase, the crops were at the seeding stage.

The perimeter trap-cropping system practiced for all four trap crops varied in the attraction of stinkbugs along the perimeter of the field and inner row. *B. hirta* and *B. juncea* attracted a high number of *N. viridula* along the perimeter but fewer in the inner row. The *B. hirta* and *B. juncea* recorded the highest number of *N. viridula* in the inner rows and outer rows, compared to the other four trap crops, followed by *V. ungiuculata.* This study has demonstrated a significant potential of using trap crops as biological alternative for managing stinkbug pests in cucurbit crops.

KEY TERMS

Trap crops, Stinkbugs and Cucurbits.

DECLARATION

Student number: 39385760

I declare that Effectiveness of Trap Crops for the Control of Stinkbugs (*Heteroptera pentatomidae*) in Edible *Cucurbitaceae* Species, in Limpopo Province, South Africa is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

February 2013

SIGNATURE
(Mr. Lukhwareni H)

DATE

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All the work done in this dissertation was motivated and supported by my late wife Chauke Glory and I therefore, dedicate this work to my son Lukhwareni Mutali.

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LIST OF ABBREVIATIONS

ANOVA:	**ANALYSIS OF VARIANCE**
COAG:	**COMMITTEE ON AGRICULTURE**
DF:	**DEGREE OF FREEDOM**
FAO:	**FOOD AND AGRICULTURE ORGANIZATION**
GAP:	**GOOD AGRICULTURAL PRACTICES**
IPM:	**INTEGRATED PEST MANAGEMENT**
LSD:	**LIST OF SIGNIFICANT DIFFERENT**
MS:	**MEAN SQUARE**
SAS:	**STATISTICAL ANALYSIS SOFTWARE**
T:	**MEAN TEMPERATURE (ºC)**
TM:	**MAXIMUM TEMPERATURE (ºC)**
Tm:	**MINIMUM TEMPERATURE (ºC)**

APPENDIXES

CHAPTER 1: INTRODUCTION

1.1 Background

Watermelons (*Citrullus lanatus*) and cantaloupes (*Cucumis melo*) were historically used not only as a fruit, but also as a source of water and animal feed (Anonymous, 2008a). These crops belong to the family *Cucurbitaceae*. In South Africa, the open-pollinated watermelon varieties, such as Sweet Princess, Congo, Crimson Sweet and Charleston Grey, are cultivated, whereas the common cantaloupe varieties that are cultivated include Imperial 45, Honeydew, Hale’s best cantaloupe and Edisto cantaloupe (Anonymous, 2008b).

Watermelons and cantaloupes are commonly subjected to attack by several pests, such as stinkbugs (*Heteroptera pentatomidae*), therefore certain insect-management practices need to be applied to ensure cost-effective decision making (Adams, 2000). Input costs are soaring and many agrochemicals have not only become scarce but have also seen significant price increases (Altieri, 1989; Gliessman, 2007). Pesticides are thus becoming increasingly expensive and some major problems are also associated with their usage, such as environmental degradation and human health problems (Heeren *et al*., 2003; Shelton & Badenes-Perez, 2006). According to Shelton and Badenes-Perez (2006), the potential negative impacts, result in pesticide resistance and general unfavourable economic effects on agricultural production. The alternative practices of crop pest management that are environmentally and human friendly, relatively cheap and are also sustainable to use, offer a possible solution to the problems of pesticide usage in the farming systems in Africa (Majumdar, 2010).

The Pentatomidae family consists of 4000 species of insects including (*Nezara viridula)* southern green stinkbugs and *Coenomorpha spp* (brown stinkbug (Skaife, 1992) In the present thesis, when specific Pentatomidae insect pests are identified, they have been named according to their specific scientific names of either *N. viridula* or *Coenomorpha spp*. They attack various crop plants, ranging from vegetables to fruit trees, in South Africa and these are controlled by means of registered chemicals for agricultural crops (; UC IPM, 2009). In this family of pests, stinkbugs are regarded as the predominant pest that attacks a wide range of agricultural crops, such as fruits, vegetables and field crops (Strand, 1999). Due to a lack of efficacy on the part of the pesticides, trap-cropping systems are currently being investigated for integrated pest management (UCONN, no date). Mizell, (2008) expressed similar views when measuring the tolerance behaviour of stinkbugs to many pesticides, and also concluded that stinkbugs are difficult to suppress.

Bottrell, (1979) defines integrated pest management as the selection, integration and implementation of pest control based on the predicted economic, ecological and sociological consequences which make the maximum use of naturally occurring control agents. The latter include the weather, pathogens, predators and parasites. The current usage of integrated pest management (IPM) systems also involves the social aims of IPM, as well as the biological underpinnings of IPM, which are yield loss and pest population dynamics, and pest management strategies and tactics for IPM, which include physical, biological, cultural or chemical control and compatibility of all these tactics (Andow & Rosset, 1990). Hagen *et al*., (1999) contend that predators of terrestrial arthropods are important natural enemies of these pests. Predator and parasitoid efficacy depends on conditions set by production technologies such as varietal development, cropping systems, tillage practices and chemical inputs (Letourneau & Atieri, 1999).

The stinkbug is a pest that occurs sporadically and seasonally. It feeds on immature fruit, thereby causing growth distortion, irregular surfaces and internal spots on crops (Evans, 1984; UC IPM, 2009). Adams (2000) considers the stinkbug to be a miscellaneous insect pest of watermelons which only feeds if the preferred host is not available. Due to polyphagous behaviour, they show a distinct preference for certain plant species. Consequently, attractive host plants can potentially be offered to entice this pest away from the main crop (Mizell *et al.*, 2008a).

The species has been controlled for over 40 years with organophosphate insecticides but deemed resistant to insecticides (Alberts, 2010). It was investigated by Alberts (2010), who found that, in macadamia crops, stink bugs could cause up to 80% of crop loss if the pest is not controlled, but under general conditions, stinkbugs can cause about 50% of the overall damage in a field. Damage to avocadoes by stinkbugs has been detected and is considered to probably increase in the future (Joubert, 1994).

1.2 Problem Statement

Bruwer (1992) determined that South Africa has the most complex and difficult stinkbug pest problems in the world and therefore, suggested that further research need to be done in order to find solution to this problem. A crop that has been fed on by a stinkbug may rot and subsequently fail to reach maturity or becomes spoiled and unmarketable. When the ecological knowledge at our disposal is used to our advantage, pest problems such as this one under investigation can potentially be controlled effectively without causing major disruptions to the biological balance in crop fields. Only registered chemicals are effective tools that are used to control stinkbugs; currently, no other control method has been deemed effective (Schoeman, 2010). Presently, crop protection practices in crop fields depend largely on the application of crop protection products such as the various synthetic agrochemicals, including the pesticides. Nevertheless, pesticides are, unfortunately, regarded as a health and environmental hazard. They are also costly and, ultimately, unsustainable to use in crop production systems in Africa. The main problem identified and addressed during this study relates to the transition of commercial watermelon and muskmelon (cantaloupe) cultivation, which depends largely on chemical control methods, to a more sustainable cultural and organic cultivation method.

1.3 Research Question

Which crops have the potential to be effective trap crops for stinkbug pests in watermelon and cantaloupe cultivation?

1.4 General Objective

To study the effect of selected trap crops to attract stinkbugs in watermelon and cantaloupe crops as an alternative method to the use of chemicals to control the insect pest incidence.

1.4.1 Specific Objectives

1.4.1.1 To investigate the potential of the following trap crops to attract stinkbugs in watermelon and cantaloupe crop cultivation:

1. *Abelmoschus esculentum* (Okra)
2. *Brassica juncea and Brassica hirta* (Mustard mixture)
3. *Crotalaria juncea* (Sunnhemp)
4. *Vigna unguiculata* (Cowpea)

1.4.1.2 To investigate the potential of two different deployment strategies of the mentioned trap crops, i.e.:

1. Perimeter trap cropping
2. Inside-row trap cropping

1.4.1.3 To investigate the influence of trap crop maturity on the attractiveness of the crop to the stinkbugs.

1.5 Hypothesis

Trap crops can be used to provide an organic solution for crop protection against stinkbug pests in selected *Cucurbitaceae* crops.

1.6 Motivation

The principle of trap cropping depends almost entirely on the fact that all pests show a varying degree of fondness for certain plant species and cultivars, or a certain degree of crop stage growth, such as maturity. Manipulation of the trap crop stands, in terms of time and space, is practised in order to offer pests attractive host plants at a critical time in the pests' and/or the crop's phenology, leading to the concentration of the pests at the desired site, thus creating conditions for ease of trapping by using the trap crops (Hokkanen, 1991).

1.7 Delineation and Limitations

1.7.1 Delineation

The focus of this dissertation will be limited to investigating the potential of four selected trap crops to attract stinkbug pests in watermelon and cantaloupe crops.

1.7.2 Limitations

Other job commitments were a factor in the timely completion of the research. More extensive work could also not be explored in a laboratory setup.

1.8 Definition of Terms and Concepts

Trap crops: Shelton and Badenes-Perez (2006); Mizell (2012) defined this as plant stands that are grown to attract insects or other organisms, such as nematodes, to protect target crops from attacks by pests, thereby preventing the pests from reaching the crop or concentrating them in a certain part of the field where they can be destroyed economically.

Sustainable agroecosystem: A sustainable agroecosystem is one that maintains the resource base upon which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from the disturbances caused by cultivation and harvest (Altieri, 1989; Edwards *et al.,* 1990; Dalsgaard *et al.,* 1994; Gliessman, 2001; Buchs, 2003).

Phytophagous insects: These are insects that feed on plants only (Mizell *et al*., 2008b).

Polyphagous insects: These are insects feeding on a variety of cultivated crop plants (Mizell, 2012).

Perimeter trap cropping: This occurs when a more attractive trap crop is planted to encircle and protect the main cash crop against pests (Shelton *et al*. 2006; Badenes-Perez *et al*., 2005; UCONN, no date; Majumdar, 2010).

Conventional trap cropping: a trap crop planted next to the higher-value crop that is naturally more attractive to a pest as either a food source or an oviposition site than the main crop, thereby preventing the pest from arriving on the main crop whereby the pest is concentrated in the main crop where it will be economically destroyed (Shelton *et al.*, 2006; Mizell, 2012).

