FIELD EVALUATION OF *TEPHROSIA VOGELII* AND *DICHAPETALUM CYMOSUM* CRUDE BOTANICAL EXTRACTS IN THE CONTROL OF FALL ARMYWORM (*Spodoptera frugiperda* J. E Smith) IN ZIMBABWE

A dissertation submitted in partial fulfilment of the requirements for the Master of Science Degree in Food Security and Sustainable Agriculture

(Production option)

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DECLARATION

I hereby declare that the research project entitled 'Field Evaluation of *Tephrosia vogelii* and *Dichapetalum cymosum* Crude Botanical Extracts in the Control of Fall armyworm (*Spodoptera frugiperda* J.E Smith) in Zimbabwe' submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of the original work done by me under the guidance and supervision of **Prof R. MANDUMBU** and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science Degree in Food Security and Sustainable Agriculture. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree or diploma

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DEDICATION

This research effort was inspired by my mother and late father, two subsistence farmers who persevered to produce and put food on the family table in the face on seemingly insurmountable challenges.

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda* J.E Smith) which invaded Africa in 2016, is inflicting serious damage on crops particularly staple maize thereby threatening food security. This is further worsened by little information on host -pest relationship in the new environment. Response to the pest has mainly relied on synthetic pesticides which are usually out of reach of small farmers and has paid little regard to economic threshold levels. The objectives of this experiment were to evaluate the efficacy of locally available botanicals (*T. vogelii* and *D. cymosum*) on fall armyworm in maize. The research also sought to understand the host-pest complex by studying the relationship between damage indices and yield. The experiment was set up as a Completely Randomised Block Design with five treatments of two botanicals, their mixture, a positive and negative control replicated three times. Data were analysed using GenStat version 16. Deltamethrin and pirimiphos-methyl (ecoterex) was consistent and outperformed all the other treatments on damage indices, plant height and fresh cob weight. On the same note, the botanicals outperformed the negative control on leaf damage, plant height and damaged cobs. *Dichapetalum* treatment had similar performance as ecoterex on yield while *Tephrosia* + *Dichapetalum* had similar effect on damaged cobs. The regression analysis showed a negative relationship between damage indices (leaf damage score, percentage plants affected and percentage barren stalks) and yield. The regression model explained the general relationship (P= 0.003) but analysis of individual predictors indicated that only barren stalks was significant (P = 0.03). Though the botanicals were better than the negative control, their performance was not consistent. As such, farmers can use the botanicals under study as integrative components of crop protection as they did not produce consistent results on their own. Reliance on percentage infestation and leaf damage scoring in implementing control measure, predicting economic thresholds and yield reduction may not produce accurate results.

Key words

Spodoptera frugiperda leaf damage botanicals synthetic pesticides cob damage

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
Bis	Botanical insecticides
Bt	*Bacillus thrungiens*
CABI	Centre for Agriculture and Biosciences International
CIMMYT	International Maize and Wheat Improvement Centre
Cm	Centimetre
Comp D	Compound D fertiliser (7:14:7)
CRBD	Completely Randomised Block Design
DAP	Days after planting.
DF	Degrees of freedom
DNA	Deoxyribonucleic acid
FAO	Food and Agricultural Organisation
FAW	Fall armyworm
G	Gramm
GR	Granule
GMOs	Genetically Modified Organisms
Ha	Hectare
ITCZ	Inter Tropical Convergence Zone
IPM	Integrated Pest Management.
K	Potassium
Kg	Kilograms
kg/ha	Kilograms per hectare
Km	Kilometres
L	Litre
Lc	Lethal concentration
Ld	Lethal dose
LSD	Least significant difference
M	Metre
M	Million
m^2	Square metre

m.a.s.l	Metres above sea level(altitude)
Ml	Millilitre
Mm	Millimetre
Ms	Mean squares
N:P: K	Nitrogen: Phosphorous: Potassium ratios
P	Phosphorous
SS	Sum of squares
SSA	Sub Saharan Africa
T	Tonnes
USD	United States Dollar
WAP	Weeks after planting.
ZIMVAC	Zimbabwe Vulnerability Assessment Committee

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CHAPTER 1

INTRODUCTION

1.1 Background to the study

Maize (*Zea mays* L) is among the three most important cereal crops and is staple to more than a billion people world-wide (Salem & El-Gizawy, 2012). In addition, the crop is used in the manufacture of animal feed, bio fuels, edible oils, alcohol and other industrial products such as starch. Maize is one of the traded commodities providing incomes and employment opportunities to many people (Oyewo, 2011). Globally the crop is grown in more than 160 countries and of these 125 are developing economies from Sub-Saharan Africa, Asia and Latin America (Mugo and Prasanna 2017). In Africa, maize is grown on over 100M hectares and is staple to about 300M people (Chikobvu et al, 2010 and Shiferaw et al, 2011). The importance of maize in Southern Africa is reflected by the annual per capita consumption of different countries such as Lesotho- 174kg, South Africa-113kg, Zambia -133kg and Zimbabwe-93kg (Rodomiro et al., 2010 and Mhike et al ., 2011).

In Zimbabwe, maize accounts for 80% of cereal production and is grown on approximately 1.2 million hectares with an average annual output of 2.1million tonnes (Chikobvu et al, 2010 and Mhike et al , 2011). Due to its adaptability, the majority of producers who are small scale grow maize in various agro-ecological regions (Muzemu et al, 2013). In these circumstances, low maize productivity realised is usually attributable to biotic and abiotic stresses as well as socio-economic factors (Zimbabwe Vulnerability Assessment Committe, 2017).

Abiotic factors that affect maize production include soil pH, fertility, salinity, sodicity and meteorological (temperature and rainfall) conditions. The socio-economic factors affect resource availability and allocations for improved varieties, fertilisers, agrochemicals and other production inputs (Ncube et al ., 2009). Various pests, diseases and weeds are among the biotic stresses that limit maize production. Major maize diseases include maize streak virus, grey leaf spots (*Cercospora zea maydis)* and rust among others. Several pests also inflict damage on maize thereby reducing yields. The major ones are a lepidopteron insect complex whose larva feeds on leaves, stems, tassels and ears causing significant direct and indirect damage (Midega et al., 2018). Of great concern is the fall armyworm (*Spodoptera frugiperda)* whose recent invasion and rapid spread in Africa is threatening maize production and food security of millions of people within the region (Farmers voice, 2018 and Kebede and Shimalis, 2018).

The pest is expected to establish permanent populations and spread further afield including to other continents (Braimoh et al., 2018)

The Fall armyworm(FAW) is an invasive pest of more than eighty plant species including important field crops (Cruz et al., 1999 and Carroll et al., 2006). In Africa, FAW has mainly been recorded on staple crops (maize, sorghum, rice and millet) and therefore pose serious food security challenges (Carroll et al., 2006 & Carvalho et al., 2013). Furthermore, the moth is a strong flier as it can travel over 200 km per night with the aid of wind currents (Day, et al., 2017). It is thus able to disperse and colonise large areas in a short space of time making the pest of transboundary significance (Meagher & Nagoshi, 2004). The female moths can lay over 2000 eggs and is also known to breed continuously throughout the year under favourable climatic conditions (Day, et al., 2017 and Tavares et al., 2014). The larvae defoliate leaves, growing points and reproductive structures thereby reducing crop yields. Yield losses on maize as a result of fall armyworm damage can exceed 30% and for Southern African countries is expected to range between 2, 481M and 6,187M United States dollars (Ramos-López et al., 2010 and Day et al., 2017)

The pest which is believed to be native to tropical regions of the Americas was introduced to Africa in 2016 (Hinds and Dew, 1915, and Carvalho, et al, 2013 and Mugo & Prasanna, 2017). The pest has since spread to many Sub Saharan African countries including Zimbabwe and Madagascar after its discovery in West Africa (FAO, 2018). The threat of spreading to more countries is still significant (Day et al., 2017; Mugo & Prasanna, 2017). Indigenous knowledge systems and integrated pest management options to deal with FAW have not been fully developed hence widespread reliance on synthetic pesticides for its control (Kebede & Shimalis, 2018).

Given the devastating nature of damage by FAW, governments and farmers have naturally instituted emergency response mechanisms dominated by extensive use of synthetic insecticides (Carvalho, et al., 2013). Despite producing consistent results and being fast acting, synthetic pesticides also cause unintended impacts on the environment, non-target biota and human health (Ngadze, 2014; Paradza et al., 2012). Additionally the cost, availability and knowledge of pesticides also militate against their use by resource poor subsistence farmers who are threatened by FAW (Day et al., 2017 and Muzemu et al., 2013). Reports of pesticide resistance to carbamates, organophosphates and pyrethroids have been recorded in the Americas (Carvalho et al., 2013 and Yu & Nguyeni, 2003). While, pesticide resistance has not

been recorded in Africa, the threat remains significant. In these circumstances, sustainable alternative and integrative control measures must be developed and promoted.

Botanical pesticides have been touted as one of the sustainable options for the control of various domestic and agricultural pests particularly for resource poor farmers (Tavares et al., 2014). Botanical pesticides are usually locally available, familiar and may be comparatively cheaper and accessible than conventional pesticides (Lal & Verma,2006; Cespedes et al., 2005; Muzemu et al., 2013 and Tibugari et al., 2012). In most instances, botanical compounds do not persist in the environment as they are readily degraded. Also botanical plants usually contain several compounds which act synergistically and through various modes of action (Amoabeng et al., 2013).They are usually effective at levels that may be harmless to mammals and may therefore pose less danger of pesticide resistance build up, environmental and human contamination.

Use of botanical pesticides is as old as civilisation and forms the basis of traditional knowledge systems acquired and passed between generations (Murray, 2008). It is touted as one sustainable agro-ecological production option available to small farmers. Many botanicals including *Solanum nigram*, *Tephrosia vogelii*, *Azadiracta indica*, Pyrethrum, *Ricinus communis* and *Datura stramonium* have been used on field and storage insect pests (Fusire, 2008; Gadzirayi et al., 2009; Tibugari et al., 2012; Wheeler & Isman, 2001). Tavares et al., 2011 and Colom et al., 1999 have demonstrated the toxicity of piperine and Annonoceae (pawpaw) against fall armyworm.

Muzemu et al., 2013 and Fuchs et al ., 2011 highlighted that for botanicals to be relevant to resource poor farmers they must not require complicated equipment and extraction procedures to make them usable. The plants must be naturally available or integrated into existing farming systems so that they can be obtained at no or minimum cost.

1.2 Statement to the problem

Fall armyworm is an invasive, exotic and often devastating pest that was recently introduced to Africa (Day et al., 2017; Mugo & Prasanna, 2017). ZIMVAC 2017 report indicated that pest affected about 36% of households across the country during the 2016/17 season and was mainly a problem on maize. The affected hectarage by the pest in 2017/ 18 season was recorded on 150 000 ha (Herald, 2018). Of those affected households significant number ranging from

4 – 77% where not using pesticides due to unavailability, lack of funds to purchase and limited knowledge of pesticides. As a result, serious economic losses are associated FAW damage. However, Chimweta et al.,2019 working in lower Muzarabani in Zimbabwe discovered that farmers were experimenting with about 68% of the study population using highly restricted pesticides. This therefore creates the need to build knowledge on ecological control measures which may be locally available to small farmers (Day et al., 2017). In this regard, this experiment seeks to evaluate the efficacy of locally available and home prepared *Tephrosia vogelii and Dichapetalum cymosum* botanical pesticides, against *Spodoptera frugiperda* in this field.

The most noticeable feature of Fall armyworm invasion is usually extensive leaf damage. The host – pest relationship with regards to correlation between damage indices and yield loss in the new environment is little known. Some authors have indicated that yield loss estimates as a result of fall armyworm damage may range between 30 – 100% (Ramos-López et al., 2010, Carvalho et al., 2013 & Day et al., 2017). Chimweta et al., 2019 in experiments in lower Muzarabani estimated that yield losses were approximately 58%. This is contradicted by Baudron et al 2019, working on maize in eastern Zimbabwe who indicated that yield loss due to fall armyworm attack may be as low as 11.57%, further highlighting that the other figures could have been an overestimation. This is further complicated by limited information on economic threshold and/or injury levels for fall armyworm in its new environment (Africa). Establishment of relationship between damage indices (mostly this is what the farmer sees) and yield will form the basis for further research, that can scientifically guide pest management decisions.

