Split-split plot design analysis, in exploring the efficacy of plants as natural measures, (biocides) of maize stem borer control.

By

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Declaration by Student

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Abstract

In this paper, comparison between the use of botanical methods of pest control and dipterex 25% grounded in controlling maize stem borer was done. An experiment was carried out at Midlands State University main campus during the rainy season of 2015-2016. A split-split plot design was used with two nitrogen levels as whole plot factor (0kg/ha and 100kg/ha), two varieties of maize as subplot factor (SC627 SeedCo and Pioneer 30G95) and six treatments of maize stem borer control methods as sub-subplot factor (lantana camara leaves extract, lantana camara flowers extract, euphorbia flesh extract, euphorbia fruit extract, dipterex 25% granular, and a control with nothing applied). Model assumptions diagnostic checking was performed and all the assumptions were satisfied. Analysis was done using Genstat version 14 and the results showed that all the biocides perform better with lantana leaves being the most effective. Interactional effect of nitrogen (100kg/ha), maize variety (Pioneer 30G95) and lantana leaves was an effective combination that includes botanical methods of pest control.

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Tables of Contents

List of Appendices

List of Tables

List of Figures

Chapter 1 Introduction

Overview

The purpose of this chapter is to define the problem of the study. The background to the study will be presented, so as to lay the foundation on which this study is based. An outline of aim, objectives, justification, limitations, and the scope of the study will be provided with a statement of the problem being formulated. Key words are identified and defined in subsequent sections of the chapter.

1.1 Background of study

The availability of Maize is an important indicator of the food security in Zimbabwe. Maize constitutes about 50% of all the food consumed and its demand is increasing (Byerlee and Eicher, 1997). Despite being a staple food, Zimbabwe's agriculture sector has been going through a heavy decline in the maize productivity over the past years (Food and Agriculture Organisation (FAO), 2015). This can be attributed to a multifarious of factors such as biotic limitations, drought, agricultural practices and floods. Of these factors, biotic limitations and agricultural practices are some of the factors that can be controlled.

One of the main biotic limitation in the maize production is the maize stem borer (James, 2003). The maize stem borer can cause devastating damages on maize resulting in low yields. In Zimbabwe there are three types of maize stem borers namely Busseola Fusca Fuller (Lepidoptera: Noctuidae), Chillo Partellus (Swinhoe) (Lepidoptera: Crambidea-Pyralidae) and Sesamia calamistis Hampson (Lepidoptera: Noctuidae) (Chinwada and Overholt, 2001). The lepidopteran species attack plants in a unique way whose discussion ensues:

- Eggs are laid on the maize leaves,
- In young maize plants, the larvae enter and feed on the tender leaves causing leaf damages,
- In mature plants, the larvae penetrates into the stem and start tunnelling which may result in dead hearts of the plant.

The resultant effects on affected plants are poor and stunted growth, low yield and are more prone to wind logging and secondary infections (Pathak and Othien, 1992). The loss caused by stem borers to maize plants has been estimated to be high when no chemical treatment is applied, but such a loss varies with the intensity of infestation.

To alleviate these problems, several control options are being used in Zimbabwe these include, chemical, biological, cultural, and host plant resistance (use of different seed varieties). Cultural methods of controlling maize Stem borer relies on planting maize at the start of rains. The use of chemical treatment at the appropriate time reduces the loss by about 20% (Pathak and Othien, 1992). There are several chemical pesticides which are registered for stem borer control which include dipterex, carbofuron 3G, profenofos, abanectin and fipronil 4G.

In Zimbabwe, large scale farmers, use chemical pesticides either as granules or spray applications for stem borer control owing to their effectiveness and relatively ease of application (Getu et al, 2002). However, smallholders and communal farmers rarely use chemical pesticides to control maize Stem borer. According to, Chinwada and Overholt, (2001), most smallholders and communal farmers do not control the maize Stem borer. This can be attributed to a myriad of factors such as the prohibitive prices of chemical pesticides and ignorance. Chemical pesticides are not only exorbitantly expensive, but are also threats to the environment (Kogan, 1998). They can also be abused as human poisons for example dimethoate (rogor) or misused as they can be over-or under- applied thus leading to pest and disease resistance to particular chemicals.