Dead-end trap cropping: These are plants which are highly attractive to the insects but the latter's offspring cannot survive (Shelton *et al.,* 2006).

Push-pull trap cropping: This is a combination of trap crop (pull component) with a repellent intercrop (push component) to attract the insect pest and divert the insects away from the main crop (Shelton *et al.,* 2006; Cook *et al.,* 2007).

Sequential trap crop: This is when trap crops are planted earlier or later than the main crop to enhance the attractiveness of the trap crop to the targeted insect pest (Shelton *et al.*, 2006).

Multiple trap cropping: This is when several plant species are planted simultaneously as a trap crop; with the purpose of managing many insect pests simultaneously or controlling insects by combining those trap crops' attractiveness to the pest at varying stages (Shelton *et al.*, 2006).

1.9 Underlying Assumptions

Environmental variables such as climate and soil, as well as management practices which may have an impact on stinkbug behaviour additional to the trap crop treatments applied, will be assumed to be insignificant and will be held to be constant for the purpose of this research project.

1.10 Significance of the Study

The phytophagous stinkbugs (*Heteroptera pentatomidae*) are pests with an important impact on many crops (including watermelon and cantaloupe), feeding mostly on immature fruits. During feeding, they utilize their piercing and sucking mouth parts to remove the host plant's cell contents. The resulting damage includes the dropping and/or malformation of fruits (Sqiutier, 2011).

South Africa currently produces watermelon and cantaloupe for local consumption. Cultivating these crops more sustainably will therefore have a significant impact on the industry for both commercial and small farmers as well as the environment. Economic spin-offs and the impact on unemployment and poverty alleviation will be significant as current conventional practices have become unsustainable, both economically and ecologically (Anonymous, 2003). Agroecological approaches to farming produce food more cheaply, are free of potentially hazardous chemical residues, are ecologically more sustainable and also guarantee producers a higher premium, due to organically cultivated products. The Global Good Agricultural Practice (GLOBAL GAP), adherence to predetermined maximum residue limits (MRLs) is required before any farmer may export any product, but with a trap-cropping system, no such limitations are imposed but, the food and agriculture organization (FAO) of the united nation and committee on agriculture (COAG) (Anonymous, 2003) set the Global GAP standard for agricultural product.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The management of habitat and vegetation can be implemented effectively with an ecological approach for pest management methodologies in sustainable agricultural production (Douglas *et al.,* 2000). Habitat management is an environment-based approach to favour natural enemies and to enhance biological control in agricultural systems; however, high levels of disturbance may influence many agroecosystem environments to be unfavourable for natural enemies (Douglas *et al.,* 2000). The concept of trap cropping fits into the ecological framework of habitat manipulation of an agroecosystem for the purpose of pest management (Altieri & Nicholls, 2005).

Certain plants that are highly attractive to polyphagous insects have the potential to be used as bait to trap them (Mizell *et al.,* 2008a). The phytophagous stinkbug is one of the Hemipterans that affect these crops, feeding mostly on immature fruit. Panizzi (1997) further states that *Nezara viridula* is a generalist feeder which prefers legumes and brassicas. The potential success of a trap-cropping system depends on the interaction of the characteristics of the trap crop and its deployment within the ecology and the behaviour of the targeted insect pest (Shelton & Badenes-Perez, 2006). In general, the attractiveness of the trap crop and the proportion of trap crops in the field are important factors in attracting the insect and in the success of the trap-cropping system (Velasco & Walter, 1992).

Various trap crops have been recorded that attract stinkbugs significantly in various agricultural crops (Velasco & Walter, 1992; James *et al.,* 2001; Shelton & Badenes-Perez, 2006; Knight & Gurr, 2006; Mizell *et al.,* 2008b). In their study of the stinkbug's behaviour, Mizell *et al.* (2008a) indicated that placement of the trap crops is critical because pests prefer to travel from plant to plant rather than stream through corridors where they might be spotted by predators. This was confirmed by Mizell *et al.,* (2008b) when they found that the trap crops worked best when planted between the crops. Majumdar (2011) supported the idea when emphasising that trap crops need to be densely sown.

Similarly, Shelton *et al*., (2005) defined conventional trap cropping as a practice where the trap crop plant is planted next to the higher-value crop to attract insects. The stinkbugs invariably use the host plant as a source of food or oviposition site in preference of the main crop. The representation based on crop-plant characteristics are conventional trap cropping, dead-end and genetically engineered trap cropping, whereas deployment trap cropping is distinguished by perimeter, sequential, multiple and push-pull trap cropping (Shelton & Badenes-Perez, 2006). *Crotolaria juncea* is used as a perimeter trap crop for preventing insect movement from the trap crop to the main crop (Shelton *et al.,* 2006). Shelton *et al.,* further indicated that *C. juncea* attracts insects, but their offspring do not survive on a trap crop plant, and this is where the push-pull characteristic exists.

Majumdar (2011) addressed the arrangement of trap crops as a spatial pattern, where the choice of design depends on the targeted pest, pest pressure and the size of the field. The arrangement includes perimeter trap cropping, row trap cropping and strip trap cropping. In the present study, the perimeter and the multiple trap-cropping methods were preferred; this follows principles expounded by Badenes-Perez *et.*, *al* (2005) on trap cropping. They found very good results with the perimeter trap cropping method when used simultaneously with the multiple trap cropping method.

2.2 Trap Cropping

The entomological definition of trap cropping is the presence of a second crop in the surrounding area of a commercial crop to divert a pest which would attack the commercial crop (Mizell, 2012). The agronomic definition, however, focuses on the planting of an attractive trap crop to protect the commercial crop. Majumdar (2011) further states that a trap crop may be harvestable or not thereby, leaving the farmer with more than one option. According to Squitier (2010), the use of trap crops to control the southern green stinkbug as a cultural practice is widely unacceptable, but has exceptional potential as a control method.

2.2.1 Trap-Cropping Modalities

For the effective functioning of trap crops, the characteristics and deployment of trap crops play a major role. The modalities of trap cropping are classified according to characteristics and deployment (Shelton & Badenes-Perez, 2006).

2.2.2 Characteristics of a Trap-Crop Plant

Shelton & Badenes-Perez (2006); Majumdar (2010) described conventional trap cropping as a practice whereby a trap crop is planted or sown next to the main crop (a higher-value crop or a crop to be protected) which is more attractive than the main crop. Therefore, the trap crop will serve as a food source or oviposition. The trap crop will then divert the pest from the main crop so that, it can be destroyed in the trap crop if necessary. Alfalfa has been used as a trap crop for Lygus bugs in cotton. The highly attractive varieties of squash have also been used as a trap crop to manage squash bugs and cucumber beetles in several cucurbitaceous crops.

A dead-end trap crop attracts insects highly, but the offspring cannot survive on the same plant. This plant serves as a sink for pests, thereby preventing them from migrating from the trap crop to the main crop later in the season. Sun hemp has been suggested as a dead-end trap crop for the bean pod borer. Shelton *et al.* (2006) suggest that dead-end trap crops should be planted at the borders of the main crop, where they can intercept insect pests and reduce pest damage in the field.

Shelton & Badenes-Perez (2006) confirm that genetically engineered trap-crop genes are intentionally manipulated through the use of biotechnology. The potatoes which have been used as a trap crop to manage Colorado potato beetle (*Leptinotarsa decemlineata*) populations were genetically engineered to express proteins from *Bacillus thuringiensis* (Bt). Genetically engineered trap cropping can also be used as an early season trap crop for Colorado potato beetle.

2.2.3 Trap Crop Deployment

The main distinguishable modalities of trap cropping, based on their deployment, are perimeter, sequential, multiple and push-pull trap cropping (Shelton *et al*. 2006). The more attractive trap crops are planted at the field margin, where they protect the main crop from insect pests Majumdar. (2011), planted potatoes early and they were used as a border trap for Colorado potato beetles (Cook e*t al*.2007) The Colorado potato beetles passed through from overwintering sites close to the main crop and became concentrated on the outside rows. They could then be easily treated mechanically, culturally or chemically.

Sequential trap cropping was practised by Shelton & Badenes-Perez (2006) when they used Indian mustard as a trap crop for diamond-back moths. They indicate that Indian mustard needs to be planted two or three times before the cabbage season because they have a short crop cycle. They further indicate that sequential trap cropping improves the attractiveness of the trap crop.

Badenes-Perez *et al.,* (2005) implemented multiple trap cropping with the purpose of controlling several insect pests or improving the control of one pest by combining plants' growth stages to promote attractiveness to the pest. Shelton *et al*., (2006) indicate that a mixture of Chinese cabbage, marigold, rape and sunflower have been used successfully as trap crops for pollen beetles (*Melighetes aeneus)* in cauliflower fields in Finland. Castor, millet and soya beans were also used to control ground nut leaf miner (*Aproarema medicella*) by Shelton *et al*., (2006) as multiple trap crops. They further implemented a combination of corn and potato plants in fields of sweet potato as trap crops to control wireworm.

Push-pull trap cropping, as practised by Shelton *et al*., (2006) ; Cook et *al*., (2007), entails planting a pull component (the trap crop) in order to attract the insect pest and a push component (a repellent intercrop) to distract them away from the main crop. They confirmed the planting of Napier and Sudan grass as a push-pull trap crop around the main crop and plant desmodium or molasses grass within the field as a repellent intercrop to control stem borer for corn production. They encouraged the use of molasses grass as a repellent intercrop because it promotes and improves stem borer parasitoid abundance and control in the fields.

They further promoted the use of push-pull trap cropping in subsistence farming to control stem borer in maize and sorghum. They used intercropping and trap cropping simultaneously using molasses grass (*Melinis minutiflora*) and silver leaf desmodium (*Desmodium uncinatum*) as a push component. The push component concentrated them to attractive pull trap crops such as napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare Sudanense)*

The push-pull strategies also used in intensive arable agriculture to control *Helicoverpa spp*, Colorado potato beetle and *Sitona lineatus* on cotton, potato and beans respectively. They further exercised the strategy in horticulture and forestry.