1.3 Objectives of the study

The objective of the study is to evaluate the efficacy of *Tephrosia vogelii, Dichapetalum cymosum* and their combination on fall armyworm larvae in Zimbabwe. In the same research a relationship between damage indices (leaf damage scores, percentage infestation and barren stalks) and yield will also be studied.

1.3.1 Specific objectives

- To evaluate the effectiveness of *Tephrosia vogelii* and *Dichapetalum cymosum* and their cocktail on fall armyworm on maize grain yield under the field conditions in Zimbabwe.

- To establish the relationship between damage indices (leaf damage scores, percentage infestation and barren stalks) and yield.

1.4 Research Questions

- Are local botanical extracts such as *Tephrosia vogelii* and *Dichapetalum cymosum* effective in fall armyworm control in Zimbabwe?
- Is there any relationship between damage indices as a result of FAW and yield reduction?

1.5 Hypothesis

- *Tephrosia vogelii, Dichapetalum cymosum,* their cocktail and ecoterex induce same level of control on fall armyworm larvae under field conditions.
- There is a strong relationship between multiple insect herbivory variables (leaf damage score, proportion of affected plants and barren stalks) and yield.

1.6 Significance of the study/ Justification

This research is expected to generate information on the efficacy of botanical pesticides Tephrosia vogelii and Dichapetalum cymosum on fall armyworm. The information which may provide the most affordable way to manage the pest as the botanicals are usually locally available and therefore can be obtained comparatively cheaper than the conventional pesticides by small farmers.

Also expected to be generated is the information on damage indices and yield reduction, the information which will be expected to guide farmers in making economic decisions on control efforts as well as yield loss predictions as such information is currently unavailable. Conflicting reports on yield loss are currently available with some authors indicating that losses can range from 30% to 100% at high infestation levels(Ramos-López et al., 2010). Baudron., et al 2019 indicated that expected losses from Fall armyworm have been exaggerated and were found to be about 11.5% in Manicaland area of Zimbabwe. On the other hand, Chimweta., et al 2019 observed losses of about 50% in lower Muzarabani area (Mashonaland Area) of Zimbabwe.

1.7 Scope/ Delimitations and limitations of the study

Botanical pesticides are important for Integrated Pest Management strategies, organic farming systems and for use by the resource poor farmers. Most of the times, these poor farmers do not have physical and economic access to synthetic pesticides (Muzemu, et al., 2013). They may also lack the knowhow, skills and requisite tools needed to safely dispense such synthetic chemicals. As such yield loss due to pest damage especially among small scale farmers is still significant.

Botanical pesticides are usually safer local resources that have short persistence and less off target damage. They usually contain more than one active ingredient which enhances broad spectrum of activity and stalls onset of pesticide resistance build up by pests.

However, crude extracts have several limitations. Their availability may be limited in time and space (Muzemu, et al., 2013). Their toxicity may vary with plant parts, geographical location and maturity stage. Synergistic effect of several compounds in the botanical plants may make it difficult to come up with universal and consistent dose response data. It therefore becomes imperative to isolate individual compounds and come up with standard active ingredients. But such will require expensive and time-consuming procedures and equipment, which may not be available to small farmers.

Cheaper and simpler extraction techniques make botanicals attractive and more likely to be embraced by the small farmers who have limited resources. These botanical plants with no competing needs must either be naturally occurring or easier to integrate into existing farming systems. The experiment will reveal toxic effects of the botanicals under study using simple tools and extraction methods which are likely to be afforded by resource poor farmers.

On the other hand, FAW is a new pest in Africa. The threshold larval or damage levels that justify control measures have not yet been established. The information that reveals the extent of relationship between damage indicators and yield is still limited. As such some farmers are implementing control measures upon sight of FAW which might not be economically justified.

1.8 Outline of Thesis

The first part of the thesis reveals the importance of maize as a staple crop to majority of farmers who are small scale and subsistent in the developing world. It also goes on to show how fall

armyworm which recently invaded Africa from the Americas is causing widespread damage on maize and other important crops. As governments and individual farmers try to contain the pest, they are embarking on unsustainable strategies premised on chemical control. In order to plug the knowledge gap, it then becomes critical to research on plants with known pesticidal properties such as *T. vogelii* and *D. cymosum* that might offer sustainable alternatives and/ or commentary pest control role. Also critical is the study which tries to understand pest behaviour in its new environment. It is important to establish the relationship between damage indicators to yield reduction, which will further be used to estimate the real effect of the pest on maize in the experimental environment. The next chapter reveals the literature of what is known about origin, biology, spread, control and expected impacts of fall armyworm and the two botanicals under study. Chapter three shows how the experiment is conducted, variables to be measured and statistical analysis that will be employed. The results sections show the actual measurements and how the treatments compare to one another on variables under consideration. The discussion of results will indicate the outcomes of this experiment and how they compare to past works by other researchers. The summary and recommendations are presented at the end.

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CHAPTER 2
LITERATURE REVIEW

2.1 Introduction.

*Spodoptera frugiperda (*fall armyworm) is a known pest from tropical Americas which is not only invasive but also feeds on more than eighty crop and non-crop species throughout the year (Cruz et al., 1999 and Carroll et al., 2006). Its recent invasion and spread in Africa has caused production challenges of staple crops (maize, sorghum, rice and millet) and is expected to pose serious food security challenges (Carroll et al., 2006 & Carvalho et al., 2013). Yield losses on maize as a result of fall armyworm damage can exceed 30% and these has implications on loss of employment and trade opportunities (Ramos-López et al., 2010 and Day et al., 2017)

Fall armyworm is a recent pest in Africa and little information exists on its performance in the new environment. Answers to economic threshold levels in various micro agro-ecological zones, safer and integrative control options are being sought. What is generally clear is that FAW in its native environment has developed resistance to some pesticides and Genetically Modified Organisms expressing Bt proteins. Various chemical and non-chemical FAW control measures are being promoted, but these need to be validated in various climatic zones. Unique plants with known pesticidal properties available in specific areas offer possible control options. Plant based pesticides (part of indigenous knowledge systems) have been used in crop, livestock and human health for a long time where they are usually touted as sustainable, safer and cheaper. From time to time when faced with new challenges (pests) it becomes imperative to redefine these indigenous knowledge systems and generate information to deal with arising situations.

2.1.1 *Spodoptera frugiperda*

Fall armyworm is a damaging pest which originated from tropical Americas (Midega et al., 2018). It is a cosmopolitan pest that feeds on more than 80 plant species from 40 different families (Cruz et al, 1999 and Carroll et al, 2006). FAW belongs to the order Lepidoptera which include various pests of agricultural crops such as *Spodoptera exempta* (African armyworm), *Spodoptera exigua* (lesser army worm), *Spodoptera littoralis* (tobacco worm), *Helicoverpa amigera* and *Busseolla fusca* (maize stalk borer). However, while many of these Lepidoptera pests have been resident in Africa, fall armyworm is a recent introduction to the continent (Day,

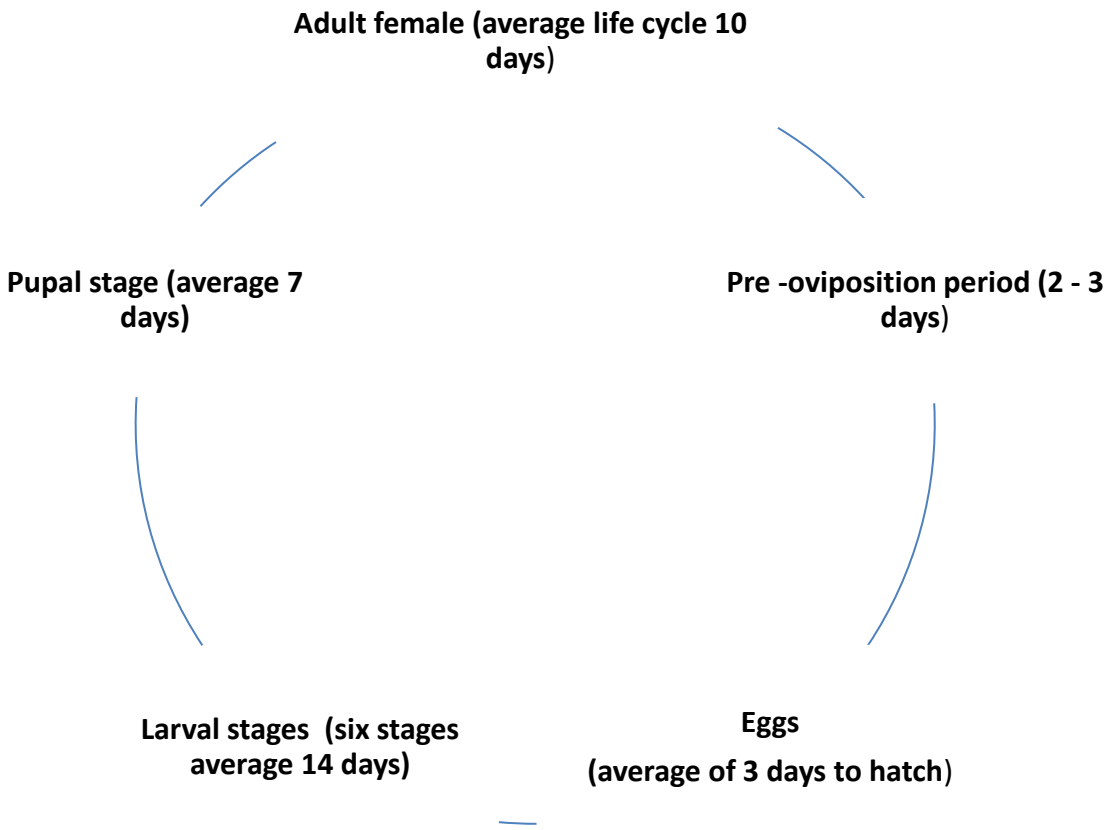
et al., 2017). Having been discovered in West Africa in 2016, the pest has spread to most countries in Sub Saharan Africa (SSA) including the island of Madagascar (CABI, 2018). The moth can disperse quickly over long distances thus making it a transboundary problem likely to compromise food production in Africa and surrounding continents (Nagoshi et al, 2017).

There are two genetically distinct but morphologically similar strains of Fall armyworm which exhibit host preference on either rice (rice strain) or maize (maize strain) (Juarez, et al., 2012). The maize strain also attack sorghum (*Sorghum bicolor*) and cotton (*Gossypium hirsutum)* while the other type infests rice (*Oriza sativa*) and smaller grasses like couch (*Cynodon dactylon*). Differentiation of the two is only possible at the molecular level, for example using mitochondrial DNA analysis (Salinas-Hernandez and Saldamando-Benjumea 2011). Apart from host affinity other physiological variations that exist include pesticides tolerances and growth rates (Nagosh et al, 2007).

Reduced sexual compatibility between the two strains has been observed. Groote, et al 2010 indicated that this could possibly be due to differences in pheromone composition, timing of reproductive activity and space (host preference) between the strains. While the rice strain female has been observed to mate with the maize male, the maize female and rice male are sexually incompatible (Prasifka et al 2009). Both strains have been positively identified in Africa (Early et al, 2018).

Fall armyworm does not diapause and can breed throughout the year under favourable climatic conditions with each female moth laying over 1000 eggs (Tavares et al., 2014 & Day et al., 2017). Tavares et al., 2014 and Prasanna (eds) et al., 2018 also reported that the life cycle of FAW can be completed in approximately 30 days under favourable climatic conditions. This added to long distance dispersal of the pest it is possible to find overlapping generations of endemic and migrant population infesting a single crop.

Figure 1 shows fall armyworm biology and ecology



Adopted from Syngenta (2017)

Fig 2.1: FAW biology and ecology.

Spodoptera frugiperda life cycle can be completed in 30 - 90 days under warm and cool conditions respectively (Kebede & Shimalis, 2018). However, under favourable climatic conditions FAW breeds continuously (CABI, 2018).The adult moth is the reproductive stage with a lifetime of 10 days. The female moth has a pre-oviposition of 4 days and oviposition period of 6 days during which it can lay over 1000 eggs. The moth is active during the night (feeds, mates and lays eggs) and hides in the canopy and darker spots during the day. The male moth has brighter forewings with triangular spots on the tip at the centre whilst those of the female have shades of grey and brown (Kebede & Shimalis, 2018). The moth is a strong flier and is responsible for long range dispersal from favourable areas that with permanent pest population presence. Sporadic FAW infestations resulting from long range dispersal is a fitness mechanism as the pest does not diapause and hence cannot survive freezing temperatures experienced in some locations (Nagoshi et al., 2012).