However, plants as biocides can be used instead of chemical pesticides or a combination of the two by farmers in maize Stem borer management, owing to their inexpensive and reduced danger to the environment. According to, Salwa, (2010), the world's largest reservoir for farmers which can offer a cheaper alternative to artificially made pesticides are natural products. There are many plant materials such as leaves, flowers, roots, barks, fruits and other parts of the plant that can be used in Stem borer management. Plants that can be used for controlling maize Stem borer are lantana leaves, lantana flowers, euphorbia fruits, euphorbia flesh, cassava, lemon grass, thorn apple (*Datura stramonium*) to mention a few. The combined effort of biocides, cultural, agricultural practise and use of pesticides is more effective on maize Stem borer management than using only one method.

Efforts are being done by research institutions, academics, experts and farmers in determining the best Maize Stem Borer Management (MSBM). A number of approaches which include mathematical and statistical complemented by agricultural methods have been used in addressing this problem. Some involved a single factor while others involved multiple factors at both small and large scale. In this paper we explore the efficacy of biocides (lantana leaves, lantana flowers, and euphorbia flesh and euphorbia fruits) in comparison to one chemical pesticide (dipterex) based on the split-split-plot design (SSPD) analysis.

1.2 Statement of the Problem

Maize Stem borer is one of the insect pests in Zimbabwe that can result in total crop failure during epidemics and is reported to affect 43% of the yield (Chinwada and Overholt, 2001). To alleviate this problem, a number of chemical pesticides are being used. These chemicals may endanger the inhabitants and different species. Some of them reach underground water table and some are deposited in different sources of drinking water. Still on that, using chemical pesticides is not only a devastating toll to the environment and harmful to human life, but they are also exorbitantly expensive as compared to the use of biocides which are naturally available. However, though botanical pesticides are less harmful to species and the environment, their effectiveness in controlling maize stem borer in comparison of chemical pesticides is certainly unknown at the moment. Many studies had been done with or without the essence of randomisation being considered. In most cases, researchers miss specify the Design of Experiment (DoE), for example in the event when the possibility of randomisation is restricted (Webb, Lucas and Borkowski, 2004).

1.3 Aim of the study

This study aims to determine the efficacy of botanical methods of pest control in comparison to dipterex 25% grounded in controlling the maize stem borer on two varieties of maize.

1.4 Objectives of the study

The objectives are:

- To compare the degree of crop damage for each treatment.

- To determine the impact of maize stem borer damages on maize grain yield subject to botanical methods of pest control, dipterex 25% grounded and no control as pests management schemes.
- To model the relationship between maize grain yield, main effects and the interactions.

1.5 Scope of the study

This study targeted the two varieties of maize and was limited to the use of lantana leaves, lantana flowers, euphorbia flesh, euphorbia fruits (botanical pesticides) and only one chemical pesticide (dipterex 25%-grounded) as the pest management schemes. It focused on the impact of these pest management schemes on grain yield of the two varieties of maize (SC627 SeedCo and Pioneer 30G95) under two levels of nitrogen top dressing fertilizers to enhance soil fertility of two soil pH fields. The study's main thrust was to determine the efficacy of botanical pesticide over chemical pesticides as well as to establish the best Integrated Pest Management scheme based on the aforementioned factors. The split-split-plot design analysis was used in model building.

1.6 Justification

The concept of split-split plot design analysis is of the paramount importance in studying the effect of different methods in pest management and decision making in the field of agriculture. In split-split-plot design analysis the experimenter is interested in studying the effects of a three fixed factors and their interactions (Montgomery, 2013). This study endeavours to highlight a step by step approach in analysing data that was obtained using a split-split-plot design. It also contributes to the literature of maize Stem borer management. Experts, academics, researchers, agronomists and farmers can benefit from which other pest control measures they can use.