2.3 Stinkbugs, Cucurbits and Trap Crops

According to Jason (2010), the southern green stinkbug can complete its lifecycle in 65 to 70 days. Top Veg (2010) advocated that trap crops should be destroyed before the lifecycle of the pests finishes as the stinkbugs will disappear, thus avoiding the spread to the main crop. Stinkbugs were considered a miscellaneous insect pest of watermelons (Adams, 2000). They were also referred to as shield bugs (Skaife, 1992; Jason, 2010). *Nezara viridula,* a stinkbug species feed on more than 30 families of plant species, with a preference for legumes and brassicas (Panizzi, 1997).

Stinkbugs prefer to feed on tomatoes and legumes and not on cucurbits (UC IPM, 2008). Genetzky *et al.,* (2011) and Kelly *et al*., (2004) advocated that Pentatomidae was not a cucurbit pest but was associated with legumes such as soya beans and tomatoes. Genetzky *et al,*. (2011) and Kelly *et al*., (2004) postulated that the squash bug, *Anasa tristis*, was a cucurbit pest commonly confused with stinkbugs. The stinkbug was not regarded as an insect pest targeting cucurbits but as preferring legume crops and tomatoes, while *Anasa tristis* was considered a cucurbit pest by several investigators such as Genetzky *et al.*, (2011) and Kelly *et al*., (2004). Welty (1999) and Thayer *et.,al* (2001) also affirmed that squashes and gourds (which are cucurbits) are not the main target of stinkbugs.

Buckwheat, sorghum, and sunflower are some of the trap crops that can be used to manage stinkbug populations, but these need to be planted early in order to be flowering when bugs begin to migrate in high numbers (Majumdar, 2010). As a result, this practice is management intensive; insects are removed manually by hand and drowned or killed by insecticides as soon as they are visible in low numbers on the trap crops (Majumdar, 2010). The mini-vacuum is an optional method of vacuuming the insect pests from the trap crop (Top Veg, 2010).

The planting area of the trap crop is recommended to be 10% of the high-value crop, although the percentage of a trap crop needs to be determined for each particular case. Pests such as diamond back moth populations need a total area of between 5 to 13% of trap crops, according to Shelton *et al*., (2006). They emphasize that a combination of trap crop, insect and practical consideration should be the main attribute that determines the success of trap-cropping systems from a biological point of view, rather than a commercial point of view.

2.4 Conclusion

In spite of differing opinions by Welty (1999), Adams (2000), Thayer *et.,al* (2001), Kelly *et al.,* (2004), UC IPM (2008), Majumdar (2010) and Genetzky (2011) on the preference of stinkbugs for specific crops, various crops other than cucurbits have in fact been used as trap crops for stinkbugs and have been shown to be effective in many cases. This investigation therefore assists in determining the suitable trap crops for stinkbugs in the Limpopo area.

CHAPTER 3: METHODOLOGY

3.1 Location

This was an on-farm investigation, carried out at the farm Cango 677 MS in Limpopo Province, which is located 30 kilometres north of Louis Trichardt/Makhado on the R523 road to Alldays (Figure 1). The GPS coordinates are 29^{o} 32’ 59.6” E; 22^{o} 50’ 32.8” S. Identifying and controlling environmental variables that may influence results were considered carefully and treatments were replicated sufficiently to meet statistical requirements for adequate representation.

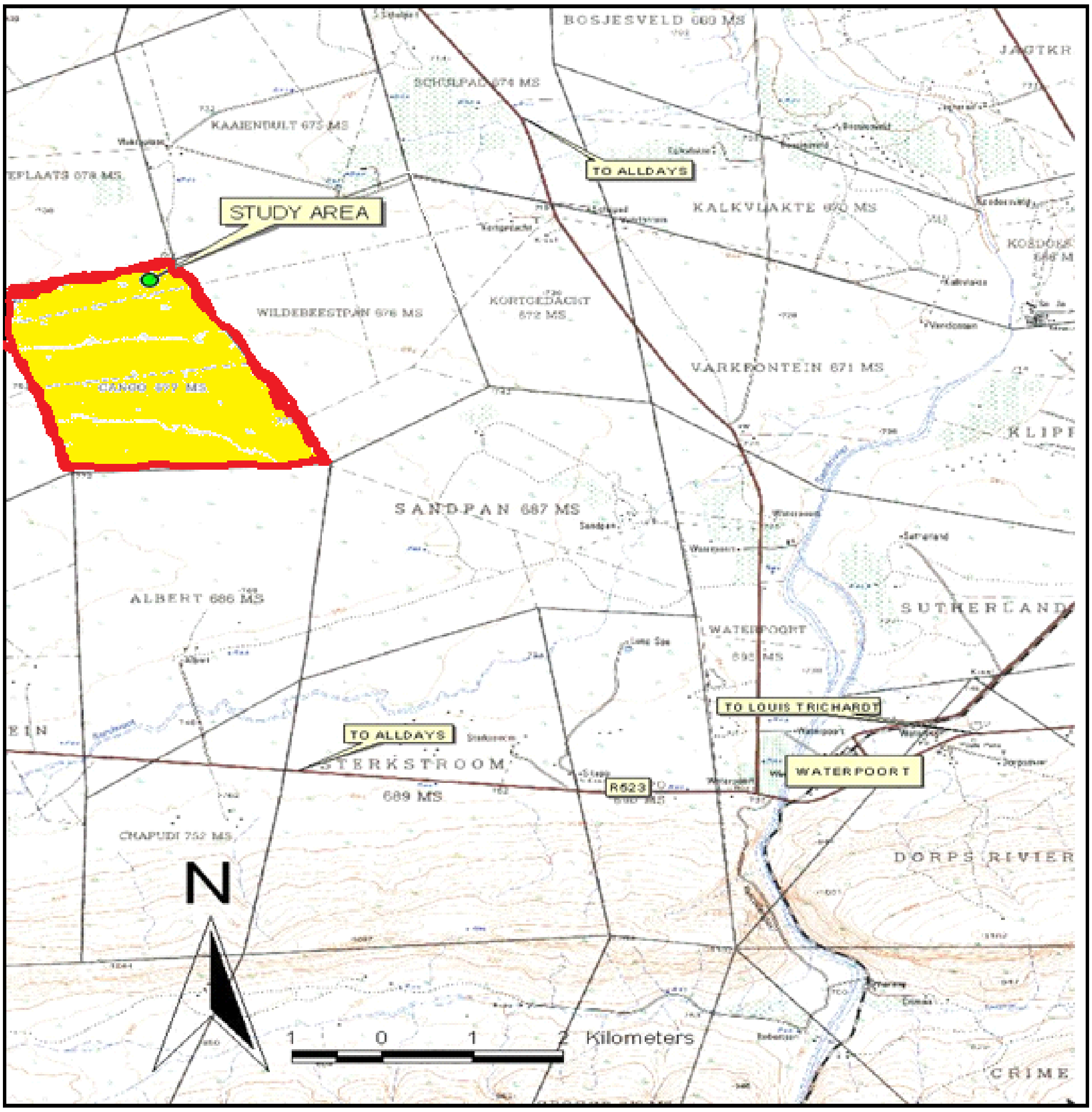

Figure 1: Study Area

3.2 Materials and Methods

3.2.1 Experimental Procedures

Two trials were conducted in two different but consecutive years during the rainy season, to evaluate the preference of stinkbugs between the trap crops and the main crop. The first experiment was conducted using the following four trap-crop species as treatments: *C. juncea, B. hirta* and *B. juncea* mixture, *V. unguiculata* and *A. esculentum*. The control was the treatment where there was no trap crop.

The second experiment was conducted to further test the ability of the *B. hirta* and *B. juncea* trap-crop mixture as this was the treatment which performed best in the previous experiment. Data were collected between the months of January and May 2011 and 2012.

The mentioned trap crops were tested for their ability to attract stinkbugs, thereby preventing them from reaching the host plants (watermelons and cantaloupes). The basic principle was to evaluate stinkbug preference between the various plant species (plants that function as a trap as well as the commercial host).

3.2.1.1 Experimental Design and Cultivation of Trap Crops

The potential trap crops were cultivated in plots along the perimeter and inside the crop field. Trap crop experiments were conducted on trial plots which were positioned as a randomized complete block design. Each plot of trap crop was 25 x 1 metres in size and each treatment was replicated four times (Figure 2 & Plate 1). Each replication contained four trap-crop plantings and a control of 25-metre-long rows. The sequential placement of each trap crop was at random in all replications. Stinkbug populations were monitored weekly in the trap crops, the main crops and the control field plots. All fruits in the main crop were assessed for stinkbug damage on a weekly basis and were subsequently compared with the control plot. Trap crop seeds were sown and germinated during December 2010. Irrigation and fertilisation was discontinued by March 2011. The main crops, i.e. cantaloupe and watermelon seedlings, were transplanted to the trial plot by the end of December 2010.

A row-trap-cropping system was implemented in the second phase of the trials, where the experiment was repeated for the evaluation of *B. hirta* and *B. juncea* against cantaloupe as a stinkbug trap crop (Figure 3 & Plate 2). Seeds were sown during January 2012 and the cucurbits transplanted in the same months. Monitoring was conducted on a weekly basis.