The eggs are laid in masses of between 50 – 500 mostly on the underside of leaves of host plant. The eggs have a flat base and are 0.4 mm in diameter and 0.3mm longer. The laid eggs which are covered with greyish anal scales for protection normally take about two to three days to hatch into larvae (Capinera, 2017).

The larval stage has six instars which take a duration of about 14 days to complete (Syngenta, 2017). This is the economic stage that feeds on the crops. The newly hatched larvae quickly disperse in an army habit hence the name armyworm. It has also been observed to aggressively disperse by wind whilst hanging on silk threads in search of food in a process called ballooning (Visser, 2017). The smaller larvae are light coloured with a dark head. Mature larva is usually 30 – 36mm long and may be brown, black and greenish with a lighter dorsal part. However, it has characteristic inverted 'Y' on the head and 4 black dots forming a square on the eighth abdominal segment (Syngenta, 2017). The late larval stages exhibit cannibalistic behaviour when faced with stiff competition and it is commonly found as one or two worms per plant (Carroll et al., 2006).

The most characteristic indicator of first and second instar neonates feeding is the window panes appearance on the young leaves (FAO, 2017). The young neonates feed on the underside of the leaves leaving the top epidermal layer intact. However, older larval instars enter the whorl and feeds on developing leaves giving rise to leaves with ragged appearance which in extreme circumstances may cause death of the apical meristematic tissue or dead heart (Carroll et al., 2006; Carvalho et al., 2013). The larva also feeds on tassels, silk and ears (kernels) of the maize crop thereby predisposing grain to fungal infection. On the ear, the larva burrows through the husk, on one side of the ear (Capinera, 2017). The most characteristic marks of infestation are windowed appearance on the leaves and frass that is deposited on the whorl or upper leaves. The larva normally hides deep in the whorls under their frass during the day and become active at night (nocturnal feeding). This reduces the chances of exposure to sprayed chemicals (Kebede & Shimalis, 2018).

Fall armyworm feeds on all the plant stages in the field. The damage can be direct and indirect. Direct damage is normally easier to predict because it can result in quantifiable losses, for example plant population and number of kernels. On the other hand, losses of leaf tissue and resultant loss of photosynthetic capacity, number of plants affected and larval infestation are indirect measurements. Generally, the pest is a voracious feeder and resultant yield losses have been estimated to range from 30 to 100%(Ramos-López et al., 2010). Various workers have

conducted studies on impact of fall armyworm on maize yield. Huska and Gould, 1992 in CABI, 2018 estimated that 55 -100% infestation can cause 15 – 73% yield loss. Cruz and Turpin, 1983 highlighted that there is an inverse linear relationship between leaf damage and yield reduction. That leaf damage can be a good predictor of yield loss. However, more recent work by Baudron et al (2019) argued that leaf damage and other indirect damage indices can lead to overestimation of damage. In their work they concluded that susceptibility varies between variety and growth stages. Thus, crops are less susceptible in the early vegetative stages and leaf damage indices may not reliably give accurate estimation of yield loss.

On reaching maturity the larva drops and burrows into the ground to transition into the pupa (Syngenta, 2017). However, if the ground is too hard it can build its cocoon on the surface with soil and vegetation debri. The pupa which is usually mahogany-black in colour and oval in shape is made out of incorporated silk and soil particles (Capinera, 2017). The pupa normally takes about ten days to transform into the moth.

2.1.2 Theories of spread to Africa

Fall armyworm is an exotic pest that was recently introduced in west Africa in 2016 (Day et al., 2017). In 2017, fall armyworm presence was reported in 28 mainland African countries but the number rose to 44 including Madagascar by September 2018 (CABI, 2018).The theory of spread of the pest from the Americas where it is endemic to West Africa (the epicentre of infestation in Africa) is thought to have occurred as contaminants of agriculture produce, trade or as stow away through air travel (Otim et al., 2018).

The exact route that led to FAW dispersal is not known, however some theories have been postulated. Cock et al, 2017 highlights that FAW has been regularly intercepted as a contaminant on agricultural commodities in Europe. There are various phytosanitary measures put in place by different countries, the possibility of FAW movement as a contaminant of international trade is possible but, however minimal.

Unaided flight dispersal from the American continent to Africa has also been downplayed for two reasons. The sheer distance between the two continents seperated by sea would make it practically impossible for the adult moth to fly accross. Furthermore, the flight path over the long distance is expected to be met with intermittent winds in the opposite direction which would make it difficult for the moths to land in Africa.

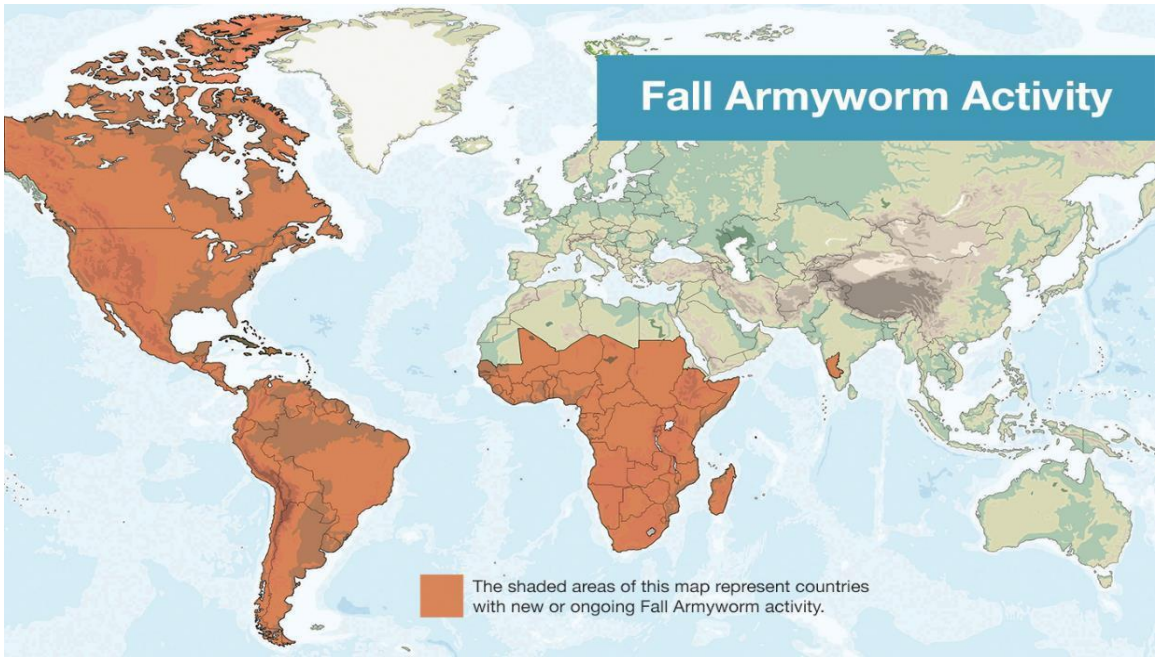
As such Goergen et al., 2016 & Day et al., 2017 concluded that the main method that could be responsible for FAW introductions to Africa could be as stowaway. It is known that in some instances (absence of hosts and high populations) FAW moths can lay eggs on any surface including inanimate objects. The eggs or moths on plane bodies or cargo holds could have been passively transported through air transport as vectors from Americas to west Africa (Cock et al, 2017& Otim et al., 2018). It is thus no coincident that FAW was first detected in countries which are air transport hubs for America- Africa traffic flow. The pest populations could have been simultaneously introduced from different American regions.

Discovery of FAW in Nigeria, Togo as well as Sao Tome at the same time, point to multiple introductions (CABI, 2018). Goergen et al., 2016 carried out DNA profiling of fall armyworm populations from Western African countries and discovered that samples from different countries had 98% variation whilst within country samples were found to be 100% similar. This reiforces the fact of simultaneous introductions from different countries. Nagoshi et al., 2017 also reportedly carried out genetic analysis of FAW samples from Togo which were shown to be similar to those from Caribbean and East American region.

Further dispersal within Africa is thought to have taken place through unaided dispersal, trade and as stowaway on planes or cross border vehicles (Goergen et al., 2016 & Cock et al, 2017). Permanent populations are expected to be restricted to warm moist areas which support survival of the pest and host plants throughout the year (Cock et al, 2017). These populations are expected to disperse to seasonally favourable zones resulting in sporadic outbreaks (Early et al, 2018). The moths are known to fly at high altitude and winds such as Inter Tropical Convergence Zones (ITCZ) are expected to play an important role in long distance dispersal (Day, et al., 2017). Trade and transportation will also be vital for further spread of the pest.

Intercontinental dispersal to countries which receive huge air transport volumes from Africa such as Australia, Asia and UK are expected to take place (CABI, 2018). Already reports indicate that FAW had invaded India by August 2018 and was expected to spread to countries within the region such as Bangladesh, Pakistan and Nepal (Shylesha et al., 2018).

Figure 2 below shows fall armywom distribution as at August 2018



Map: CIMMYT, August 2018 from Mugo et al., 2018

Fig 2.2: Fall armyworm distribution as at Aug 2018.

2.1.3 Farmers' response to fall armyworm infestations.

The important attributes of fall armyworm are its high dispersal ability, cosmopolitan nature and significant crop yield losses associated with its feeding (Carvalho et al., 2013). Faced with these challenges, the natural response by governments and farmers has been through registration , promotion and use of synthetic pesticides (Carvalho et al., 2013 & Bateman et al., 2018). In a study, farmers from Ghana and Zambia were observed to be using synthetic pesticide as the major control option (CABI, 2018). Various governments have been embarking on emergence registration of various chemicals in response to the FAW (Sisay et al., 2018 and Sunday news 2017). At times embarking on temporary registration of pesticides before conclusive results from running trials could be obtained (Sunday news 2017).

However, in the Americas the fall armyworm population has developed resistance to carbamates, organophosphates, pyrethroids and benzoylureas (Carvalho et al., 2013 and Yu & Nguyeni, 2003). Lynch et al., 1999, also reported resistance build up to Bt maize as FAW fed with Cry1A (b) maize did not die but only showed signs of reduced growth rate. Furthermore,

Huang et al, 2014 reported resistance to Bt maize expressing Cry1F ranging from 18.8 to 55.9 fold and confirmed cross resistance to Cry1 A-P and VT2P.

Kumela et al., 2018 in CABI 2018, also reported that 46- 60% of farmers interviewed in Ethiopia and Kenya respectively indicated synthetic insecticide were not effective against FAW. Furthermore, Mugo and Prasanna 2017, reported on interviews on Zimbabwean farmers who indicated that they were using various pesticides, most of which according to their assessments were not giving satisfactory results. Failure to give satisfactory results could have been as a result of inappropriate application techniques by farmers or may point pesticide resistance. However, there is little evidence that suggest pesticide resistance in Africa at the moment.

FAW has strong serrated mandibles that make it able to feed on older and stronger plant material (Goergen et al., 2016). However, previous work on resistant maize and rice accessions have been recorded (Pantoja & Smith, 1986 Brooks et al , 2007; Williams, 2008 and Ni et al, 2014). Mugo and Prasanna 2017, also reported on CIMMYT elite inbred lines which were resistance to FAW. Maize varieties with Bt (Bacillus thrungiens) toxin *(cry1B* and *cry1Ac* genes) have also been developed but these can only be utilised in countries whose legislation permits production and consumption of GMOs (FAO, 2018). It is important to note that, presently there is little evidence to suggest availability of commercial varieties with FAW resistance in Africa (Kebede and Shimalis, 2018). Development of conventional bred resistant maize varieties is expected to require considerable time and other resources which may not likely be achieved in the short run.

Reports also reveal the presence of predators and parastoids, and efforts to introduce natural enemies from Latin America were said to be under way (FAO, 2018). Presently there is limited use of biopesticides in Africa. An example is the reported use of subsidised Bt based biopesticides by some farmers in Ghana (CABI, 2018). Natural parastoids (H*ymenoptera* and *Diptera*) have also been observed in Kenya and Ethiopia (Sisay et al., 2018)**.** However, the commercial use parastoids and natural enemies has not been fully developed.

Farmers have also been observed applying ash or sand to the whorls or leaves as a control strategy (FAO, 2017). FAO, 2017, highlighted on limited use of sand, ash, washing powder as well hot chilli in controlling the pest by small scale farmers. This is further collaborated by Kumela et al., 2018 who reported that about 20% and 39% of farmers in Ethiopia and Kenya

respectively used traditional non-chemical methods such as handpicking, soil and tobacco extracts in controlling FAW.