1.7 Assumptions

The following assumptions hold for this study:

- The degree of precision and importance of the factors pH (alkalinity and acidity) block factor, nitrogen (main plot factor), variety of maize (subplot factor) and pesticides (treatments) sub-subplot factors on grain yield of maize increases respectively.
- The effects of lantana flowers, lantana leaves, euphorbia fruits, euphorbia flesh and dipterex 25% grounded in controlling maize stem borer are independent.
- Soil pH and nitrogen are assumed as very-hard-to-change (VHTC) factor while maize varieties are hard-to-change (HTC) factors and pesticides are easy to change (ETC) factors.
- There are some interactional effects between the soil pH, nitrogen, maize varieties and pesticides on the grain yield of maize.

1.8 Limitations

In this study just like in any other studies there are some limitations. The study is limited to the use of the of lantana leaves, flowers and euphorbia flesh, fruits as the only botanical extracts (biocides) while in fact there are a dozen of them. Also this study only considered dipterex 25% grounded as the only chemical pesticide under study. Thus, this study cannot be generalised on the comparison between biocides and chemical pesticides in controlling maize stem borer. The results of this study cannot be universally applied as the intensity of maize stem borer may vary from time to time and from place to place.

1.9 Definition of key words

1.9.1 Split-plot design

Split plot design (SPD) is a factorial design with at least two factors where the experimental unit with respect to factors differ in size or observation points.

The following are the components of a split-plot design:

- Whole plot (WP) – is the largest experimental unit with a smallest degree of precision. The WP factor is assigned to it.
- Subplot (SP) – is the experimental unit in which the whole plot is split into subplots where observations are made in the case of a split-plot design. Levels of SP factors are allocated to the subplot.

1.10.2 Split-split-plot design

Split-split plot design (SSPD) is an extension of the split plot to accommodate the third factor. In this case the subplots are further divided into a subplot (sub-subplot) where the observations are made (Gomez and Gomez, 1984). Levels of the sub-subplot factors are assigned to the sub-subplot.

1.10.3 Integrated Pest Management (IPM)

Integrated Pest Management (IPM) refers to a combination of efforts that involves the use of non-chemical pesticides with chemical pesticides as the last resort

Chapter 2 Literature Review

Introduction

There are numerous approaches that have been employed on design and analysis by different researchers worldwide. Split-split-plot design analysis can be applied on pest management studies in the field of agriculture. The main objective of the split-split plot design is to accommodate a third factor of the experiment which consequently enables, researchers, experts, agronomists, and farmers to gain in-depth information on the interaction of many factors. This chapter presents the literature review associated with this study. It entails highlighting the impact of maize stem borer on maize production, its life cycle and control measures at different stages of the life cycle and identifying areas in which split-split plot design analysis is applicable.

2.1 Maize Production in Zimbabwe

In the past five decades, Zimbabwe have gone through tremendous changes in maize production (Food and Agriculture Organisation (FAO), 2015). Zimbabwe reached peak production of two million two hundred and twenty-nine thousand (2,229,000) metric tonnes in 1986-1987 season and the country was food insecure in 1991-1992 season with a total harvest of three hundred and sixty thousand metric tonnes.

Research based arguments about the maize production in Zimbabwe are in two folds (Rukuni et al, 2006). The first argument is that there were green revolutions, in the 1960-1980 and 1980-1986 season (Byerlee and Eicher, 1997). Others opposed this notion by stating that the conditions for the green revolution were both procedural and influential. Fig 1, shows the production of maize in Zimbabwe before independence and after independence.