PERIMETER TRAP CROP EXPERIMENTAL PLOT LAYOUT

	25m	25m	25m	25m	25m
Trap crop row 1	A	B	C	D	E
Main crop	Cucurbits				
Trap crop row 2	E	B	C	D	A
Main crop	Cucurbits				
Trap crop row 3	C	D	A	B	E
Main crop	Cucurbits				
Trap crop row 4	E	D	A	B	C

Figure 2: First experimental plot layout of four trap crops: A = *Vigna unguiculata*; B = *Crotolaria juncea*; C = *Abelmoschus esculentum;* D = *Brasica juncea & Brasica hirta* (Caliente) E= Control

Plate 1: Perimeter trap cropping (Row one D= *B. hirta & B. juncea*)

INSIDE ROW TRAP CROP EXPERIMENTAL PLOT LAYOUT

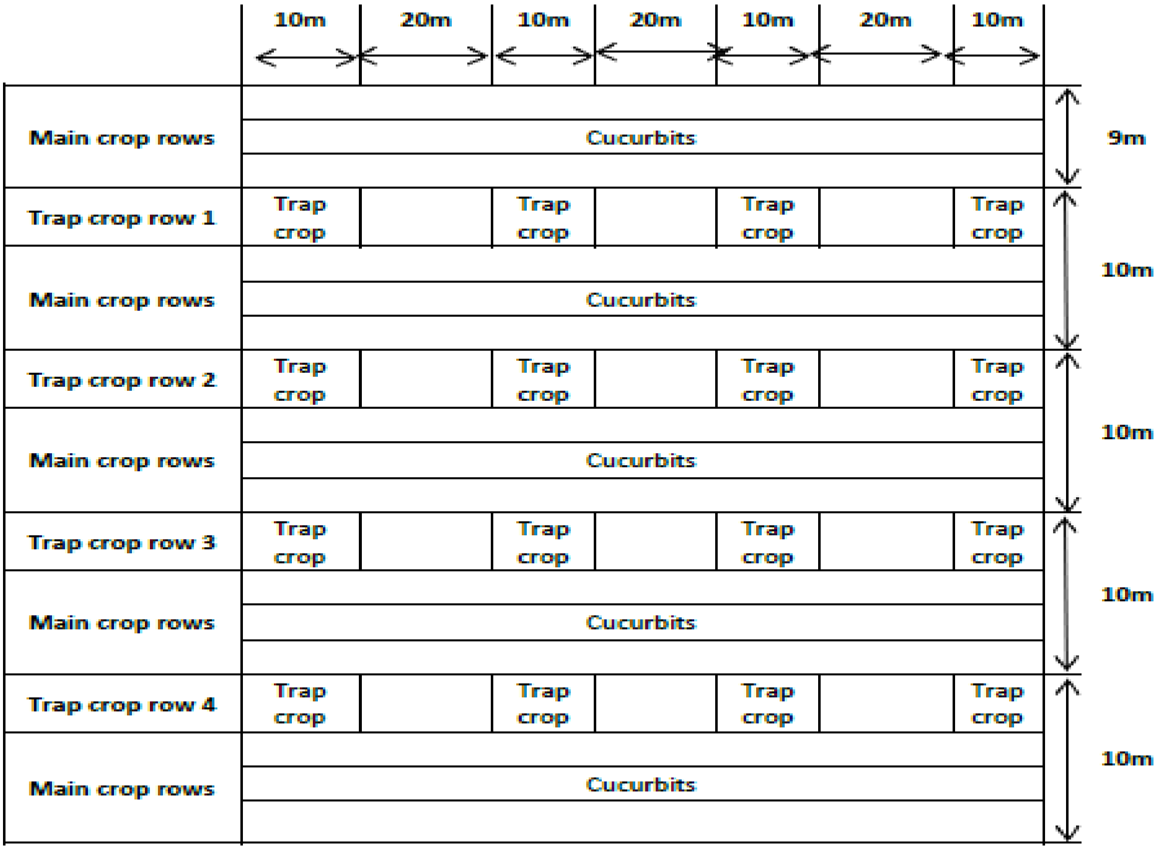

Figure 3: Second experimental plot layout of *B. hirta and B. juncea* mixture trap crop.

Plate 2: One row *B. hirta* and *B. juncea* mixture between cantaloupes.

3.2.2 Sampling and Monitoring Procedures

Data were collected between the months of January and May 2012. Temperature, time, date and name and quantity of the insects on the trap crops were recorded. All recording on the trap crops was done during the early hours of the morning, ranging from 06:30 to 11:30. This was done because insects are less mobile under cooler temperatures and surveying and recording them can be more accurate under cooler temperatures.

Stinkbug populations were surveyed by making use of two methods in all four trap crops: The first involved visual inspection of fruit damage by stinkbugs. The second method involved visual inspection of stinkbug presence on the trap crops as well as their presence on the main crop. The plants were inspected by six research assistants and one researcher, who were spending 10 minutes at a time each inspecting the fruit, leaves and stems of a row of 25-metre strips of trap crops and three rows of commercial crops surrounding the trap crop of the same measurement. The four trap crops, mixture of *Brasica juncea & Brasica hirta*; *Vigna unguiculata*; *Crotolaria juncea*; *Abelmoschus esculentum* in the trial field were monitored from January 2011 onwards. All insects recorded were collected and subsequently preserved with 70% ethanol (Mandrake, 2010).

3.2.3 Data Analysis

The data were analysed by performing analyses of variance (ANOVA) tests Little and Hills (1972). All population counts were subjected to the analyses of variance, using the repeated measurements over time as a sub-plot factor (Table 1). The residuals were tested for deviations from normality, using Shapiro-Wilk's test (Shapiro-Wilk, 1965). In order to compare means of significant effects, the student's protested T test (t) was used, and means were separated by using least significant difference (LSD), which was calculated at a 5% significance level. Due to the short time cycle of the crop, this evaluation could be repeated only nine times. All the above statistics have been performed with the SAS V9.2 statistical software (SAS, 1999).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Four trap crops were surveyed for stinkbug interception at a commercial cucurbit field from January 2011 to May 2011, which led to a subsequent trial with a mustard mix trap crop trial during January 2012. The four trap crops were also compared to each other regarding their attractiveness to stinkbugs; also the influence of deployment on effectiveness of trap crops was investigated as well as the maturity stage of trap crop on attractiveness to stinkbugs.

Because of repeated measurements over time where no stinkbugs were recorded, a decision was made to perform a final analysis of variance (ANOVA) on the cumulative totals over time. The means over the experimental time are presented in Figure 4. From the results, it is clear that, without some single outliers, there was no evidence against normality and the results can thus be considered as statistically reliable. The means of the trap crop are provided in Figure 5. No stinkbugs were recorded on the main crop from neither the preliminary nor the main trial. The preliminary trial was discontinued in May 2011 because all the crops had reached maturity. The follow-up trial with the mustard (*B. hirta* and *B. juncea* mixture) was discontinued in April 2012 after maturity of the both trap crop as well as the main crop was reached. Analysis of data summarized in Tables 1, 2 & 3 and full analysis presented in Appendix I.

4.2 Results

		Nezara virdula		*N.viridula Nymph*		*Coenomorpha spp*		*Coenomorpha spp*		TOTAL	
Source	DF	MS	P	MS	P	MS	P	MS	P	MS	P
Block (Row)	3	282.7	0.450	5.6	0.421	0.2095	0.059	6.67	0.441	295.3	0.418
Trap Crop	3	1956.6	0.012	118.0	0.000	0.0745	0.339	18.36	0.107	3546.5	0.001
Error a	9	292.8		5.3		0.0582		6.75		281.8	
Time	8	558.3	0.004	32.7	0.009	0.0638	0.431	5.39	0.227	738.3	0.004
Trap Crop*Time	23	378.1	0.008	31.8	0.000	0.0787	0.224	5.04	0.212	535.1	0.004
Error b	93	182.7		11.8		0.0629		3.98		241.6	
Corrected Total	139										

Table1: Analysis of Variance using repeated measurements over time as subplot factor

4.2.1 Trap Crop Deployment

The highest numbers of stinkbugs were recorded in the trap crops located along the perimeter of the main crop field (Figure 2: row 4) compared to those inside the field crop rows (Figure 2: rows 1, 2 and 3) located inside the main crop field. Some 131 specimens of the green vegetable stinkbug (*Nezara viridula*) were recorded along the perimeter row (Figure 4; Plate 3). Perimeter trap cropping with *B. juncea* and *B. hirta* attracted higher numbers of the green vegetable stinkbug (*N. viridula*), when compared to the other three trap crops (Figure. 4).

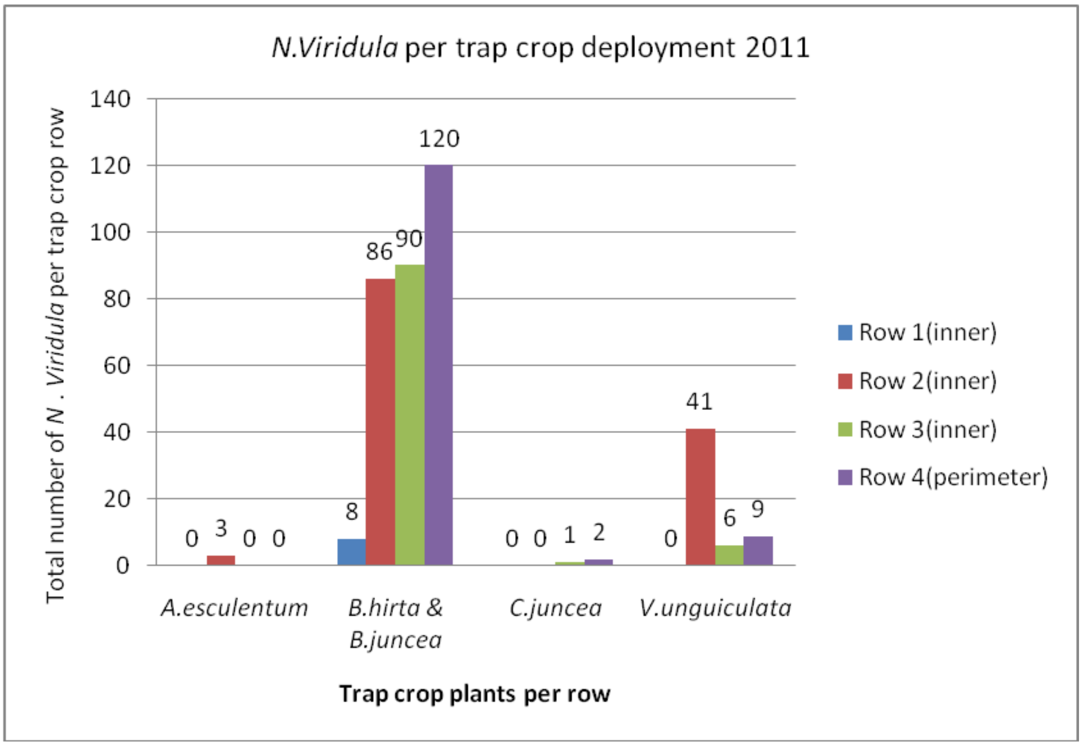

Figure 4: Comparison of stinkbug (*N. viridula*) interception per trap crop (Preliminary experiment)