Kebede and Shimalis, 2018, further added that some cultural practices utilised for FAW management also included early planting and intercropping. One method being encouraged is the "Push – Pull system" (Prasanna(eds) et al., 2018 & Midega et al., 2018). This land scape management system utilises a repellant which 'pushes' the pest away from maize field and a hedgerow planted attractant which 'pulls' both pests and natural enemies. *Desmodium spp* produces volatile compounds that discourage oviposition in the field while *Brachiara spp* attracts the pest. Experiments done in Uganda, Tanzania and Kenya revealed that this can reduce infestation rates in maize by upto 82.7% (Midega et al., 2018)

2.1.4 Use of botanicals on Fall armyworm control.

Use of botanicals is thought to be as old as agriculture itself and is linked to indigenous knowledge systems developed to deal with endemic limitations such as pests, diseases and other cultural practices (Altieri et al ., 2012). Indigenous knowledge systems are transmitted and perfected over generations through observation and experiences. However, the advent of green revolution which developed and promoted the use of novel synthetic chemicals was responsible for the displacement of these botanicals (Hubert et al., 2015). The use of these synthetic pesticides has associated problems (health, environmental pollution, pesticides resistance and secondary pest outbreak) hence the quest to seek sustainable alternatives including botanicals (Gurjar et al., 2012 & Amoabeng et al., 2013). Botanicals are often made up of complex secondary plant metabolites with broad spectrum of insecticidal activity (Namdeo, 2007; Mamun & Ahmed, 2011).

Various botanicals have been tried on FAW. Cesperdes et al., 2000 reported that *Cedrela salvadorensis, Cedrela dugessi as* well as *Melia azadarach* (neem) were found to cause larval mortality and reduce FAW growth rates at lower concentrations. Bullangpoti et al., 2012 also reported LC_{50} of 2.6 and 1.4 g/ litre of *Melia azadrach and Jatrapho gossypifolia* respectively on FAW. Jatropha was found to be more potent. Farmers in Ghana were also reported to be using Azadirachtin based products against FAW (CABI, 2018). *Azadriracta indica* (neem tree) contain limonoids which contain both insecticidal and antifeedent properties (Khatri and Meshram (eds), 2014 and Carpinella et al., 2003).

Some species in the *Asteraceae* family have been found to be toxic to both FAW larvae and eggs while being selective on *Hymenoptera* beneficial insects (Tavares et al., 2009). Figuero-Brito et al., 2011, also observed FAW mortality of between 50 – 73% on larvae fed with artificial diets treated with processed seed (at 10,100 and 1000 ppm) from certain varieties of *Carica papaya* (L.). *Ricinus communis* leaf extracts were also tested for insecticidal activity on FAW and were found to contain linolenic and linoleic acid which had insecticidal activity at $0.849x\ 10^3$ and $0.857x10^3$ respectively (Cespedes et al., 2005).

2.1.5 *Tephrosia vogelii*

Tephrosia vogelii also called fish bean poison is a tropical leguminous herb of the order Fabales and family Fabaceae (Isabirye and Mecleod, 2015). It is a branched shrub that grows to about 4 meters in height with erect stems and leaflets grouped in fives (Dafam et al., 2014). The plant has rusty-brown hairs on the stems and leaves. On maturity it bears pink to white flowers on compact racemes over a blooming period of upto 6 weeks during short day season (Dzenda et al., 2007).The flowers give rise to linear pods with 8- 16 seeds (Dafam et al., 2014 & Belmain et al., 2012). The plant can easily be propagated from seeds and thrives on poor, acidic soils much better as compared to other legumes (Gadzirayi et al., 2009). *Tephrosia vogelii* is a multiple use plant with fish toxicity, pesticidal and soil improving properties (Stevenson et al., 2012).

Tephrosia vogelii contains isoflavonoid rotenoids (rotenone, deguelin and tephrosin among others) which are mainly found in leaves, but are also present in varying proportions in the roots, stem and pods (Mamun & Ahmed, 2011). According to Dzenda et al., 2007 these isoflavins have different properties. Rotenone ($C_{22}H_{23}0_6$) is a more potent component that has insecticidal properties. On the other hand, deguelin ($C_{23}H_{22}O_6$) is an intermediate component that inhibits proliferation cancerous cells. Tephrosin ($C_{23}H_{22}0_7$) and quercetin ($C_{15}H_{10}O_7$) on the other hand are less potent but have anti-inflammatory properties. This is confirmed by Belmain et al., 2012, who indicate that rotenone has the highest biological activity followed by degueline and then tephrosin. The active ingredient (rotenone) inhibits of mitochondria electron transport during respiration (Aritho et al., 2017). This inhibition of NAD^+ during respiration causes cellular respiratory malfunction which cease energy generation leading to death (Guleria & Tiku, 2009).

Gadzirayi et al., 2009; Belmain et al., 2012 and Ismam, 2006 revealed that the acute oral toxicity of rotenone ranges from 132-1500mg/kg. It is a contact and stomach poison and as such provides protection against both sucking and chewing pests. While rotenoids have been shown to be poisonous to insects they however, have very minimal mammalian toxicity (Aritho et al., 2017). Nabukenya et al., 2014 conducted exposure trials of aqueous extracts of *T. vogelii* on rats and observed, minimal side effects at high doses. *Tephrosia vogelii* is considered safe as its oral toxicity for man is 300 – 500mg/kg (Murray, 2008). This is further supported by Gadzirayi et al., 2009, Agbon et al., 2004 and Aritho et al., 2017 who highlighted that rotenone degrades rapidly in the environment and as such pose minimal risk of bioaccumulation as well as consumption as residues on produce.

Tephrosia vogelii was used by different workers who proved its efficacy on various crop pests and animal parasites. Gadzirayi et al., 2009 reported no significant differences between triatix (a commercial acaricide) and *T. vogelii* in the control of ticks in dairy animals at a dilution rate of 50g/ 100- 200ml of water. Isabirye & Mecleod, 2015, found out that effective flea (*Echinophaga spp)* control on chicken could be achieved by 25, 33.3 and 50% w/v ratio. The reinfestation rate was observed to decline with increasing concentration suggesting increased residual effect. They also observed that the shelf life of the prepared dilution was six days.

Mudzingwa et al., 2013 reported efficacy of *T. vogelii* in the control of cabbage aphids (*Brevicoryne brassicae L.*) applied at 200g/l. While the commercial synthetic pesticide performed better, *Tephrosia vogelii* was also effective in reducing pest counts on the plants after treatment. The most notable observation was that result were registered three weeks after application suggesting slow activity.

Low uptake of plant-based pesticides has been studied by various authors. A survey conducted in Malawi and Zambia discovered that only 39% of respondents were aware of plant-based grain protectants and *T. vogelii* and *Azadiracta indica* were the most frequently used (Kamanula et al., 2011). Ogendo et al., 2004 tested *Tephrosia vogelii* and *Lantana camara* on maize weevil (*Sitophilus zeamais*) and these were found to be as effective as Actellic super 2% dust (a commercial product). The variables in the study were reduction of grain damage, seed viability among other quality parameters.

Belmain et al ., 2012, highlighted that there are two types of *T. vogelii* (chemotypes 1 and 2), of which the first one has rotenone and is more potent. Experiments conducted on *Callosobruchus maculatus* (bruchids) revealed that the highest mortality was experienced at 5% (w/ v) for chemotype 1 while chemotype was not effective. Aritho et al., 2017 working on control of sand fly (*Phlebotomus duboscqi)* collected samples of *T. vogelii* from three different sites. The samples were ground and 200g of each was mixed with larva food and fed to the pest. Only one sample out of the three recorded 100% mortality suggesting differences in chemical composition and efficacy of the three samples. Stevenson et al., 2012, also confirmed the existence of two chemotypes on samples collected in Malawi. In their trial they concluded that about 20% of Tephrosia being cultivated in that country was chemotype 2 which lacked rotenone and was thus unsuitable for use as a botanical pesticide.

Agbon et al., 2004 reported on the use of tephrosia for clearing water bodies of trash fish, mosquito larva and other unwanted biota. They reported that lethal concentration of *T. vogelii* ranged from 0.24 - 2.89 mg/l for fish and other water biota respectively. Ibrahim & Nuhu, 2015 exposed *Clarias gariepinus* fish to sub lethal (0.28mg/l) and acute (20mg/l) concetrations where they observed liver degeneration and shrinkage of gill muscles and cartilage. However, the extent of degeneration increased with the increasing dosage rates.

On the human health front, Dafam et al., 2014, reported that the plant has also been used as traditional folk medicine for various ailments. They analysed and concluded that the alkaloids and tannins present in the plant were responsible for toxic and healing properties hences its use in killing fish, as a fungicide and insecticide. It can be used for controlling fungal and bactrial infections (Dzenda et al., 2007). The root can be ground and mixed with water for treating endoparasites, lice as well as treating bone injuries and inducing abortions. It is said to have emetic as well as purgative properties and thus can be used to induce vomiting as well as treating constipation.

Stevenson et al., 2012 also highlight that Tephrosia vogelii is widely used for its soil improving properties. The plant is a nitrogen fixing legume and is therefore important for use under resource poor farming situations which are characterised by low fertiliser usage. It can also be used as green manure, mulch and for erosion control (Mafongoya et al., 2006). Mafongoya also points out that the plant was widely cultivated in Southern Africa due to its soil improving attributes. In addition, the plant is well adapted to the tropics and can grow well on acidic soils

better than most legumes (Dafam et al., 2014). It is easy to propagate from seeds and matures in six months (Gadzirayi et al., 2009).

2.1.6 *Dichapetalum cymosum*

Dichapetalum cymosum (gifblaar, poisonous leaf or umkhauzani) is a low growing poisonous shrub of tropical origin which is common in Southern Africa (Baunthiyal & Pandey, 2012). The plant is found in Angola, Namibia, Zambia, South Africa and Zimbabwe. It thrives in dry areas with poor, well- drained acidic soils (Van de Merwe and Du Plessis, 2006). Stent, 1916 and Aganga et al., 2011 indicated that the plant has simple, alternate bright green leaves with characteristic prominent veins and fine hairs. Gifblaar gives rise to small clusters of sweet smelling white flowers and oval bright yellow single seeded fruits (Aganga et al ., 2011). It can progate vegetatively as well as through the seed. The plant has an extensive undergound stem which makes it difficult to eradicate (Pule, 2013). *Dichapetalum* remains green in spring (just before the rains) and as a result attracts herbivory which cause livestock losses due to poisoning (Pegg, 2015).

The active ingredient is a fluorine containing compound called monofluoroacetate (CH_2FCOOK) which in nature is present in a few plants of the family Dichapetalaceae, Leguminosae and Rubiaceae (Marais, 1944). Eisler, 1995, indicated that monofluoroacetate has been isolated from *Dichapetalum cymosum*, *D. toxicarium*, *Acacia georginae* and *Gastrolobium spp.* Monofluoroacetate is not poisonous but upon ingestion it is converted to fluorocitrate (also called lethal synthesis) in the body (Van de Merwe and Du Plessis, 2006). Fluorocitrate interferes with aconitase enzyme (a mitochondrial acetate carrier) during the Krebs cycle which lead to increased blood acid levels, respiratory complications and death (Eisler, 1995). The oral LD_{50} for monofluoroacetate ranges from 0.5mg to 10mg/kg for rabbits and man respectively (Goncharov, 2006). Cattle exposed to Dichapetalum have been found to develop tolerance (Botha, 2008). However, other organisms such as fish, reptiles and amphibians are less sensitive to monofluoroacetate (Eisler, 1995).

Eisler, 1995 also highlighted that monofluoroacetate also has systemic insecticidal properties and is poisonous to a variety of insects including moths, ants, bees and mites but is not phytotoxic. However, monofluoroacetate has high mammalian toxicity and must be handled with care (Minnaar & Mccrindle, 2000).

Stent, 1916 reported traditional uses of the plant for pest control against rodents and wild animals (pigs and monkeys). The leaves are also used as a stored grain protectant. In the area of human medicine the leaves are said to be used in the treatment of jaundice and cancer while the roots can be used to induce vomiting or diarrhoea (Eisler, 1995). The fruit is not poisonous and can be eaten by man. However, unlike *Tephrosia spp* this plant has not been extensively studied for use on various pests.