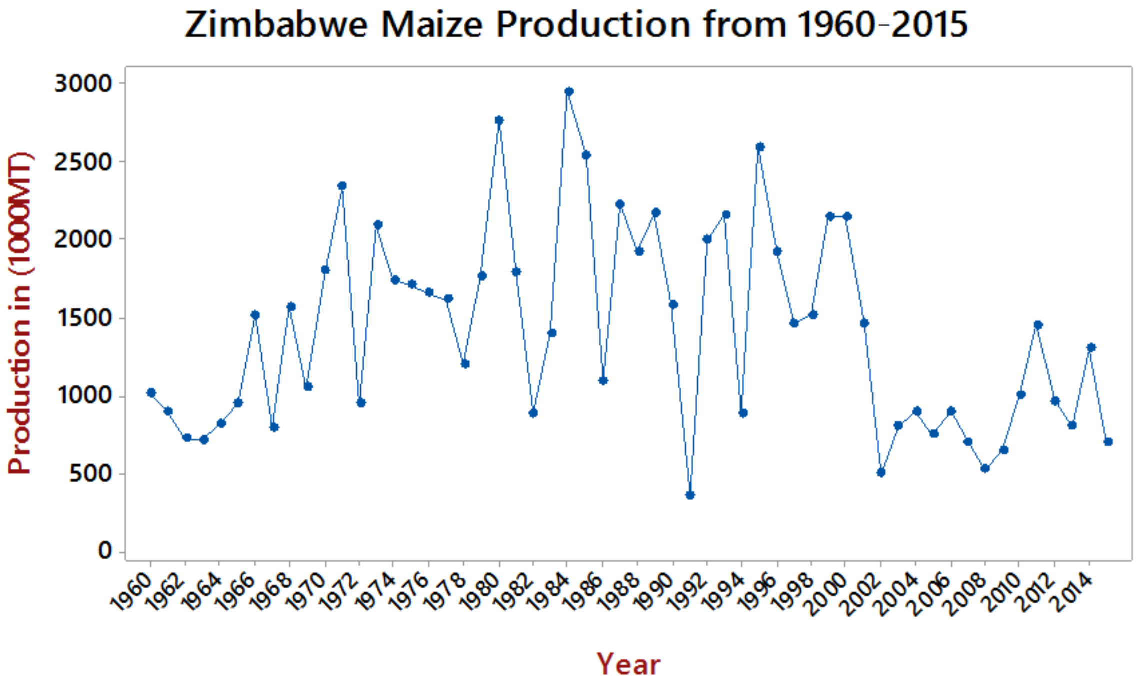


Figure 1: The production of maize in Zimbabwe, Food and Agriculture Organisation (FAO), (2015)

A number of factors had contributed to this volatility which are war, drougth, agricultural polices, flood, land invasion, wild animals invasion, pests to mention a few.

Regardless of the two incidents of presumed green revolution, very low yields are produced and this is partly due to insect pests, poor nutritional status of the soil, agricultural policies, floods, veld fire, seed varieties, and low rains (Segeren et al., 1996). The next section discusses the effect of maize stem borer on the production of maize.