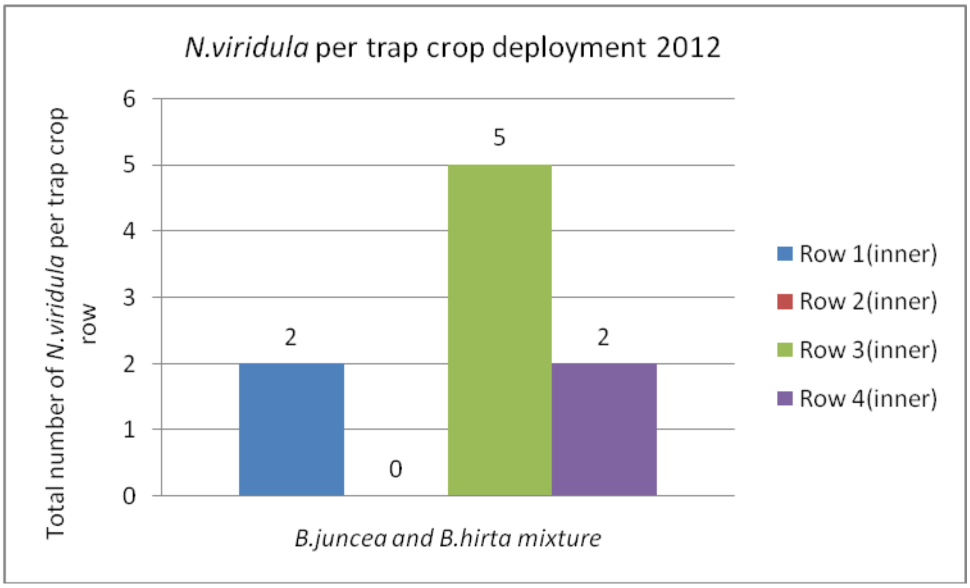

Figure 5: *Brassica hirta* and *Brassica juncea* inner rows only (follow-up experiment).

Figure 5 indicates that the inner rows of the *Brassica hirta* and *Brassica juncea* intercepted very low number of stinkbugs though the middle row showed a higher trend than the row one and two respectively.

4.2.2 Trap Crop Maturity

No stinkbugs were recorded on any of the trap crops (both trials) before the latter started flowering. First *N. viridula* as indicated on Plate 3 was recorded on pods of *V. unguiculata* during the third week. Pods reached maturity during weeks five and six and 51 *N.viridula* individuals were recorded. In week seven, the count dropped due to the natural senescence of the crop. Flowering *B. juncea* and *B. hirta* plants intercepted the first stinkbugs in week two. Thereafter, the number of stinkbugs increased significantly during the seedpod formation and maturity stages (Fig. 6: weeks 4-7). Three stinkbugs were recovered from flowering *C. juncea* plants during week three. *C. juncea* stinkbug numbers decreased until the maturity stage of the plants; only one brown stinkbug was recorded during week 7. *A. esculentum* intercepted only two stinkbugs during fruit formation and three at maturity (week 3 and week 7).

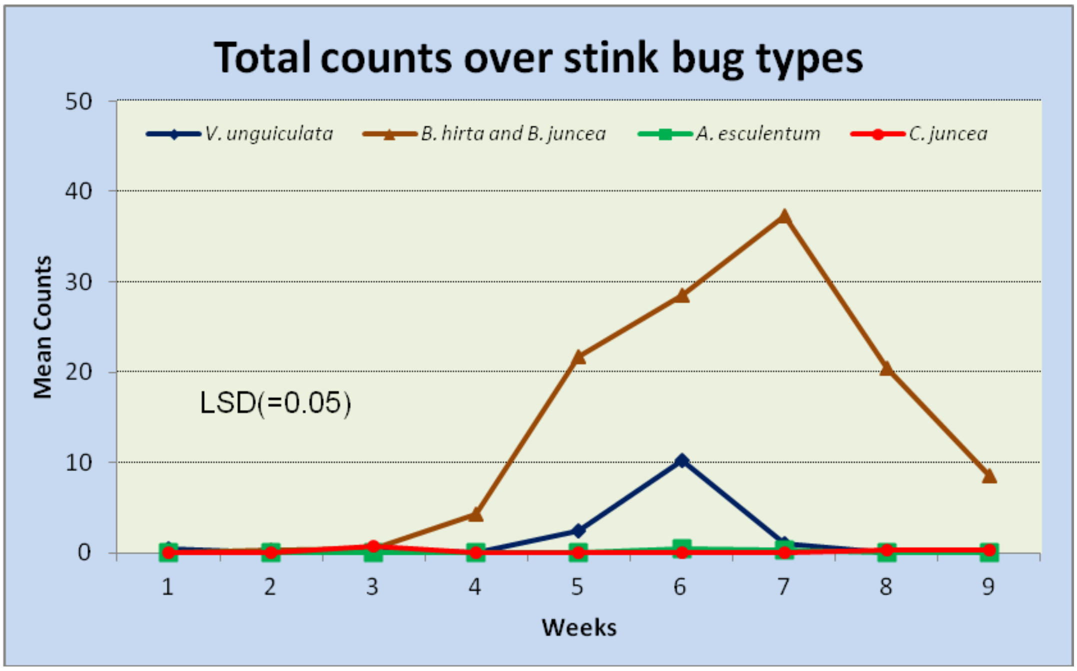

Figure 6: Cumulative counts of all stinkbug species recovered from all trap crops.

Vigna unguiculata interceptions increased to 10.3 stinkbugs by week 6 and decreased to 1.0 stinkbug by week 7, followed by 0 stinkbugs in week 8 and 9 respectively. Interception of stinkbugs by *B. hirta* and *B. juncea* increased to 37.5 stinkbugs by week 7 and dropped to 20.5 stinkbugs by week 8 and 8.5 stinkbugs by week 9. *Abelmoschus esculentum* treatment yielded its first stinkbug by week 3 and then decreased to an average of 0.3 stinkbugs by week 7 and zero by week 9. Stinkbugs recovered from *C. juncea* decreased to 0 between weeks 4 to 7, but by week 8 and 9, an average of 0.3 stinkbugs was recovered. From week 5-7 the pods of *Vigna unguiculata* and *B. hirta* and *B. juncea* were still green and tender (Fig 6).

4.2.3 Trap Crop Interception

The largest numbers of stinkbugs were recovered from *B. juncea* and *B. hirta*, followed by *V. unguiculata* and then *A. esculentum.* The *Brassica juncea* and *B. hirta* continued to attract *N. viridula* numbers until natural senescence. In 2012, the *B. juncea* and *B. hirta* still attracted higher numbers of *N. viridula*. *A. esculentum* attracted five *N. viridula*. *B. juncea* and *B. hirta* intercepted 304 *N. viridula* insects, while *C. juncea* and *V. unguiculata* attracted 2 and 56 specimens of *N. viridula* respectively (Fig.7).

Figure 7 indicates that *V. unguiculata* only intercepted an average of 0.5 N. *viridula* specimens (plate 3) and an average of 0.8 *Coenomorpha* spp (plate 4). *Brassica hirta* and *Brassica juncea* intercepted an average of 88.0 *N. viridula* specimens (Plate 3), 32 *N. viridula* nymphs, 14 *Coenomorpha* spp (Plate 4), were also recovered. The *Abelmoschus esculentum* intercepted only an average of 0.8 *N. viridula stinkbugs* (Plate 3) while *C. juncea* intercepted averages of 0.8 *N. viridula* (Plate 3) and 0.5 C*oenomorpha* spp specimens respectively (Plate 3).

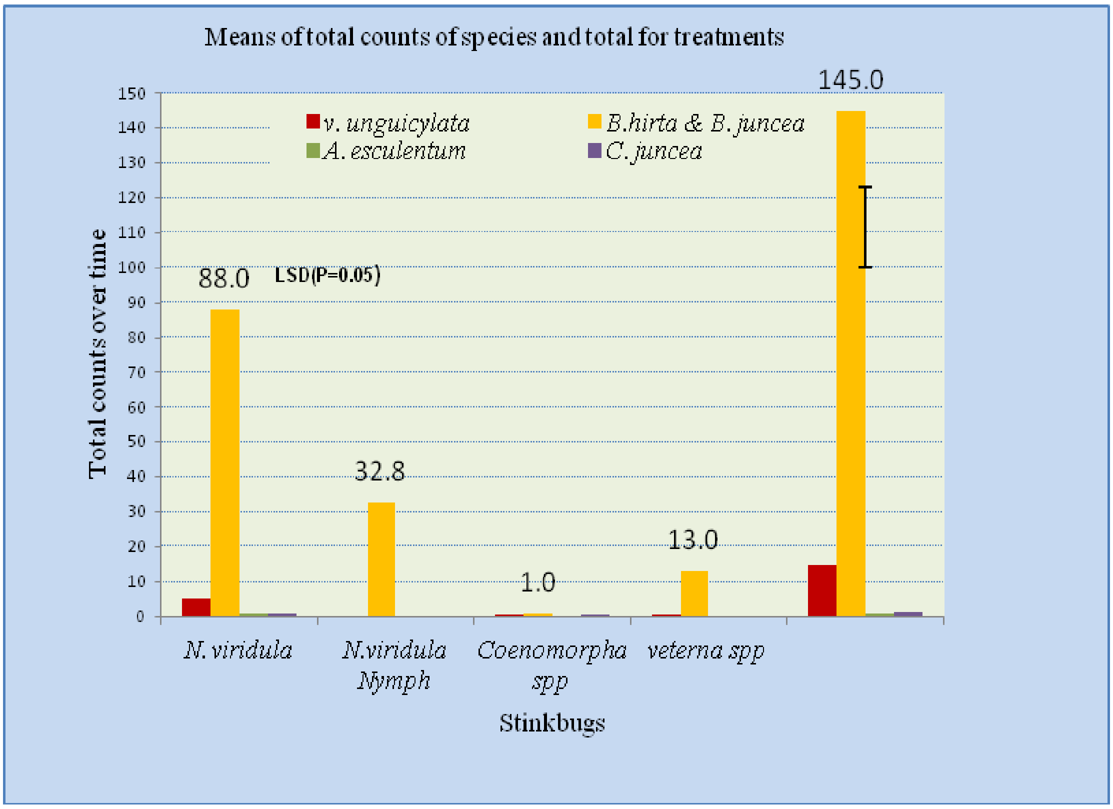

Figure 7: Cumulative counts of all stinkbugs recovered on all four trap crops.