Monofluoroacetate has low persistence in the environment as it has been found to be biodegraded in both water and soil (Weaver, 2003). Weaver, 2003 and Ahrih, 1994 reported that monofluoroacetate hydrolyses into fluoride and glycolic acid. Eisler, 1995 also reported microbial defluorination to contribute to low persistence.

2.1.7 Summary of Literature Review.

FAW is a known pest of various crop and non-crop plant species. The larvae feeds on leaves, stems and reproduction parts leading to significant yield reduction. Faced with the FAW problem both farmers and governments are embarking on control measures that rely mainly of use of synthetic pesticides. However, use of synthetic pesticides is known to disturb the non-target ecosystem as well as causing human health problems. Issues of availability, cost and appropriate knowledge of effectively dispensing these synthetic pesticides come to play in the context of small resource- constrained farmers. The fall armyworm pest in its native Americas is known to have developed resistance to some synthetic pesticide and Bt endotoxins (genetically modified crops). Studies on FAW have indicated that it has a number of enzymes that enhances detoxification, rapid excretion from the body and /or alter target site. While there is general lack of evidence suggesting pesticide resistance in Africa, a number of reports in which farmers indicated low efficacy of some pesticides that they used have been generated. A number of non- chemical methods are being researched on and promoted, but these need to be validated in various agro-ecological conditions. The use of available pesticidal plants is also another sustainable control option. *T vogelii* and *D. cymosum* are two known plants with poisonous properties that may offer alternative or integrative FAW control in Africa where the plants are found.

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CHAPTER 3
METHODOLOGY

3.1 Introduction.

The field trial to evaluate efficacy of *Tephrosia vogelii*, *Dichapetalum cymosum* and their cocktail (mixed 1:1 w/w) was established in Harare, Zimbabwe during 2018/19 summer season. The trial also contained negative control and a positive control treatment using Deltamethrin and pirimiphos-methyl (ecoterex). The leaves of the botanicals where collected, dried and stored in a shed upon which they were pounded by mortar and pestle into dust just before application. The dust was then applied into the whorls of the maize crop during vegetative stages and onto the developing ear after tasselling.

3.2 Description of study area

3.2.1 Brief Description of study site

The experiment was conducted under field conditions at Chikurubi Farm in Harare, Zimbabwe (17^o 47' 32S; 31^o11' 19S E and 1550m above sea level). The farm has subtropical climate with an average annual rainfall above 750mm (agro-ecological region 2b). The rainfall period extends from October to March and has an average annual temperature of 18^oc. The area has red clay loams on high ground and black clays on low lying areas. The trial was established on low lying black clay soils with a moderate north facing slope.

3.3 Research design

The field experiment was established as a Completely Randomised Block Design (CRBD) of 5 treatments with three replications. The blocking factor of the slope was used. Two botanicals (*Tephrosia vogelii, Dichapetalum cymosum*) and their mixture (1:1 w/w) were applied as dust. A positive control treatment of Deltamethrin and pirimiphos-methyl and a negative control were used as shown on table 1 below:

Table 1: Research treatments

Treatment	Pesticide type
1	Tephrosia (dust)
2	Dichapetalum (dust)
3	Positive control (ecoterex)
4	Tephrosia + Dichapetalum (dust)
5	Negative control (no control)

The botanicals were applied as dust at one level 198kg/ham (200g/plot) whilst a mixture of 1:1 of the two botanicals was also applied at the same level. The positive control was applied ecoterex 0.5 GR (deltamethrin and pirimiphos- methyl) was applied at 8kg while the negative control was not treated at all.

3.4 Collection and preparation of botanicals.

The leaves of the botanicals were ones of interest. *Tephrosia vogelii* was collected from a managed plot at Fambidzanai Permaculture Training Centre in Mount Hampden, Harare (latitude 7°51'50S; longitude 31°1'47E and 1150 m asl). *Dichapetalum cymosum* was collected from the veld in the property of Lupane State University in Matabeleland North Province (latitude -18°56.790S; longitude 027°45.682E & 970 masl). The collected leaves of the plants were dried under a shed for two weeks and stored in a dark room in sealed plastic bags. The dried leaves were pounded into powder using a mortar and pestle just before application on the plants. The crop was left to naturally infested with FAW and the different pesticides were applied on the whorl of the crop to control the pest.

3.5 General Crop Management

The piece of land that was used for the trial was previously under vegetables. Land preparation was achieved using a trailed disc harrow after which final tilth, land levelling and marking of planting rows at 0.9m spacing was done manually using hoes. General fertiliser applications used in this experiment were adopted from Seedco, 2018. Compound D (7:14:7) was banded along the row at a rate of 400kg/ ha before planting. AN (34.5N) was applied at a rate of 400 kg/ ha at 7 weeks after crop emergence (WACE).

The initial variety (SC401) that was planted on 12/01/2019 was destroyed by quail birds (*Coturnix coturnix*) on germination. The trial area was moved to a more secure site within the same general area where a new variety (SC608) was planted on 25/01/2019. The seed was drilled in row close together and was thinned to 0.2m apart two weeks after germination to achieve 55 000 plants/ha.

The field experiment was established during the summer rains. However, due to the poor rainfall pattern (drought period) experienced during the season, the crop received supplementary irrigation using sprinkler system on two occasions. The first irrigation was applied at 7 WAP and the second at 9 WAP. In both instances the irrigation was applied during the day for a set time of six hours.

3.6 Pest Management.

The experiment composed of five treatments which are *Tephrosia* dust, *Dichapetalum* dust, *Tephrosia+ Dichapetalum* dust, positive control (ecoterex 0.5 GR) and negative control (no treatment). The botanicals and ecoterex were applied at 200g/13.5 m^2 (Mudzingwa et al., 2013) Deltamethrin and pirimiphos - methyl was applied at 8kg/ha as per the manufacturer's recommendations. Both were applied on to the whorls of growing maize crops at weekly intervals after natural infestation from 6 WACE stage.

3.7 Weed management

All the experimental units and surrounding areas were kept weed free. Initial weeds were destroyed by tillage operations. Subsequent weed management was achieved through manual weeding using a hoe at 3, 6 and 10 WAP.

3.8 Data collection methods

3.8.1 Sampling procedures

The gross plot consisted of three rows of maize crop spaced at 0.9m and 5m in length giving a total area of 13.5 m^2. The net plot was middle row minus one metre on both ends and was 2.7m^2. The plant population of the net plot was targeted at 18 plants but the final ranged from 11 - 18 plants.

3.8.1.1 Plant height

Plant height was assessed on three randomly selected plant positions and was measured from the ground level to the flag leaf at flowering. The three measurements were then averaged in order to represent the whole plot.

3.8.1.2 Damage score on leaves

The damage score as in Kaya, et al., 1995 in (Chapman, et al 2000) on a scale of zero to nine. Leaf score rating of zero for no visible damage, and nine for severely damaged as shown on table 2 below:

Table 2: Leaf Damage Score Rating

Damage	Damage score
No visible damage	0
Few pin holes on older leaves	1
Few shot holes on a few leaves	2
Several shot holes on leaves (<50%)	3
Several shot holes on leaves (>50%) or small lesions (<2cm long)	4
Several shot hols and elongated lesions on few leaves.	5
Elongated lesions (>2cm long) on a few leaves.	6
Several leaves with long lesions with leaf tattering	7
Several leaves with long lesions with several leaf tattering.	8
Plant dying due to death of growing points (dead hearts)	9

CIMMYT, 1989

The experiment was left to naturally infest with FAW upon which the treatments were applied to the experimental plots. Initial leaf damage scoring was conducted just before the commencement of the pesticide application from the 10th of March 2019 and subsequently at 13- day intervals. All the plants in the sampling plot were scored and an average for the treatment was arrived at by dividing the total score by the number of plants in the net plot.

3.8.1.3 Percentage plants showing leaf damage.

The plants exhibiting leaf damage in the net plot were counted and then expressed as a percentage of the total net plot plant population.

3.8.1.4 Dead hearts and plants with failed tassels.

Dead hearts were evaluated during the course of the trial. A dead heart was defined as a plant with a dead meristem. Also, the experimental plots were assessed for failed tassels by counting the total number of plants with no tassels and expressing them as a percentage of the total net plot population.

3.8.1.5 Percentage barren stalks.

Percentage barren stalks was taken three weeks after ear initiation. It was arrived at by counting the total number of plants devoid of ears in the net plot and expressing them as a percentage of the total net plot population.

3.8.1.6 Grain yield.

The experiment targeted to harvest the grain on maturity and weigh the grain yield, kernel weight as well as come up with percentage kernel damage. A short season variety SC401 which was planted in January 2019 was damaged by birds upon which SC608 (medium season variety) was then planted. The crop was then harvested before maturity at soft dough stage and these variables could not be used.

Instead the fresh cob weight of the net plots was weighed and the weight taken to represent each treatment. However, the weight of the affected kernels could not be established as the maize was harvested at soft dough stage when the grains were still grain filling.

3.8.1.7 Percentage of ears showing damage

After the plots were harvested, the number of ears with damage were counted and expressed as a percentage of all the ears from the net plot.

3.9 Data Analysis Method

Data was analysed using Genstat version 16. Analysis of variance was performed on all the measured variables after checking the assumptions (normality, homogeneity and independence) using the same package.

The least significant difference test was used to separate the means at 5% level of significance. Regression analysis was run on leaf damage score, percentage plants showing damage, percentage barren stalks and fresh cob weight.

3.10 References

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CHAPTER 4

RESULTS AND DISCUSION OF RESULTS

(Field Evaluation of *Tephrosia Vogelii* And *Dichapetalum Cymosum* Crude Botanical Extracts in The Control of Fall armyworm (*Spodoptera frugiperda*) in Zimbabwe).

Abstract

Fall armyworm (Spodoptera frugiperda J. E Smith) is a new pest of maize and other crops in Africa. Governments and farmers are responding through seemingly unsustainable control strategies premised on synthetic pesticides despite knowledge of pesticide resistance to some chemical groups in its native environment. In addition, resource-handicapped subsistence farmers usually lack means to buy and use these synthetic pesticides. The objective of this experiment was to evaluate the efficacy of locally available botanicals (*T. vogelii* and *D. cymosum*) on fall armyworm in maize. The experiment was set up as a Completely Randomised Block Design with five treatments and three replications. GenStat version 16 was used for statistical analysis. Ecoterex treatment performed significantly better and was consistent than all treatments on leaf damage score and percentage plants infected. However, the botanicals outperformed the negative control on leaf damage, plant height and damaged cobs. *Dichapetalum* treatment performed just as ecoterex on yield while *Tephrosia + Dichapetalum* had similar effect on damaged cobs. Due to lack of consistency in performance by botanicals it is recommended, that farmers adopt the use the botanicals under study as integrative components of crop protection. However, in cases where there are no chemicals, the botanicals can be utilised.

Keywords

Spodoptera frugiperda botanicals resistance sustainable efficacy

4.1 Introduction.

Maize is among the three important crops that are produced in the world. Maize is particularly important in the developing world where it is mostly produced by small scale farmers as a staple food crop. A number of abiotic and biotic factors affect maize production but fall armyworm (*Spodoptera frugiperda*) which recently invaded Africa from the Americas is causing serious production and economic losses to the extent of threatening food security within the region. Faced with this dilemma governments and farmers are embarking on seemingly unsustainable control strategies premised on synthetic pesticides.

In as much as the synthetic pesticides perform much better, small resource poor farmers face challenges of availability, affordability and appropriate knowledge of their use. In the Americas fall armyworm has already developed pesticide resistance to some family groups such as carbamates, organophosphates and some Bt toxins from GMO crops has been recorded. It is therefore imperative that sustainable alternative and/ or complementary fall armyworm control options be developed. Local plants with known pesticidal properties are one such example.

4.2 Materials and Methods

The trial was established during the 2018/19 summer season. The experiment occupied 202.5m^2 and consisted of fifteen plots measuring 13.5m^2 each. Each plot composed of 3 rows spaced at 0.9m and 5m long. The net plot was the middle row minus one metre on both ends measuring 2.7m^2. *T. vogelii* and *D. cymosum* leaves were collected from the field and dried in a shed. The dried leaves were then stored in the shed and pounded to dust using a mortar and pestle. The dust from the two botanicals was applied at a rate of 148kg/ ha (200g/plot) whilst ecoterex was applied at the recommended rate of 8kg/ha.

4.2.1 Description of study area.

The trial was carried out at Chikurubi Farm which is 25 km due east of Harare. The farm is geographically positioned at $17^0$47’32S and $31^0$11’19E and at an altitude of 1150 metres above sea level. The farm is in agro-ecological region IIa which normally receives over 750mm of rainfall during the summer season.