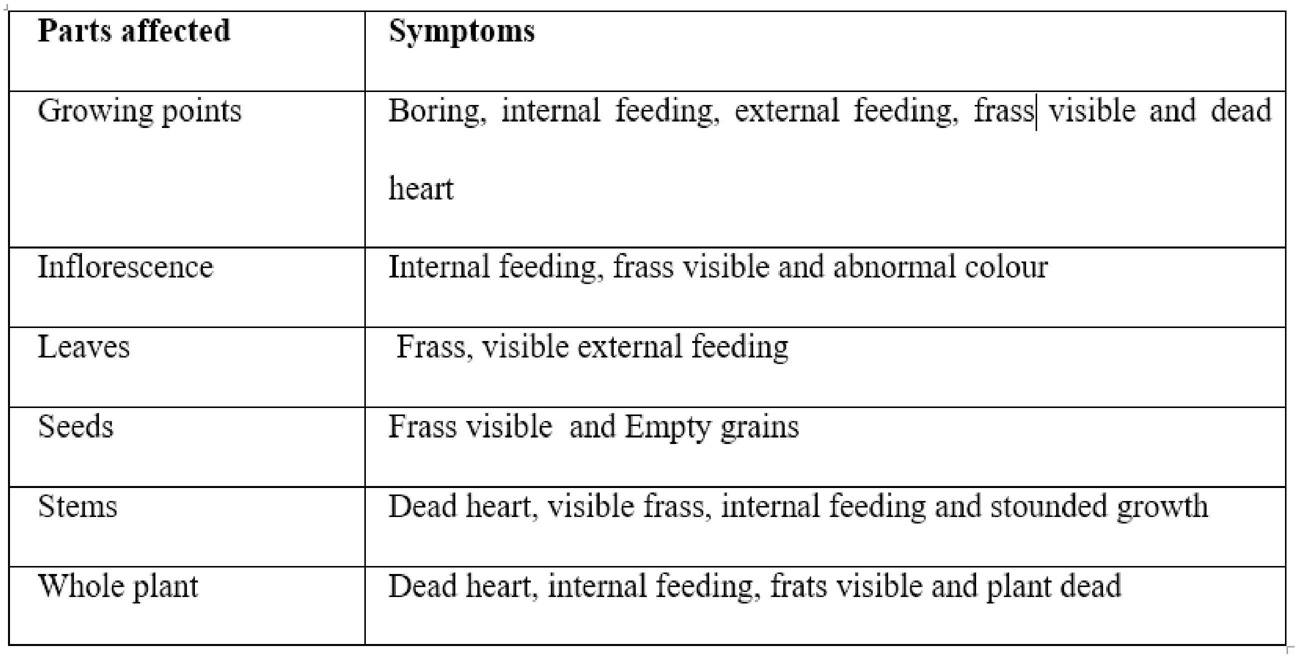
2.1.1 Effects of Maize Stem Borer on Maize Productivity

Maize stem borers are pest that can result in severe yield losses when combined with the effect of other factors which lead to the reduction of yields, for example drought. In Zimbabwe, three types of maize stem borer are Busseaola Fusca Fuller (Lepidoptera: Noctuidae), Chillo Partellus Swinhoe

(Lepidoptera: Crambidea-Pyralidae) and Sesamia Calamistis (Lepidoptera: Noctuidae). The lepidopteran stem borer's larvae can significantly result in fatal damages of maize hence low yields if uncontrolled (Chinwada and Overholt, 2001).

Pearl millet and sorghum, are some crops that are susceptible to infestation. Dryer; (1987) emphasised that maize is very susceptible to attacks of maize stem borer as compared to sorghum and pearl millet plants. In mature plants, inside tunnelling of the maize stem borer is very extensive. This then disturbs the movement of nutrients to all parts of the plant including grains. The resulting effects are wind logging or total plant failure in some cases (Pathak and Othien, 1992). The lepidopteran larvae through tunnelling into the stem may extremely affect grain thus it is essential to assess the exit holes, leaf damage, tunnelling length and dead hearts as well as grain yield. Table 1 shows the consequences of the maize stem borer on the crop.

Table 1: Damages caused by maize stem borer



Parts affected	**Symptoms**
Growing points	Boring, internal feeding, external feeding, frass visible and dead heart
Inflorescence	Internal feeding, frass visible and abnormal colour
Leaves	Frass, visible external feeding
Seeds	Frass visible and Empty grains
Stems	Dead heart, visible frass, internal feeding and stounded growth
Whole plant	Dead heart, internal feeding, frats visible and plant dead

Source of adaptation Munyini et al (2012)

Frass is the waste and dung of leaf-eating or boring insects.

2.1.2 Studies on Maize Stem Borer Bio-Ecology

Rice and Davis, (2010) provided the following account for the stem borer:

The forewings of the pest are greyish brown or reddish with distinctive white spots or unclear cloudy areas. The third of the moths outside area is pale, covered by a thin snowy line and a grey-reddish back on the exterior. The eggs are flattened longitudinally and 0.4 to 0.6 mm long. Soon after being laid a snowy colour is recognised which changes to amber or brown as they are nearly hatched. A female moth can lay 200 eggs in its entire life. A dark reddish or brown band is observed at early larval stage.