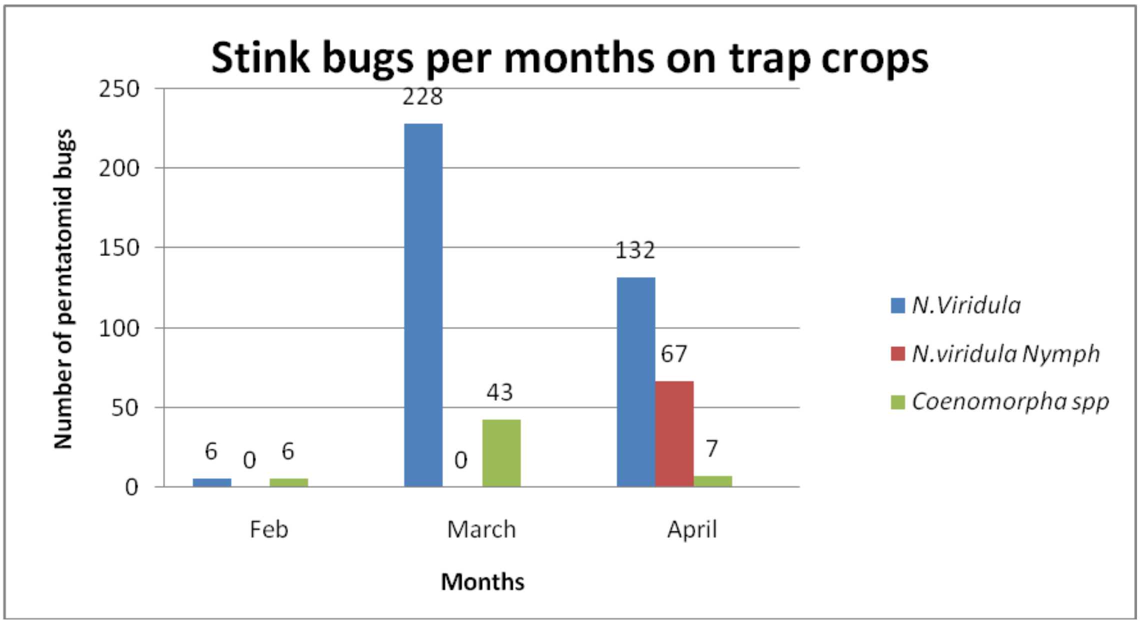

Figure 8: Monthly totals of Pentatomid bugs recovered from the various trap crops.

The numbers of stinkbugs types in each experimental plot were recorded weekly during the growing season for nine times. Because of repeated measurements over time where no stink bugs were recorded, a final analysis of variance on the cumulative totals over time was performed (Table 2). Deviations from normality were caused by lots of zero counts for some periods of time. The means over time are presented in Figure 6. From this ANOVA it is clear that without some single outliers there was no evidence against normality and the results can be considered as statistical reliable. The trap crop means were given in Figure 7.

	Nezara viridula				*Nezara viridula Nymph*		*Coenormorpha spp*		*Coenomorpha spp*			TOTAL	
Source	DF	MS	P	DF	MS	P	MS	P	MS	P	DF	MS	P
Block (Row)	3	425.4	<0.001	3	48.6	0.436	1.833	0.057	58.4	0.456	3	2148.2	0.003
Trap Crop	3	5445.7	<0.001	3	1072.6	<0.001	0.667	0.323	166.9	0.107	3	9461.6	<0.001
Error	7	21.1		9	48.6		0.500		61.3		7	156.3	
Corrected Total	13			15							13		
Shapiro-Wilk(Pr<W)			0.1			0.01		0.997		0.062			0.953

Table 2: Analysis of Variance on cumulative totals

Plate 3: *Nezara viridula*

Plate 4: *Coenomorpha spp*

4.3 DISCUSSION

The results show that conventional trap cropping (trap crop planted along the perimeter of the main crop) yielded the best results in attracting stinkbugs. According to Mizell (2012), plant phenology appears to be the main feature in attracting stinkbugs to the trap crops (Fig. 6: week 3 to week 7); this was also confirmed by Mizell *et al*. (2008) and Panizzi (1997). Both authors concur that stinkbugs prefer feeding on the seeds of host plants during the milk stage as well as on immature fruit. During March 2011, the *B. hirta* and *B. juncea* and *V. unguiculata* intercepted large numbers of *N. viridula* when these trap crops were flowering and producing pods. The stinkbug numbers decreased by April as the attractiveness of these trap crops declined with maturity. When the trial with the *B. hirta* and *B. juncea* mixture was repeated, the numbers of *N. viridula* however increased during April 2012 as they were again flowering and producing pods. During March 2011, an increase of *Coenomorpha spp* on the *B. hirta* and *B. juncea* was recorded. *Coenomorpha* spp (Plate 4) were again recorded from the 2012 experiment, but to a lesser extent than the 2011 trials.

The stages of the trap crop differ significantly in attracting stinkbugs, as argued by Diez (2007) and Tillman (2006) in their studies, when saying that the developing flower, fruit and pods are mostly preferred over the leafy part of the crop plant during the growing stages. Fig. 8 corresponds with the contention of the above-mentioned authors. According to Tillman (2006), fruits and pods are preferred by *Nezara viridula*, and this fact was supported by the findings of this study when the number of stinkbugs increased significantly during March 2011 (fig. 8). The vegetative and early reproductive growth of the trap crop had shown low densities of the stinkbugs in the study field, and this is also supported by Cerruti (2011) when emphasizing that the vegetative and early reproductive plants intercept fewer stinkbugs. During February, *Vigna unguiculata* and *B. hirta* and *B. juncea* were in flower, which was when the interception of stink bugs was low.

In March 2011 and 2012, the number of stinkbugs increased significantly because the crops were at the pod-filling stage. This is supported by Cerruti (2011) and Tillman (2006) when they clarify the fact that stinkbugs generally find legumes most alluring during the full-seed stage. During the fruit-developing stage, stinkbugs like feeding on the pods and fruits, but this preference decreases as the seed pods dry out (Squitier, 2011). During April, the number of stinkbugs went down because the seed pods of *Brassica hirta* and *B.juncea*, as well as *Vigna unguiculata*, had completely dried. During April, the number of adult *Nezara viridula* decreased while the nymphs of *Nezara viridula* started to appear during April 2011 and 2012 respectively. These findings are also supported by Squitier (2010) in his study when he indicates that female *N. viridula* lay eggs during April and the nymphs hatch in five days while the adult *N. viridula* is overwintering.

The damaged pods of *Vigna unguiculata* and *Brassica hirta* and *Brassica juncea* appeared to be brownish to black spots on the pod. The actual feeding punctures were not easily visible during the time the bugs were feeding, but they were clearly visible when the *Vigna unguiculata* and *Brassica hirta* and *Brassica juncea* reached their senescence (Squitier, 2010). These spot marks were also visible on the stems and leaves of *V. unguiculata* when it reached its natural senescence.

The stinkbugs densities were generally low during the vegetative and (flowering) early reproductive stages (Cerruti, 2011). According to Figure 6, an average of 0.5 stinkbugs was recovered during the flowering of *V. unguiculata* plants, while no stinkbugs were recovered on any of the other species during the first week because they were not at their reproductive stage (flowering). The same scenario persisted in week two in the three other treatments, except in the *B. hirta* and *B. juncea* mixture, where an average of 0.3 stinkbugs was recorded. By week three, *C. juncea* had attracted an average of 0.8 stinkbugs, *V. unguiculata* and *B. hirta* and *C. juncea* had attracted an average of 0.5 stinkbugs and *A.esculentum* had intercepted zero stinkbugs. In the latter case, however, all the replicates were at the fruiting stage. The stinkbug populations began to increase during (seed formation) pod development and dropped during plant senescence as they moved to more succulent plant parts and/or overwintered (Tillman, 2006).

The short cycle of the crop necessitated that this assessment be conducted over a nine-week period, as indicated in Fig 6. Other studies by Shekhawat *et al*., (2012) and Buchanan *et al*., (2011) also show that the crops (*B. hirta and B. juncea*) mature from planting in a relatively short period of 156 days, but the 50% flowering of the latter crop ranges from 2,5 to 3 months. The trap crops were sometimes overgrown by the cantaloupes in the trial field in the early stages, and this indicates that the space between the trap crops and the main crop should be at least a meter (Mizell *et al*., 2008a; Majumdar, 2010). Mizell (2012) promotes a gap between the trap crop and the main crop in order to reduce the movement of stinkbugs to the main crop as they are afraid of becoming prey to their natural enemies. Large numbers of stinkbugs were recorded among the perimeter trap crops, compared to the trap crops in the inner rows, during 2011. This compelled a follow-up trial, where the *B. hirta* and *B. juncea* trap crops were deployed only inside the main crop and no perimeter planting was done. The number of stinkbugs from this second trial did not exceed the 2011 numbers recovered from either the perimeter trap crops or the inner rows respectively. Mizell (2012) and Tillman (2006) indicate that trap crops such as *B. hirta* and *B. juncea*, which attract *Trichiopoda pennipes*, may be able to reduce the probability of the *N. viridula* population’s increasing and dispersing to the main crop. In this regard, no stinkbugs were found in the watermelon and cantaloupe fields.

These studies recorded no stinkbugs feeding on cucurbits in the trial and control plots, but the bugs were often found feeding on the green pods of the various trap crops and resting on *amaranthus spp* weed in the control field. In this follow-up trial, *Nezara viridula* was caught with its stylet stretched to the *B. hirta* and *B. juncea* green pod. Tillman (2006) and Majumdar (2011) support this in their studies when they indicate that stinkbugs mostly prefer the fruiting part of the plant.