4.2.2 Research Design

The experiment was carried out as a completely randomised block design with five treatments and replicated three times. *T. vogelii*, *D. cymosum*, *T. vogelii + D. cymosum*, positive control (ecoterex) and a negative control were used as the treatments as explained in section 3.3.

4.2.3 Sampling procedure.

The gross plot had a total of 13.5m^2 of which the net plot had the middle row minus one metre on both ends. As such the net plot was 2.7m^2 and this is the area that was used for all the samples. All the plants within the net plot were sampled for leaf damage score rating, percentage plants affected, fresh cob weight, percentage cobs affected, percentage plants which failed to tassel, percentage barren stalks, dead hearts, total fresh cob weight, plant population and percentage cobs showing damage. Only plant height was assessed on three random plant positions within the net plot.

4.2.4 Data collection procedure

Various data collection procedures were undertaken for each variable. Leaf damage score used a key which ranged from 0 to 9 (CIMMYT, 1989). Score 0 was assigned to plants with no visible leaf damage whilst 9 for plants with a dead heart and almost completely defoliated as shown in table 2. The percentage plants with leaf damage was achieved by counting all the plants showing leaf damage and expressing the figure as a percentage of the total population in the net plot. Percentage barren stalks also considered the total number of plants devoid of ears at R2 crop growth stage and expressing the figure as percentage of the total population in the net plot. Percentage plants which failed to tassel and dead hearts also expressed the respective plants as a percentage of the total net plot population. The plant population was achieved by counting all the plants within the net plot. All the plants within the net plot were harvested at soft dough stage and the total weight of fresh dehusked cobs recorded. Plant height was measured at three random plant positions within the net plot. The height was measured from the ground to the flag leaf using a tape measure.

4.2.5 Data analysis procedure.

Refer to section 3.9

4.2.6 Challenges encountered during data collection

Since the experiment was conducted in the open field, initial plans to artificially infest the plots with live larvae were dropped due to ethical concerns. As such direct measurements on actual mortality of fall armyworm larva were not conducted as this was not standardised from the onset. Indirect measurements such as leaf damage scores and cobs damaged and percentage plants infested were used instead.

The late onset and inconsistent rains characterising the 2018/19 summer season, resulted in the initial planting being conducted in January 2019. This was further worsened by the destruction of the initial short season variety by birds which led to replanting of a long season variety that was immediately available. As such parameters such as grain yield, kernel size and kernel damage could not be used. The crop was harvested at soft dough stage and fresh cob weight as well as percentage cobs affected were used instead.

4.3 RESULTS.

4.3.1 Leaf damage score.

The experiment was left to naturally infest with FAW larva and the first leaf damage score (baseline) was recorded just before the first application of the pesticides at 7 WAP. Subsequent leaf damage scoring was conducted on three occasions and the result are shown on table 3.

Initial results at 7 WAP show that negative control had the highest mean leaf damage score of 5.33, whilst *Dichapetalum + Tephrosia* was the least with a mean score of 2.33. However, the mean leaf damage scores across all the treatments at inception were not significantly different with a Pvalue of 0.381.

At 9 weeks after planting Deltamethrin and pirimiphos-methyl treatment had the lowest mean score of 1.67 and the negative treatment had the highest mean score of 8. As shown on table 3 only ecoterex treatment was significantly different. Botanical pesticides and the negative control treatment were not significantly different. This trend continued on 11 WAP where Deltamethrin and pirimiphos-methyl treatment had the least mean leaf damage score of 1.67 and the negative control had the highest of 7. The botanicals were not statistically different but this time around *Tephrosia* treatment showed differences with the negative control.

The final leaf damage score had *Tephrosia* and ecoterex with the lowest mean leaf damage score of 2.67 whilst the highest of 6.67 was recorded for the negative control. *Dichapetalum* and *Tephrosia + Dichapetalum* mixture significantly different from the negative control.

Table 3: Leaf damage score results of treatments.

Treatment	First leaf damage score (7 WAP)	Second leaf damage score (9 WAP)	Third leaf damage score (11 WAP)	Fourth leaf damage score (13 WAP)
Tephrosia	3.33	7.33^{b}	4.33^{b}	2.67^{a}
Dichapetalum	4.33	7.33^{b}	5.67^{bc}	5.00^{b}
Ecoterex	4.33	1.67^{a}	1.67^{a}	2.67^{a}
Tephrosia + *Dichapetalum*	2.33	6.67^{b}	5.67^{bc}	5.33^{b}
Negative control	5.33	8.00^{b}	7.00^{c}	6.67^{c}
LSD	3.394	1.375	1.945	1.479
P value	0.381	<0.001	<0.001	<0.001

There is no statistical significance among the figures with the same superscript.

4.3.2 Percentage plants showing leaf damage.

Percentage plants showing leaf damage was arrived at by counting the number of plants with leaf damage out of the net plot population and expressing those as a percentage. This parameter was recorded at 7, 9 and 11 weeks after planting and results are shown on table 4.

The initial results show that the negative control had the lowest number of affected plants per net plot with a mean score of 61%, followed by *Tephrosia +Dichapetalum* treatment 81.7%. The highest mean percentage plants showing leaf damage was recorded 87.7% for Ecoterex treatment. However, there were no significant differences amongst the treatment.

At 9 WAP, there were highly significant differences with ecoterex treatment having the lower mean percentage plants with leaf damage at 21.3% and all other treatments at 100 %. The trend was also observed at 11 WAP where again the other treatment still had 100% plants showing

leaf damage which was significantly different from the least mean of 31.57% for ecoterex treatment.

Table 4: Percentage plants showing leaf damage.

Treatment	Percentage of plants showing leaf damage (7 WAP)	Percentage of plants showing leaf damage (9 WAP)	Percentage of plants showing leaf damage (11 WAP)
Tephrosia	83.7	100[b]	100[b]
Dichapetalum	84.0	100[b]	100[b]
Ecoterex	87.7	21.3[a]	31.57[a]
Tephrosia+ Dichapetalum	81.7	100[b]	100[b]
No control	61.0	100[b]	100[b]
Lsd	30.09	10.83	4.955
Pvalue	0.340	<0.001	<0.001

Values with the same superscript are not significantly different.

4.3.3 Plant height

Plant height was measured on three random plant positions in the net plot from the ground level to the flag leaf after tasselling. The results of plant height were highly significant and are shown on table 5. Negative control had the least mean height of 1.153m whilst the tallest of 1.677m was recorded for ecoterex treatment. Botanicals were significantly taller than the negative control whilst the ecoterex treatment was also significantly taller than all the other treatments.

4.3.4 Percentage barren stalks.

The results of analysis of percentage barren stalks were significant and are shown on table 5. Grand mean percentage barren stalks for the whole experiment was 33.47.

Deltamethrin and pirimiphos-methyl treatment (positive control) had the least mean percentage barren stalks of 3.70% while the highest of 50% was recorded for the negative control. However, only ecoterex treatment was significantly different from other treatments.

4.3.5 Fresh cob weight.

Since the experiment was established late and a long season variety was used, the crop was at soft dough stage by the time the crop was harvested. Instead of the grain weight, the grand fresh cob weight of the plants in the net plot was taken to represent the various treatments. The results of the fresh cob weights are shown on table 5 below. It can be observed that the positive control had the highest fresh cob weight of 3.80kg and the negative treatment had the lowest of 1.69kg. There were no significant differences between the positive control (ecoterex) and *Dichapetalum* treatment. In the same manner *Tephrosia* and *Tephrosia + Dichapetalum* were not significantly different from the negative control.

4.3.6 Percentage of cobs showing damage

Cobs showing damage were counted and expressed as a percentage of the net plot population. The mean percentage cobs showing damage varied from 13.9% to 65.5% as shown on table 5. The results show that ecoterex treatment had the least mean number of affected cobs which stood at 13.9%, and the negative control was 65.5%. As has been the trend in most instances ecoterex treatment was significantly different from the other treatments except *Tephrosia + Dichapetalum* treatment. However, *Tephrosia + Dichapetalum* was not significantly different from *Tephrosia* treatment and *Dichapetalum* treatment. Negative control had the highest number of affected cobs and was significantly different from all other treatments.

4.3.7 Plant population.

Analysis of plant population was performed in order to explain the differences in total net plot fresh cob weights. The plant population across the treatments varied from 15 (ecoterex treatment) to 17.33 for the negative treatment. However, there were no statistical differences with a Pvalue = 0.608 as shown on table 5.

Table 5: Results for mean plant height, percentage barren stalks, fresh cob weight, percentage maize cobs showing damage and plant population of the treatments.

Treatment	Mean plant height (m)	Mean percentage barren plants	Mean fresh cob weight.	Percentage cobs showing damage	Mean plant population.
Tephrosia	1.287[b]	40.51[b]	2.11[ab]	32.2[b]	16.67
Dichapetalum	1.287[b]	32.86[b]	2.91[bc]	44.6[b]	17.00
Ecoterex	1.677[c]	3.70[a]	3.80[c]	13.9[a]	15.00
Tephrosia+ Dichapetalum	1.352[b]	40.31[b]	2.36[ab]	29.7[ab]	16.67
No control	1.153[a]	50.00[b]	1.69[a]	65.5[c]	17.33
LSD	0.1208	20.288	1.60	17.4	3.489
Pvalue	<.001	0.006	0.013	0.001	0.608

There are no statistically significant differences among the treatments with the same superscript.

4.3.8 Dead hearts and Plants which failed to tassel

A plant displaying a dead meristem was described as a dead heart. The crops were assessed for dead hearts during the vegetative stage and no dead hearts were observed in all the treatments. The plants were also assessed for tassel emergence failure two weeks after tasselling. All the plants observed displayed tassels and therefore there were nil records for failure to tassel.

4.4 DISCUSSION OF RESULTS

Initial leaf damage score was recorded before the application of pesticides. These results showed that there were no significant differences among the treatments at the time. However, from 11 WAP improvements in botanicals were noted with the last recording statistically different from the negative control. It must be noted that ecoterex treatment was consistent and superior except in week 13 where there was no statistical difference between *Tephrosia* and ecoterex. Alao et al., 2011, working on thrips in cowpeas made similar observations whereby

botanicals induced some control but were however found to be slow acting. This also agrees with Mkenda et al., 2015, where BIs under study (*T. vogelii, D. ambrosioides, L. javanica, T. diversifolia and V. amygdalina*) were not as effective as Actellic dust in controlling bruchids (cowpea storage pest) as they required relatively more time to induce mortality. Cespedes et al., (2005) on experiments with Meliaceae discovered that larval mortality occurred seven days after treatment and the active ingridients also functioned as insect growth regulators (IGR). Alao & Adebayo, 2011 in an experiment of *Vigna unguiculata* field pests control T vogelii, P alliaceae and Decis (synthetic pesicide) made two observations. The first that the pesticides had lower control levels as compared to the synthetic petsicide could be attributed to environmental stability of the synthetic pesticide. When exposed to elements under field conditions, the botanicals may undergo rapid degradation rendering them less effective. Both *Dichapetalum spp* and *Tephrosia spp* degrade rapidly upon exposure to light, rain and microbes (Agbon et al, 2004, Weaver, 2003 & Aritho et al., 2017).

Generally, first and second instar neonates of fall armyworm are found in high concentration but inflict less damage (window pane appearance) on the crop. However, later larval stages are cannibalistic and are found in low numbers per plant, but inflict heavier damage (Ayala et al.,2013). Generally, where control is fast acting crops with neonate damage tend to repair the injury, whereas older instar damage may not heal completely. This agrees with Buntin, 1986 who indicated that plants can tolerate significant leaf defoliation when affected early as affected material can recover. This is further evidenced by the number of affected plants per net plot that did not fully recover for botanicals and the negative control. This may suggest that there was a long-sustained attack on the plants by the pest as a result of slow control action. The differences in damaged cobs then suggest that the botanical pesticides had some effect.

Gadzirayi, et al, 2009, findings were that *T. vogelii* was as effective as Triatix (synthetic acaricide) at higher rates (50g/ 150 – 200ml water) in the conrol of ticks in dairy cattle. In this experiment, the both *T. vogelii* and *D. cymosum* were not as effective as ecoterex. The other workers have suggested that the chemical constitution of the botanicals depended on time of use, location and subspecies invloved. *D. cymosum* is said to be most poisonous during the spring time (Eason et al., 2011). The late onset of 2018/19 rain season resulted in late shoot development and consequent harvesting of the leaves in early December. Concentration of rotenoids in the leaves of *Tephrosia* were said to be at their highest in January (Belmain et al, 2012). Belmain et al, 2012, also highlighted that there are two chemotypes of *T. vogelii*. Chemotype 1 with rotenoids while Chemotype 2 was defined by absence of rotenone.