2.1.3 Maize Stem Borer Management

This section present a discussion on maize stem borer control with major focus on dipterex 25% grounded, two plants extracts namely lantana camara and euphorbia plants in an effort to provide a detailed survey of literature on their uses as pesticides. The discussion is only limited to their application as pesticides in the field of agriculture. Plants just like in medicine had been playing a tremendous role in agriculture dating back to the ancient time (Saxena et al, 2012).

2.1.3.1 Dipterex 25% grounded

In Zimbabwe a registration standard for the dipterex is 25% grounded dipterex which was issued in June 1984 (Berge, 1986). The other related chemical pesticide is trichlorfon which is used to control insects such as crickets, bed bugs, cockroaches, fleas, silver fish, flies, leaf miners and ticks. The pesticide can be used as dust, emulsifiable distillate, fly bait, soluble powder preparations or granular. Kefir et al (2002) stated that, control is attained by smearing dust on the leaf funnel of the seedlings so as to control the larva at premature stages. The control is limited, once in the stem the larvae continues to grow irrespective of the chemical. The other chemical pesticides include endosulfan, carbaryl, trichlofon, diazinon, carbofuran or fenitrothion. Chemical pesticides are poisonous containing elements that control or kill insects.

Chemical pesticides may affect human health indirectly by disrupting the ecological arrangements that exists in lakes, rivers, oceans, wetlands, streams, fields and forests as these are source of drinking water (Kagon, (1998). Chemicals once deposited in the surroundings they presents a death toll to humans and other species directly or indirectly. The result can be pollution of the environment either by target insects.

2.1.3.2 Use of Biocides

Plant extracts or simply botanical methods of pest control are used as pesticides both at homes and for commercial use. Murray, (2008) noted that plant pesticides affect in many ways, as repellents by repelling away the pests due to their taste or smell or by inhibiting the pest from laying of eggs, or as inhibitors of feed intake and thus starving the pest to death.

Plant pesticides have the following benefits:

- Once used, they last for a while and are not fatal to people and other species.
- They are even harmless to natural enemies or affected by plant as biocides for instance lady bird beetle.
- Biocides are inexpensive, preparation is very easy and are readily accessible as natural measures even in the forestry (Salwa, 2010).

Studies on the use botanical pesticides, crop protection and pest management in Africa are less influential in informing farmers as they are still using ‘poisonous’ chemical pesticides.

2.1.3.1 Lantana Camara

Lantana camara is a small, scrub which can grow up to 2-4m in height. The leaf is ovate oblong or just ovate, 2-6cm and 2-10cm long wide arranged in opposite pairs. Leaves are green, uneven finely furry, with serrate borders and produce a pungent smell when crashed. Flowers are pink, cream or orange with a number of small round crown like heads usually yellow and red in colour.

Lantana contains many chemical mixtures, with great difference in their substances influenced ecological conditions (Abdel-Hardy et. al, 2005). Chloroform and methanol present in Lantana camara were reported to be very effective in controlling termites. Herna'dez et.al, (2003) established that the resulting effect of lantana flowers and leaves against maturation of the house fly (Musca domestica) larvae under laboratory experiments reached a mortality rate of 80%.

Akhter et al, (1990) found out that Lantana extracts produces a phototoxic likely to act against crops particularly during germination of bacteria of *Aster Ella Angusta* (liver wart). He suggested that when swallowed lantana stops the use of food nutrient by susceptible insect, therefore death results from insufficient food or starvation. Lantana plants have a poisonous effects therefore it is a systemic and or repellent biocide.

2.1.3.2 Euphorbia plants

A deciduous shrub, usually found in open spaces. Its bark is bright greyish, smooth, branches usually splitting in three whorls, mostly spine-tipped. Leaves are found in bunches on small branches, fairly blue-green, barely lanceolate, usually 3cm to 4 cm long, margin entire. Greenish yellow flowers are found in slight dense crowns like heads at the tips of branches and spurs. The species usually bear three-lobbed fruits during wet seasons. Cristofaro, et al (1998) indicated that there are two thousand known types of euphorbia plants ranging from trees to annuals and all types contain latex fluid. The group of genus euphorbia have the tumour skin irritating triterpenoids which have myrsinane, jatrophane and volatile compounds. The plants contains poisonous compounds which when exposed may cause irritation to eyes and mucus membrane which causes inflammation to skin (Ozbilgin and Citolgin, 2012).