Mizell (2012) argues that stinkbugs choose perimeter plants rather than inner rows as a result of predation by their natural enemies, which are more plentiful inside the crops than on the perimeter. Therefore, they prefer to move along the edges of the crop. The 2012 experiment (Fig. 5) and the 2011 experiment (Fig. 4) support the argument made by Mizell (2012) that the recording of stinkbugs was lower along the inner row, when compared to the recording along the perimeter row of the 2011 experiment with *B. hirta* and *B. juncea*. Majumdar (2010) investigated the use of buckwheat, sorghum and sunflower as trap crops for stinkbugs along the perimeter of the main crop in a densely sown manner; these crops serve as a shelter for stinkbugs' natural enemies and prevent the movement of stinkbugs to the main crop. In this study, the *B. hirta and B. juncea* were densely sown and attracted larger numbers of stinkbugs than the other three crops in the study field, which were sown sparingly. The study by Majumdar (2011) supports the idea of sowing trap-crop seeds densely in order to promote the capturing of insect pests in large numbers and reducing their movement to the main crops.

Nezara viridula is a pest that was found on all the trap crops used in the experimental field of 2011 (Fig. 4) because it was recorded on all four trap crops (Table 3) during 2011 and 2012 (Fig. 5). The latter statement is also supported by Tillman (2006) when he indicates that *Nezara viridula* is a pest found in many field crops such as sorghum, soya beans, mustard, etc. Mizell (2012) and Tillman (2006) recognize that stinkbugs can overwhelm plants on the edges of the main crops when the bugs are dispersing from vegetation growing close to the crop; therefore, planting the trap crop along the perimeter of the main crop is essential for controlling this pest.

Stinkbugs per trap crops				
Trap crops	*N. viridula*		*Coenomorpha* spp	
	Adult	Nymph	Adult	Nymph
V. unguiculata	56	0	3	0
C. juncea	3	0	1	0
A. esculentum	3	0	2	0
Brassica mix	304	67	50	0
Total:	366	67	56	0

Table 3: Number of stinkbugs per trap crop

Nezara viridula was formerly regarded as an insect pest on tropical and subtropical fruit but not on vegetables; however, currently it is considered to be a pest that attacks various other crops, including some vegetables. This happens to the extent of reaching the economic threshold value of those crops (Joubert and Claasens, 1994; Alberts, 2010; Majumdar, 2010 and Mizell, 2012).

According to Florence Grovinda (2011), garden vegetables such as cowpea, bean, cabbage, corn, cucumber, eggplant, okra, squash, sweet potato and tomato are likely to be the most common hosts of *Nezara viridula*. This bug also prefers to feed on field crops such as clover, peanut, sugarcane, rice and tobacco, with the inclusion of fruit such as oranges and peaches. It is also considered a limiting factor in soya beans. In this study, *Nezara viridula* was observed feeding on mustard, cowpea and okra, and in the control field, *Coenomorpha spp* was found on a weed, *Amaranthus spp.*

Figure 8 indicates that six adult *N. viridula* specimens were recovered during February, compared to 228 and 132 recorded during March and April 2011 respectively. *N. viridula* nymphs recovered during April amounted to 67, but no immature specimens were recorded during February and March 2011. Six *Coenomorpha* spp were recovered during February, 43 during March and only seven during April. The number of *Nezara viridula* decreased during April, when they overwinter (Squitier, 2010).

Daniel *et al.* (2005) indicated that cucumbers, as well as several other kinds of crops, fall prey to stinkbugs but, although the watermelons and the cantaloupes are of the same family as the cucumbers, they do not seem to be as attractive to stinkbugs in the study field. Because of the bugs' resistance to various pesticides, trap cropping has become an important method to be investigated as an option for integrated pest management (I.P.M) (Mizell *et al.*, 2008).

Tillman (2006) indicates that the use of a mustard mix (*B. hirta* & *B. juncea*) in trap-cropping systems is an effective control strategy for *N. viridula.* He further divulges the importance of host plants with panicles as the stinkbugs, including *N. viridula*, like feeding on panicles. This was revealed in the 2011 study, when *Nezara viridula* were clustered on *B.hirta* and *B. juncea* as well as on *V. unguiculata* seed pods in the field.

Crotolaria juncea can also be used as a dead-end trap crop, as it had intercepted adult *Nezara viridula* rather than *Nezara viridula* nymphs in this study. Neither the perimeter nor the inner-row trap crop of *Crotolaria juncea* attracted *N. viridula* nymphs. The findings of Shelton & Badenes-Perez (2006) support this contention, indicating that the offspring do not survive on *C. juncea*, which provides support for the use of *C. juncea* along the perimeter of the main crop.

4.3.1 Discussion on stinkbugs

The southern green stinkbug, *Nezara viridula*, also named the true bug, is associated with various agricultural crops, such as mustard mix, cowpea, okra and sunn hemp, in this study. Vegetable, tropical and subtropical crops are subject to damage by *Nezara viridula* (Joubert and Claasens, 1994; Alberts, 2010; Squitier, 2010; Majumdar, 2011 and Mizell, 2012). The damage inflicted by the bug's piercing-sucking mouthparts on the succulent part of the plant and/or fruit then results in the wilting and/or dropping of flowers and fruit at their immature stage .

Nezara viridula is in the family *Pentatomidae*, and the adult is recognized by its shield shape and the five segmented antenae. When handled, stinkbugs release a stinking liquid which dyes the hand an orange or yellow colour. Adult *Nezara Viridula* encountered in the study were a dull green color, with dark red or black eyes. The wings are generally also green but cover the abdomen of the adult *Nezara viridula* completely (Squitier, 2010). Stinkbugs undergo an incomplete metamorphosis (Mizell, 2012).

The female *Nezara viridula* lays an average of 260 eggs in her life span. The egg laying ranges between three to four weeks after reaching the adult stage. The eggs are laid in clusters underneath the leaves of the plants or in the debris of fallen leaves lying on the ground (Alberts, 2010). The eggs are always glued together in clusters that range from 30 to 130 eggs and are found in April and December. In the 2011 and 2012 experiment, nymphs of the *Nezara viridula* were found only in April. *Nezara viridula* undergoes five nymphal stages to become an adult (Squitier, 2010).

The economic threshold value of *Nezara viridula* in a cowpea field is reported to be 5000 per hectare. According to Squitier (2010) and Alberts (2010), different crops have different economic threshold values of stinkbugs per hectare or per plant. The sowing of trap crops also determines the prevalence of stinkbugs. The mustard mix was densley sown, compared to the other three, and attracted large number of sinkbugs since stinkbugs fear being preyed on while streaming through corridors (Mizell, 2012). To increase attractiveness, trap crops should be sown densely.

Mizell, in his study of stinkbugs and trap crops, indicates that stinkbugs react very strongly to vegetation borders as they do not like to cross open areas where they will be vulnerable to natural enemies (2012). Consequently, the movement of the stinkbugs is frequently along the edges of the crops and other natural structures.

4.3.2 Conclusion

The practise of trap cropping for the management of insect pests depends on the preference of the pest for the host plant over the main crop (Badenes-perez *et al*., 2005, and Majumdar, 2012). In both the 2011 and 2012 experiment, *N. viridula* adults show greater preference for *B. hirta and B. juncea* than for watermelon and cantaloupe in the field. A large number of *N.viridula* was recorded on *Brassica hirta* and *Brassica juncea*, *Vigna unguiculata, Abelmoscus esculentum* and *Cotolaria juncea*, and the numbers for each were compared. The perimeter trap crops attracted more stinkbugs than the inner rows of the *B. hirta* and *B. juncea.*

In the 2011 and 2012 experiment, the study suggests that using *Brassica hirta* and *B. juncea* may reduce the presence of *N.viridula* because they aggregated on the *B. hirta and B. juncea,* as well as the *V. unguiculata*, trap crops in the study field. Because no *N. viridula* were recorded in the watermelon and cantaloupe crops, the finding suggests that these pests were diverted away from the main crop to the trap crops. This finding is supported by Mizell *et al*. (2008b), who suggest that trap crops be sown densely to prevent the movement of stinkbugs to the main crop.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The perimeter and inside-row trap-cropping methods were conventionally implemented. The trap crops attracted high numbers of pentatomid bugs at the flowering and seed-formation stage. All these substantiate the contention that stinkbugs are insects that have the potential to be managed with trap crops. If the right trap crops can be found and applied correctly, it could lead to ecologically and environmentally sustainable management techniques that could be considered in future agricultural ecosystems. All trap crops were highly attractive to *Nezara viridula* during the flowering and fruiting stage. If the right trap crops can be cultivated so that they flower and produce pods at a time when the main crop is vulnerable to stinkbug damage, these trap crops will attract the stinkbugs away from the main crop which will lessen stinkbug damage to the main crop. Some cases of total stinkbug control with trap crops have been reported; Rea *et al.,* (2002) planted black mustard (*Brassica nigra*) and white mustard (*Sinapis alba*) as trap crops for *Nezara viridula* adjacent to the main crop (sweet corn). Percentages of damaged sweet corn cobs in the outside row of fields protected by the trap crops varied between 0% and 1%, compared with up to 22% damage in control fields. Stinkbugs could also be controlled with a pesticide on the trap crop to prevent them from breeding or moving back to the main crop at a later stage.

This study concludes that mustard as well as cowpea and sunnhemp can be used as trap crops for stinkbugs on watermelons and cantaloupes. The hypothesis “Trap crops can be used to provide an organic solution for crop protection against stinkbug pests in selected *Cucurbitaceae* crops” can therefore be accepted, as the potential for this has clearly been demonstrated.

5.2 Recommendations

B. hirta and *B. juncea* mixtures can be used as a multiple perimeter trap crop but not as a dead-end trap crop for watermelons and cantaloupes as it will not only attract adults, but may become a breeding habitat for these stinkbugs, as was experienced in this case. Trap crops should be sown earlier or on the same day as the commercial crop, so that the flowering or fruit set will coincide with the commercial crop fruit development. One should also consider staggering the trap crops; that way, one will always have plants available that will attract stinkbugs. The trap crop should be irrigated and fertilized, so that it will grow well, which in turn will promote its ability to intercept the insect pest. The trap crops need to be sown at least 1 m away from the main crop to avoid shading. Alternatively, one could practice strip trap-cropping, with rows of trap crops adjacent to the main crop around the perimeter as well as inside the field. The deployment and characteristics of trap cropping requires further research for better understanding and knowledge of trap cropping in cucurbit crops.