Chemotype 1 was found to be more effective in bruchids than 2. However, Chemotype 2 while less effective performed better than no control treatment. Aritho et al., 2017, also highlited that genetic introgression over time as a result of persistent backcrossing of individuals within mating distance could result in a shift on coding and expression. It is thus possible to find variations in chemical composition and pesticidal constitution within the same species being affected by location. The above may have played a role in lower efficacy of the two botanicals under study.

Reports of pesticide resistance to carbamates, organophosphates and pyrethroids have been recorded in its native Americas which was the source (Carvalho, et al., 2013). Yu et al., 2003 revealed that fall armyworm is a highly versatile pest that has multiple resistance mechanisms including detoxification, rapid excretion and target site alterations among others. Both botanicals work as respiratory inhibitors and it may be possible that the pest could have been exposed to similar chemicals and was thus able to tolerate the botanicals under study hence the delay in effect.

The observation by other authors was that effectiveness of these botanical pesticides depended on concentration. Tephrosia was found to be effective at 20% concentration, meaning there is a requirement for more pesticidal material to register effectiveness. This is in agreement with findings by Alao & Adebayo., 2015 who found out that the control of watermelon (*Citrullus lanatus* T.) pests by *T. vogelii* and *Moringa oleifera* ranged from 45 – 65% depending on concentration. However,in many instances the effectiveness of these BIs was achieved at high concentration but overally performed significantly better than the negative controls. In this experiment the botanicals were used as dust at one level. The effect of increase in concentration could thus not be explored. The fact that the botanicals were not as effective as the synthetic pesticide ecoeterex, may be as a result of the concentration which could have been too low to register effective control.

The 2018/19 season was a drought year, which delayed onset and also experienced mid season drought. Supplementary irrigation had to be employed during the season. The pesticides were applied as dust on the whorl of the maize plants. Both botanicals are stomach poisons which must be ingested (Guleria & Tiku, 2009 and Goncharov et al., 2006) . They would require a carrier to take the pesticide to the target site for larval feeding. In this regard, the drought period extending during the vegetative stage could have affected the efficacy of the pesticide, possible except for the two instances where sprinler irrigation was used.

Poveda et al., 2003 and Prasifka et al., 2012 discovered that herbivory resulted in reduced plant height and at times biomass. Plant height was measured at 100% tasselling from the ground to the flag leaf. The negative control had the least height which was significantly different from all other treatments. It can aslo be observed that the positive control also had the tallest plants and was significantly different from the other treatments. Brooks et al, 2005 and Goergen et al., 2016, highlighted that leaf feeding and stem tunnelling constituted indirect damage which disturbs photosynthesis and transport system. **S**tem damage reduces the movement of photosynthates and nutrients while leaf damage reduces photosynthetic capacity of the plants. Under such circumstances stressed plants also remobilise photosynthates to repair damaged tissue material. Ayala et al.,2013 also pointed out that such attack on the meristematic tissue may result in complete stoppage or slowed growth rates. As such plants under serious attack are likely to be shorter.

The yields of Deltamethrin and pirimiphos-methyl and *Dichapetalum* treatments were the highest and were not statistically different. It can be observed that the negative control which recorded the least yield had the shortest plants and highest barren stalks. Prasifka et al., 2012 discovered that corn borers reduced biomass of grasses. It follows, therefore that dry matter partitioning would result in higher yield for the treatments with more biomass. However, Buntin, 1986 and Poveda et al., 2003, concluded that if leaf damage occurred in the vegetative stage plants may compensate for the damage. While this may explain statistically similar yields obtained from other treatments with different leaf damage, it does fall short in explaining a significantly lower yield for the negative control. This may be explained by Cruz & Turnip, 1983 who indicated that the yield loss as a result of pest herbivory was directly related to yield forming apparatus like kernel number and others. As can be observed the negative control had the highest number of barren stalks, this could have been the reason for its significantly lower yield.

Grain yield could not be obtained as the crop was harvested at milk dough stage, but would naturally depend on physiological, environmental and pest damage factors (Alao et al., 2011). The actual yield from maize takes consideration of the actual weight of clean wholesome grain. The negative control had the highest mean percentage (65.5%) of affected cobs which was significantly different from the other treatments. This translates to significant yield loss as the spoiled kernels would have to removed and discarded. Cob or kernel damage constitutes direct damage by the larva and reduces actual yield because the spoiled grain has to be removed. In

this regard while the fresh cob weight was statistically similar for the negative control and the botanicals, differences in spoiled cobs would have resulted in less yield for negative control had the crop reached harvesting maturity.

The mixture of the two botanicals (*T. vogelii* and *D. cymosum*) may suggest synergistic effect on percentage cobs showing damage which was similar to ecoterex. However, this is not evident on other measured parameters but the resultant increase in unspoiled grain and possibly yield may point to a benefit of mixing the two.

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CHAPTER 5

RESULTS AND DISCUSION OF RESULTS

(Field Evaluation of *Tephrosia Vogelii* And *Dichapetalum Cymosum* Crude Botanical Extracts in The Control of Fall armyworm (*Spodoptera frugiperda*) in Zimbabwe).

Abstract

Fall armyworm (*Spodoptera frugiperda* J. E Smith) which recently invaded Africa is a pest of more than 80 plant species, but is causing serious maize production challenges in the region as it prefers the crop. The first sign of fall armyworm invasion is leaf damage which manifests as short holes or ragged leaves. Most often farmers' pest management decisions are based on visible leaf damage. Previous studies have produced contrary results on yield loss as a result of fall armyworm damage on a range from 11.57% (Baudron et al 2019), 58 % (Chimweta et al 2019) and complete write off (Day et al 2017). The objective of this study was to evaluate the host – pest complex paying particular emphasis on damage indices (percentage plants affected by FAW, leaf damage scores and percentage barren stalks) and yield. The regression analysis indicated a negative relationship between damage indices (leaf damage score, percentage plants affected and percentage barren stalks) and yield. While the regression model explained the general relationship (P= 0.003), analysis of individual predictors indicated that only barren stalks was significant (P = 0.03). This may mean that using leaf damage to predict yield loss may be misleading and cause overestimation.

Key words

Spodoptera frugiperda pest management regression model leaf damage score barren stalks**.**

5.1 Introduction.

Maize is among the three important crops that are produced in the world (Salem & El-Gizawy, 2012). Maize is particularly important in the developing world where it is mostly produced by small scale farmers as a staple food crop (Chikobvu et al, 2010). A number of abiotic and biotic factors affect maize production but fall armyworm (*Spodoptera frugiperda*) which recently invaded Africa from the Americas is causing serious production and economic losses to the extent of threatening food security within the region (Day et al 2017). The impact of this alien pest in a new environment devoid of natural enemies can be devastating (Toepfer et al 2019). Information on FAW behaviour and its impact in the new environment may be scarce, but governments and individual farmers are embarking on seemingly unsustainable control strategies premised on synthetic pesticides.

The most noticeable damage of fall armyworm attack on maize are shot holes or skeletonised leaves during the vegetative stage (Kumela et al 2018). The implication of leaf damage, number or proportion of attacked plants and other damage indicators in this new environment is not clear. However, farmers start implementing control strategies as soon as they observe leaf damage on the plants. Various writers have proffered conflicting impacts of fall armyworm damage on yield. Kumela et al 2018 indicates that yield losses from FAW can range from 32 – 47% while Hruska & Gould in CABI 2018, indicates put losses at 73% at 100% infestation. At the same time, Burtet et al 2017, indicates that control must start when 20% of the crop show damage. While there is a negative linear relationship between damage parameters and yield, the real relationship between these may not be that straight forward. Baudron et al 2019, working in Eastern Zimbabwe found out that the impact of FAW on maize yield may be as lower as 11.57% and highlights that the previous figures may actually be overestimation of the impact of the pest. Yield loss estimates based on damage scores and percentage infestation may be real cause of that estimation.

5.2 Materials and Methods

The trial was established during the 2018/19 summer season. The experiment occupied 202.5m^2 and consisted of fifteen plots measuring 13.5m^2 each. Each plot composed of 3 rows spaced at 0.9m and 5m long. The net plot was the middle row minus one metre on both ends measuring 2.7m^2. *T. vogelii* and *D. cymosum* leaves were collected from the field and dried in a shed. The dried leaves were then stored in the shed and pounded to dust using a mortar and pestle. The dust from the two botanicals was applied at a rate of 148kg/ ha (200g/plot) whilst

ecoterex was applied at the recommended rate of 8kg/ha.

5.2.1 Description of study area.

The trial was carried out at Chikurubi Farm which is 25 km due east of Harare. The farm is geographically positioned at $17^0$47'32S and $31^0$11'19E and at an altitude of 1150 metres above sea level. The farm is in agro-ecological region IIa which normally receives over 750mm of rainfall during the summer season.

5.2.2 Research Design

The experiment was carried out as a completely randomised block design with five treatments and replicated three times. *T. vogelii, D. cymosum, T. vogelii + D. cymosum*, positive control (ecoterex) and a negative control were used as the treatments as explained in section 3.3.

5.2.3 Sampling procedure.

The gross plot had a total of 13.5m^2 of which the net plot had the middle row minus one metre on both ends. As such the net plot was 2.7m^2 and this is the area that was used for all the samples. All the plants within the net plot were sampled for leaf damage score rating, percentage plants affected, percentage barren stalks, and total fresh cob weight.

5.2.4 Data collection procedure

Various data collection procedures were undertaken for each variable. Leaf damage score used a key from which ranged from 0 to 9 (CIMMYT, 1989). Score 0 was assigned to plants with no visible leaf damage whilst 9 for plants with a dead heart and almost completely defoliated as shown in table 2. The percentage plants with leaf damage was achieved by counting all the plants showing leaf damage and expressing the figure as a percentage of the total population in the net plot. Percentage barren stalks also considered the total number of plants devoid of ears at R2 crop stage and expressing the figure as percentage of the total population in the net plot. All the plants within the net plot were harvested at soft dough stage and the total weight of fresh dehusked cobs recorded.

5.2.5 Data analysis procedure.

Refer to section 3.9

5.2.6 Challenges encountered during data collection

Since the experiment was conducted in the open field, initial plans to artificially infest the plots with live larvae were dropped due to ethical concerns. As such direct measurements on actual mortality of fall armyworm larva were not conducted as this was not standardised from the onset. Indirect measurements such as leaf damage scores and cobs damaged and percentage plants infested were used instead.

The late onset and inconsistent rains characterising the 2018/19 summer season, resulted in the initial planting being conducted in January 2019. This was further worsened by the destruction of the initial short season variety by birds which led to replanting of a long season variety that was immediately available. As such parameters such as grain yield, kernel size and kernel damage could not be used. The crop was harvested at soft dough stage and fresh cob weight as well as percentage cobs affected were used instead.

5.3 Results.

5.3.1 Relationship between damage indices and fresh cob weight.

A regression analysis was done to establish the relationship between the damage indices (leaf damage score, percentage plants with leaf damage and barren stalks) and fresh cob weight. Table 10 below show the relationship

Table 6: Regression relationship between damage indices and fresh cob weight (yield).

Parameter	Estimate	P value
Constant	4.169	<.001
%plants with leaf damage	-0.00333	0.706
Barren stalks	-0.0311	0.030
Leaf damage score	-0.0604	0.543

The ANOVA table refer to appendix 11, is significant (P=0.03). The equation that can best explain the relationship is shown below;

Fresh cob weight (Y) = -0.00333 Percentage plants with leaf damage (X_1) + -0.0311 Barren stalks (X_2) + -0.0604 (X_3) Leaf damage score + 4.169.

Mathematically the model can be written as follows;

$Y = -0.00333X_1 + -0.0311X_2 + -0.0604\ X_3 + 4.169.$

The relationship model indicates that when there are zero damage indices obtainable yield per plot could have been 4.169kg. However, if proportion of affected plants increase by 1 unit, the resultant yield decline would be by 0.00333kg. In the same manner, an increase by 1 unit of barren stalks would effectively reduce obtainable fresh cob weight by 0.0311kg while leaf damage would reduce by 0.0604kg. The relationship, therefore is an inverse one in that the increase of damage indices would cause a general decline in obtainable fresh cob weight.