2.1.3.3 Cultural Control

There are several cultural control practices on pests which had been used in the past. These include crop rotation, use of maize varieties, soil quality enhancement, planting early, multiple cropping, monitoring/screening, management of water, and post-harvest treatments (Ogah and Ogbodo, 2011).

In Nigeria during 2009/2010 seasons, a research on farming practices was done. In the research, Ogah and Ogbodo, (2011) established that intercropping of maize with Bambara groundnut as a way of controlling maize stem borer was very effective. They concluded that amongst the larval number reduced extremely, as well as the percentage of dead hearts, exit holes and tunnelling length were realized to be lower than that of maize mono cropped. Higher yields were noted from plots that were intercropped as compared to mono-cropped ones.

2.2 Design of Experiment and Analysis

In applied statistics there exist a systematic approach that enable researchers to describe the variability in one or more outcome variables in terms of various factors. This process is referred to as design of experiment (DoE) or experimental design. One of the crucial technique in the design of experiment is to model the response variable based on one component of variance

(Ganju and Lucas, 1999). When conducting experiments it is recommended that the trails should be in completely randomised procedure and this is referred to completely randomised design (CRD). Montgomery, (2013), stated that the construction of a completely randomised design is important in eliminating bias in the outcome variable resulting from lurking hidden variables. In addition, completely randomised design lays the foundation for modelling the dependent variable based on a single component of variance which simplifies the analysis.

However, in other scenarios it is exorbitantly expensive or time consuming to use completely randomised design (Ganju and Lucas, 1999). That is it may be difficult and costly to change levels of some experimental factors for several times. As a result, in order to get accurate results the experimenter needs to compromise between failure to randomise and complete randomisation (that is restricted randomisation), (Wooding, 1973).

2.2.1 Procedure for designing an experiment

Wooding, (1973), provided an outline of the stages that are involved in design and analysis of an experiment as follows:

1) Recognition of the statement of the problem

It is necessary to develop all ideas about the objectives of the experiment. A clear statement of the problem often contributes much in exploring the phenomena and the final solution to the problem.

2) Choice of factors and levels

This involves a process of selecting independent variables or factors to be investigated in the experiment. Levels may be chosen specifically at random from the set of all possible factor levels.

3) Selection of response variable

In choosing a response variable there is need for the experimenter to be certain that the response to be measured really provide information the underlying problem.

4) Choice of experimental design

The experimenter should determine the difference between each design and the magnitudes of risks that are associated with each design as well as the benefits they have. A mathematical model of the experiment must also be proposed as the provisional model to the data to be analysed.

5) Performing the experiment

This is the actual data collection process in which the experimenter carefully monitors the progress of the experiment to ensure that it is proceeding according to the design plan. Particular attention must be paid to the principles of the experiment, measurements, accuracy and making as uniform an experimental environment as possible.

6) Data analysis

In general statistical methods cannot prove that a factor has particular effect but only provide guidelines as to the reliability and validity of results. When properly used statistical methods allow measures that will result in a sound conclusion.

7) Conclusion and recommendations

Once the data has been analysed the experimenter may draw conclusions about the inferred results. The statistical inferences must be physically interpreted and practical significance of these must be made.

2.2.2 Three principles of experimental design

This section presents the three principles of the experimental design in regard to this study.

1) Replication

Replication refers to a process of repeating an experiment in the same manner using the same treatment combinations. The benefits of replication in experimental design include:

a) It allows the experimenter to obtain an estimate of the experimental error which is regarded as the basic unit of measurement for determining whether the observed are statistically different.

b) If the sample mean is used to estimate the effect of a factor in the experiment then replication permits the experimenter to obtain a more precise estimate of the effect.

In general replication is best for the experiment in that it allows for the accurate estimation of the controllable factor level means. More precisely, it improves the sensitivity test for comparing factor level means (Montgomery, 2013).