Ethical Statement

Ethical considerations were not a problem in this research as it only involved the cultivation of some plants and surveying of insect populations. The UNISA ethics committee has approved the topic.

Dissemination

Accredited journals and magazines were used for the research and a presentation was also made at a colloquium.

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APPENDIX 1

Statistical analysis of raw data

Appendix

```
Dependent Variable: GREEN

                              Sum of
  Source                 DF        Squares     Mean Square    F Value    Pr > F

  Model                  46     22516.03254       489.47897       2.68    <.0001

  Error                  93     16991.13889       182.70042

  Corrected Total           139     39507.17143


             R-Square     Coeff Var      Root MSE    GREEN Mean

             0.569923      308.1977      13.51667      4.385714


  Source                 DF       Type I SS     Mean Square    F Value    Pr > F

  Row                    3      848.142857      282.714286       1.55    0.2075
 Trap crop               3     5869.671429     1956.557143      10.71    <.0001
Trap crop Row            9     2635.218254      292.802028       1.60    0.1258
  Time                   8     4466.093750      558.261719       3.06    0.0043
Trap crop   Time          23     8696.906250      378.126359       2.07    0.0078
```

Randomized block (Rows) design with repeated measurements over time as subplot factor

```
Dependent Variable: GREEN

                         Sum of

  Source                DF       Squares     Mean Square    F Value    Pr > F

  Model                 46     22516.03254       489.47897       2.68    <.0001

  Error                 93     16991.13889       182.70042

  Corrected Total          139     39507.17143


              R-Square     Coeff Var      Root MSE    GREEN Mean

              0.569923      308.1977      13.51667      4.385714


  Source                DF       Type I SS     Mean Square    F Value    Pr > F

  Row                   3      848.142857      282.714286       1.55         0.2075
Trap crop               3     5869.671429     1956.557143      10.71       <.0001
Trap crop  *Row         9     2635.218254      292.802028       1.60         0.1258
  Time                  8     4466.093750      558.261719       3.06         0.0043
 Trap crop  *Time       23     8696.906250      378.126359      2.07        0.0078
      Tests of Hypotheses Using the Type I MS for trap crop*Row as an Error Term

  Source                DF       Type I SS     Mean Square    F Value    Pr > F
```

```
 Row                  3    848.142857    282.714286    0.97      0.4503
Trap Crop             3   5869.671429   1956.557143    6.68      0.0115



Dependent Variable: GREENNYMPH

                                Sum of
 Source               DF        Squares    Mean Square   F Value   Pr > F

 Model                46    1412.421429     30.704814      2.61    <.0001

 Error                93    1094.000000     11.763441

 Corrected Total        139    2506.421429


          R-Square    Coeff Var     Root MSE    GREENNYMPH Mean

          0.563521     366.5422     3.429787          0.935714


 Source               DF      Type I SS    Mean Square   F Value   Pr > F

 Row                  3     16.6500000      5.5500000     0.47      0.7027
 Trap crop            3    354.1158730    118.0386243     10.03     <.0001
 Trap crop*Row        9     48.1000000      5.3444444     0.45      0.9012
 Time                 8    261.2711227     32.6588903     2.78      0.0085
 Trap crop*Time      23    732.2844329     31.8384536      2.71     0.0004


      Tests of Hypotheses Using the Type I MS for trap crop *Row as an Error Term

 Source               DF      Type I SS    Mean Square   F Value   Pr > F
```

```
  Row                  3     16.6500000      5.5500000      1.04        0.4212
  Trap crop            3    354.1158730    118.0386243      22.09     0.0002


Dependent Variable: BROWN


                                Sum of
  Source               DF          Squares     Mean Square    F Value    Pr > F


  Model                46      3.69563492      0.08033989       1.28    0.1589


  Error                93      5.84722222      0.06287336


  Corrected Total         139      9.54285714



             R-Square     Coeff Var      Root MSE    BROWN Mean


             0.387267      438.8048      0.250746      0.057143



  Source               DF        Type I SS     Mean Square    F Value    Pr > F


  Row                  3      0.62857143      0.20952381       3.33         0.0228
  Trap crop            3      0.22341270      0.07447090       1.18         0.3200
 Trap crop*Row         9      0.52420635      0.05824515       0.93         0.5062
  Time                 8      0.51041667      0.06380208       1.01          0.4305
 Trap crop*Time       23      1.80902778      0.07865338       1.25         0.2243



     Tests of Hypotheses Using the Type I MS for trap crop*Row as an Error Term


  Source               DF        Type I SS     Mean Square    F Value    Pr > F
```

```
  Row                  3     0.62857143     0.20952381      3.60    0.0590
  Trap crop            3     0.22341270     0.07447090      1.28    0.3394


Dependent Variable: SMALLGREY

                               Sum of
  Source              DF        Squares     Mean Square    F Value    Pr > F

  Model               46     294.9461310       6.4118724       1.61    0.0264

  Error               93     369.9895833       3.9783826

  Corrected Total         139     664.9357143


               R-Square     Coeff Var      Root MSE    SMALLGREY Mean

               0.443571      526.8724      1.994588         0.378571


  Source              DF        Type I SS     Mean Square    F Value    Pr > F

  Row                  3      20.0214286       6.6738095       1.68        0.1772
  Trap crop            3      55.0780754      18.3593585       4.61        0.0047
 Trap crop*Row         9      60.7389881       6.7487765       1.70        0.1008
  Time                 8      43.1218171       5.3902271       1.35        0.2268
  Trap crop *Time     23     115.9858218       5.0428618       1.27        0.2120


        Tests of Hypotheses Using the Type I MS for trap crop*Row as an Error Term

  Source              DF        Type I SS     Mean Square    F Value    Pr > F
```

```
Row              3   20.02142857    6.67380952    0.99   0.4407
Trap crop        3   55.07807540   18.35935847    2.72   0.1068


Dependent Variable: TOTAL

                         Sum of
Source            DF       Squares   Mean Square   F Value   Pr > F

Model             46   12175.23173     264.67895      7.88   <.0001

Error             91    3056.91319      33.59245

Corrected Total       137   15232.14493


          R-Square   Coeff Var    Root MSE   TOTAL Mean

          0.799312    149.2228    5.795900     3.884058


Source            DF      Type I SS   Mean Square   F Value   Pr > F

Row                3     427.800390    142.600130      4.25     0.0074
Trap crop          3    4459.936810   1486.645603     44.26    <.0001
Trap crop*Row      9     750.129950     83.347772      2.48     0.0140
Time               8    1992.282639    249.035330      7.41    <.0001
Trap crop*Time    23    4545.081944    197.612258      5.88   <.0001


     Tests of Hypotheses Using the Type I MS for Lokgewas*Row as an Error Term

Source            DF      Type I SS   Mean Square   F Value   Pr > F
```

```
Row                    3      427.800390      142.600130       1.71    0.2339
Trap crop              3     4459.936810     1486.645603      17.84    0.0004


                       The GLM Procedure


             Level of         ------------TOTAL------------
             Trap crop       N          Mean          Std Dev


             Cowpea         32       1.8437500       5.2860704
             Mustardmix     34      13.7941176      17.2833418
             Okra           36       0.0833333       0.3683942
             Sunnhemp       36       0.1388889       0.4244511
```

Data collection sheet record 2011

Crop : Mustard mix(Brassica hirta and B. juncea mixture) Caliente
Insect pest : Stinkbug (Heteroptera pentatomidae)
Time & Temperature during collection were recorded on weekly data collection sheet.

Date	12/02/2011	19/02/2011	26/02/2011	12/03/2011	19/03/2011	26/03/2011	07/04/2011	16/04/2011	Total
Line 1									
green	0	0	0	1	0	5	1	1	8
green nymph	0	0	0	0	0	0	7	20	27
brown	0	0	0	0	1	0	1	0	2
Small grey	0	0	0	0	0	0	0	0	0
Line 2									
green	0	0	0	0	26	31	22	7	86
green nymph	0	0	0	0	0	0	18	7	25
brown	0	0	0	0	0	0	0	0	0
Small grey	0	0	2	1	21	0	0	2	26
Line 3									
green	0	0	0	0	14	29	40	7	90
green nymph	0	0	0	0	0	0	11	12	23
brown	0	0	0	0	0	0	0	0	0
Small grey	0	0	0	0	0	0	0	0	0
Line 4									
green	0	1	0	15	18	37	28	21	120
green nymph	0	0	0	0	0	0	0	0	0
brown	0	0	0	0	1	0	0	0	1
Small grey	0	0	0	0	6	12	3	0	21
Total									
	0	1	2	17	87	114	131	77	429

APPENDIX 2

Ethical clearance letter

APPENDIX 3

Ambient weather conditions for 2011 and 2012

Climate LEVUBU January-May 2011 and 2012

Data reported by the weather station: 681820
Latitude: -23.08 | Longitude: 30.28 | Altitude: 706

Monthly means and total 2011

	January	February	March	April	May
T	21.7	22	23.9	20.3	19.1
TM	29.3	30.8	33.2	28.2	28.3
Tm	18.7	17.5	18.8	16	12.9

Monthly means and total 2012

	January	February	March	April	May
T	-	24.5	23.2	20.4	18.7
TM	-	32.7	32.3	30.4	28.8
Tm	-	19.9	18.9	14	12.6

APPENDIX 4

Proof reading certificate

10 June 2013

TO WHOM IT MAY CONCERN

I, Nicolaas Gerhardus Hoffmann, hereby confirm that I edited and proof read the work written by Mr. Humbulani Lukhwareni as part of the fulfillment of the requirements for his Masters degree. To the best of my knowledge, all the work I dealt with was his own work, written by himself. Any changes and adjustments were made with his knowledge and in consultation with him.

I performed this duty, based on my current employment as proofreader/ sub-editor of the *Zoutpansberger* and *Limpopo Mirror* newspapers, being duly qualified to do so.

Any enquiries in this regard can be addressed to me at the phone numbers provided below.

Sincerely,

N G Hoffmann

0794602160