While the model is significant, it can be seen from table 10 above that only the constant ($p<.001$) and percentage barren stalks ($p=0.03$) predictors are significant. As such the model describes only significant predictors and cannot be relied upon on percentage plants showing leaf damage and leaf damage score.

5.4 DISCUSSION OF RESULTS

The first signs of FAW damage is usually windowed leaves and/ or tattered leaf margins depending on the stage of the larvae. Most farmers usually panic because they associate leaf damage with direct yield losses. The relationship between percentage infestation, barren stalks and leaf damage score in this experiment was negative and significant. Cruz & Turnip, 1983, indicated that an inverse relation exists but yield loss was directly related to yield forming apparatus than other damage indices. In this experiment however, individual analysis of the predictors from the multiple linear regression indicated that only barren stalks was significant ($p=0.03$), while other variables were not significant. This may be attributable to a direct relationship that exist between the actual number of cobs and yield. Other indirect measurements may not accurately predict yield loss due to the fact that the crop susceptibility normally depends on growth stage. This agrees with Burtet et al., 2017 who observed that plots with different damage scores were able to produced similar yields upon crop maturity. Baudron et al, 2019, made similar observations and concluded that some varieties that exhibited higher damage scores were also found to yield significantly higher. They also discovered that yield

loss was more pronounced in later crop stages as the earlier vegetative stage were able to recover. Therefore, damage indices while showing a negative relationship may not be used to precisely predict yield. This was also further supported by Odiyi 2007, who discovered that dead hearts and stem tunnelling had a negative and strong correlation with grain yield than leaf damage due to the fact that plants tended to compensate. Compensation may be achieved at the individual level through replacement of damaged parts or increase in biochemical reactions by the plant to support yield forming apparatus. It may also occur at the plant community level where other plants utilise resources that remain unused by affected plants and therefore produce more.

The other treatments had variations in other indices but did not differ much on the fresh cob weight. This may suggest to some elasticity in tolerance to damage by plants without suffering proportionate yield loss. Peterson and Highley (eds) 2000, highlighted that crops vary in their response to insect attacks and this depended on crop phenology, plant part injured and environmental factors. This is common during the vegetative stage which are less susceptible than early seedling and early reproductive stages. Soper et al., 2003, working with sorghum crop discovered that the more vulnerable stage to fall armyworm was the soft dough stage. The third to sixth larval stages were found to feed for more time and comparatively gain more weight on soft dough stage than other stages (Soper et al., 2003). Appel et al 1993, indicated that direct feeding resulted in less kernels, misshapen ears and secondary fungal infection which directly reduced yield. Fornoni, 2011, highlights that this plasticity in response is highly dependent on resource availability. In which case the response in variable environments would reveal host-pest behaviour and therefore guide pest status forecasts and control activities. It can be observed that infested plants for other treatments was 100% except for ecoterex. However, *Dichapetalum* and ecoterex were able to produce results which were not statistically different.

Direct damage on yield forming organs results in direct yield reduction than damage on other non- yield forming organs (Peterson and Highley (eds) 2000). Strauss and Murch (2004) and Poveda et al., 2003 indicated that yield reduction could also be as a result of reduced visitations by pollinators due to reduced flower size and attractiveness. In their experiments, they discovered that damaged crops were able to produce significantly similar results to the health one by enhancing pollination. In this current experiment there were nil records of dead hearts or failure to tassel meaning pollination may not have been significantly disturbed. The relationship between damage score, percentage plants affected and barren stalks and yield was

inverse however, only barren stalks was statistically significance while other predictors were not.

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CHAPTER 6
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Fall armyworm invaded Africa in 2016 and has spread to many countries within the continent in a short space of time (Goergen et al., 2016 & FAO 2017). The pest affects various crops but prefers staple maize where it persists throughout the year under favourable conditions. FAW is also transboundary in nature and spreads quickly in a short space of time (Carvalho, et al., 2013 and Yu & Nguyeni., 2003). Faced with such circumstances the governments and farmers have panicked and instituted emergency control measures premised mainly on synthetic pesticides. However, it is known that the pest has developed resistance to some synthetic pesticides and Bt proteins from GMO varieties (Huang et al, 2014; Yu & Nguyeni., 2003) . It seems there is general lack of evidence of pesticide resistance in Africa, but some farmers have complained about low efficacy to some registered chemicals (Kumela et al, 2018). It is imperative therefore that some integrated pest management strategies be developed as fast as possible in order to deal with the FAW problem (Prasanna et al., 2018). One of these ecologically based methods is the use of botanical pesticides.

It is important to note that there is a general lack of information on the real effect of FAW in its new environment. Some authors have indicated losses from fall armyworm can range from 30% - 100% under heavy infestations (Ramos-López et al., 2010 & Day et al., 2017). The monetary value of the estimated losses in SSA as a result of FAW is estimated to reach US$ 6 187 million which is quite considerable under the circumstances (Day et al., 2017). However, Baudron et al 2019, indicates that this could be an over- estimation as the yield losses that they obtained in their experiments in Eastern Zimbabwe has just been 11.57%. This calls for the study of relationships existing on the pest attributed (damage indices and yield loss). Such information obtained over geographic locations and season may then be used to show prediction models and the real impact of the pests as well as implementing economic and sustainable control efforts.

6.2 Research Summary

The field experiment was established to evaluate the efficacy *Tephrosia vogelii, Dichapetalum cymosum* and their cocktail (*Tephrosia vogelii + Dichapetalum cymosum*)

mixed 1:1 w/w) against ecoterex 0.5 GR (deltamethrin and pirimiphos- methyl) as a positive control and a negative control. The performance of the synthetic pesticide was significantly better than the botanicals as it was fast acting and consistent across the recording period. The results of plant height, percentage plants with leaf damage and leaf damage scores were significantly. While there were no significant differences between the negative control and botanicals on percentage plants with leaf damage score, significance differences between the two were however, recorded on leaf damage scoring, plant height, and percentage cobs affected. On these parameters the botanicals performed much better that the negative control. The negative control had the least fresh cob weight but it was not significantly different to *Tephrosia* and *Tephrosia + Dichapetalum* treatments.

The general regression analysis model of percentage plants showing leaf damage, leaf damage score and percentage barren stalks and fresh cob weight was inverse and significant ($P< 0.001$). However, analysis of individual predictors revealed than only barren stalks was significant ($P=0.030$), while leaf damage score was 0.543 and percentage plants affected was 0.706.

6.3 Conclusions

Botanical pesticides were not as effective and consistent as ecoterex in the control of FAW in this experiment. However, their performance on parameters including plant height, leaf damage score, percentage cobs affected and fresh cob weight were significantly better that the negative control suggesting they have some effect on FAW.

The experiment also established that damage indices such as percentage plants affected and leaf damage scores were not significant predictors (strongly correlated) and hence could not be relied upon to explain regression relationship. As such these may not be used to accurately predict yield loss as a result of FAW.

Synthetic pesticide was fast acting, consistent and produced superior results on leaf damage scores, plants with leaf damage, plant height and barren stalks barren stalks. *Tephrosia* treatment produced similar results as the ecoterex on maize leaf damage scores at 13 WAP.
On the same note *Dichapetalum* had similar results with ecoterex on fresh cob weight while the cocktail (*Dichapetalum* and *Tephrosia*) had similar results to synthetic pesticide on cob damage.

As such in circumstances such as organic production systems and where resources are limiting the botanicals may be used for FAW control. It is also critical to come up with efficient predictors, that can then correctly inform farmers to institute control measures should FAW invade maize crop.

6.4 Policy implications and recommendations.

Attributes such as long dispersal ability, wide host range, continuous breeding and enhanced mechanisms to develop resistance to pesticides has made Fall armyworm a pest of global importance. In Africa, FAW is expected to establish permanent populations in conducive areas and will cause sporadic long-range outbreaks in other areas. Its transboundary nature has implications on regional pest management strategies. *S. frugiperda* has host preference on staple food crops (maize, sorghum and millet) and as such its presence is expected to compromise food security. Sustainable FAW management hinges upon integrated pest management strategies and uniqueness of options employed by individual countries. Botanical plant resource endowments are usually unique to specific geographical locations and might therefore offer an opportunity to control the pest differently.

Though not performing as the synthetic pesticide (ecoterex), the botanicals under study have outperformed the negative control on some recorded parameters suggesting that their use by resource poor farmers who cannot afford the synthetic chemicals or in IPM may be promoted. This work can be validated through farmer field schools which may be critical in developing knowledge and creating awareness on *S. frugiperda*. Pesticidal gardens concepts in the model of nutritional community gardens can then be used to preserve and regenerate the pesticidal plants so that their availability is sustained.

In the same manner, sustainable and scientific based FAW control programmes which take account of costs, pest or injury threshold and economic rather than the control upon sight that many farmers seem to be embarking on may be important. Such information can only be revealed by studying interacting parameters of the host and the pest.

6.5 Areas of further research

Dichapetalum cymosum and *Tephrosia vogelii* are plants with known pesticidal and medicinal properties. The botanicals and their cocktail did not perform to the level of the positive

control in this experiment. They however, performed much better than the negative control. Further studies may be required to establish the most efficient way of extracting the pesticidal compounds from the plants (active ingredient). It is also imperative to establish the formulation which is effective in controlling the fall armyworm and safer to the user. Lastly dose response information is critical as it will inform application rates that are effective against the pest while having minimal effects on other beneficial insects (parastoids and natural enemies).

Further works to establish the pest and/or injury thresholds that will economically guide pest management decision is also required. In this work it was evident that indirect damage parameters like percentage plants exhibiting damage and leaf damage scores were not reliable predictors. It may be important to continue experiments and observe stability of these observations over seasons and locations, while also including other parameters such as larval counts.

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APPENDICES

1. Analysis of variance for Leaf Damage score at 7 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
block stratum	2	13.333	6.667	2.05	
block. *Units* stratum	4	15.600	3.900	1.20	0.381
treatment					
Residual	8	26.000	3.250		
Total	14	54.933			

2. Analysis of Variance for Leaf Damage score at 9 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	0.4000	0.2000	0.37	
block.*Units* stratum treatment	4	79.7333	19.9333	37.38	<.001
Residual	8	4.2667	0.5333		
Total	14	84.4000			

3. Analysis of Variance for leaf damage score at 13 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	1.733	0.8667	1.41	
block.*Units* stratum	4	37.0667	9.2667	15.03	<.001
treatment					
Residual	8	4.9333	0.6167		
Total	14	43.7333			

4. Analysis of Variance for Percentage Plants with Leaf Damage at 7 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	1518.4	759.2	2.97	
	4	1353.6	338.4		
block.*Units* stratum					
treatment					
Residual	8	2043.6	255.4	1.32	0.340
Total	14	4915.6			

5. Analysis of Variance for Percentage Plants with Leaf Damage at 13 WAP.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	13.851	6.925	1.00	
block.*Units* stratum	4	11239.822	2809.956	405.75	<.001
treatment					
Residual	8	55.403	6.925		
Total	14	11309.076			

6. Analysis of Variance for Plant Height.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	0.046704	0.023352	5.67	
block.*Units* stratum	4	0.460230	0.115057	27.96	<.001
treatment					
Residual	8	0.032926	0.004116		
Total	14	0.539859			

7. Analysis of Variance for Barren Stalks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	483.6	241.8	2.08	
block.*Units* stratum	4	3767.8	941.9	8.11	<.006
treatment					
Residual	8	928.8	116.1		
Total	14	5180.1			

8. Analysis of Variance for Plant Population

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	6.533	3.267	0.95	
block.*Units* stratum	4	9.733	2.433	0.71	0.608
treatment					
Residual	8	27.467	3.433		
Total	14	43.733			

9. Analysis of Variance for Fresh Cob weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	0.1349	0.0675	0.21	
block.*Units* stratum	4	8.0431	2.0108	6.34	0.013
treatment					
Residual	8	2.5360	0.3170		
Total	14	10.7140			

10. Analysis of Variance for Percentage Cobs with Damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
block stratum	2	207.90	103.95	1.25	
block.*Units* stratum	4	4440.23	1110.06	13.39	0.001
treatment					
Residual	8	663.03	82.88		
Total	14	5311.16			

11. Regression ANOVA

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr
Regression	3	7.612	2.5372	900	0.003
Residual	11	3.102	0.2820	13.39	
Total	14	10.714	0.7653		