2) Blocking

Blocking an experiment refers to the sorting of the experimental units into groups of relatively homogeneous with at least one characteristics. Montgomery, (2013) advocated randomization should follow after blocking.

3) Randomization

Randomization means that both the allocation of the experimental material and the order in which individual trials are performed are randomly determined. According to Montgomery, (2013), randomization is a pre-requisite of statistical methods as it assures that residuals are identically and independently normally distributed random variables. It is a means of eliminating any bias in the experimental unit, treatment combination and factors.

Gomez and Gomez, 1984, provided an account for randomization process for split-split plot designs as follows:

The randomization process consists of three steps:

a) Main plot treatments are randomly assigned to main plots based on the design used.

b) Split plot treatments are randomly assigned to the subplots.

c) Split-split plot treatments are randomly assigned to the sub-subplots.

The randomization process is independent of each portion. In split-split plot designs randomization is restricted twice.

2.2.3 Split plot Design

Split plot design (SPD) is a factorial design with at least two factors where the experimental unit with respect to factors differ in size or observation points. Fisher, (1934) advocated for split plot design and analysis owing to their applicability in complex scenarios such as in the presents of hard-to-change (HTC) processing factors between consecutive experimental trials in agriculture.

Box and Wilson (1951) argued that, split-plot experiments are usual practise not exceptions in the field of agriculture. They proposed that split-plot designs are beneficial in terms of enhanced accuracy in exploring the subplot factors given the presence of extremely hard to adjust whole plot factors and its cost effectiveness over a completely randomized design (CRD). In support to this, Ganju and Lucas (1999) envisaged that if a completely randomized design is employed when there are hard to change (HTC) factors, it will be difficult to change factors before each trial.

The gains of a split-plot are improved accuracy in investigating the split plot factors where there is extremely inconstant whole-plot factors and the low cost as compared to a completely randomized design (Taguchi 1987). Furthermore, he stresses the significance of identifying and considering the split-plot construction in the study. According to Montgomery, (2013), if one considers three factors, that is easy to change (ETC), hard to change (HTC) and very-hard-to-change (VHTC) there are two randomisation restrictions. The first randomisation restriction in the very hard to change factor and the second is associated with the hard to change factor. The resulting design is a split-split plot design (SSPD).

2.2.4 Split-split plot Design

Split-Split Plot design (SSPD) is an extension of split plot to include a third factor. In agriculture it is ideal to include a third factor in order to have adequate evidence of the prevailing situation (Gomez and Gomez, 1984). In practise there is no restriction on the extensions that can be done so as to incorporate as many factors as we can in order to gain sufficient information on how different factors interact. However, the analysis becomes cumbersome as one incorporates more factors.

2.2.5 Arrangement of split-split plot and Analysis Of Variance ANOVA

The structure of a split-split plot is described by:

1. Different sizes of plots; which are the biggest plot for the whole plot factor, the middle sized plot for the split plot factor, and the smallest for the split-split plot factor.
2. The main factor receive the least precision, and the split-split plot factor receive the most precision.

For example, split-split plot arrangement with two levels of the whole plot factor, A, two levels of the subplot factor, B, and six levels of the sub-subplot factor, C. Table 2, shows the first replicate.

Table 2: The first replicate for split-split plot arrangement

	Subplot	Sub-subplot					
α_1 whole plot	$\alpha_1\beta_1$	$\alpha_1\beta_1\tau_1$	$\alpha_1\beta_1\tau_2$	$\alpha_1\beta_1\tau_3$	$\alpha_1\beta_1\tau_4$	$\alpha_1\beta_1\tau_5$	$\alpha_1\beta_1\tau_6$
	$\alpha_1\beta_2$	$\alpha_1\beta_2\tau_1$	$\alpha_1\beta_2\tau_2$	$\alpha_1\beta_2\tau_3$	$\alpha_1\beta_2\tau_4$	$\alpha_1\beta_2\tau_5$	$\alpha_1\beta_2\tau_6$

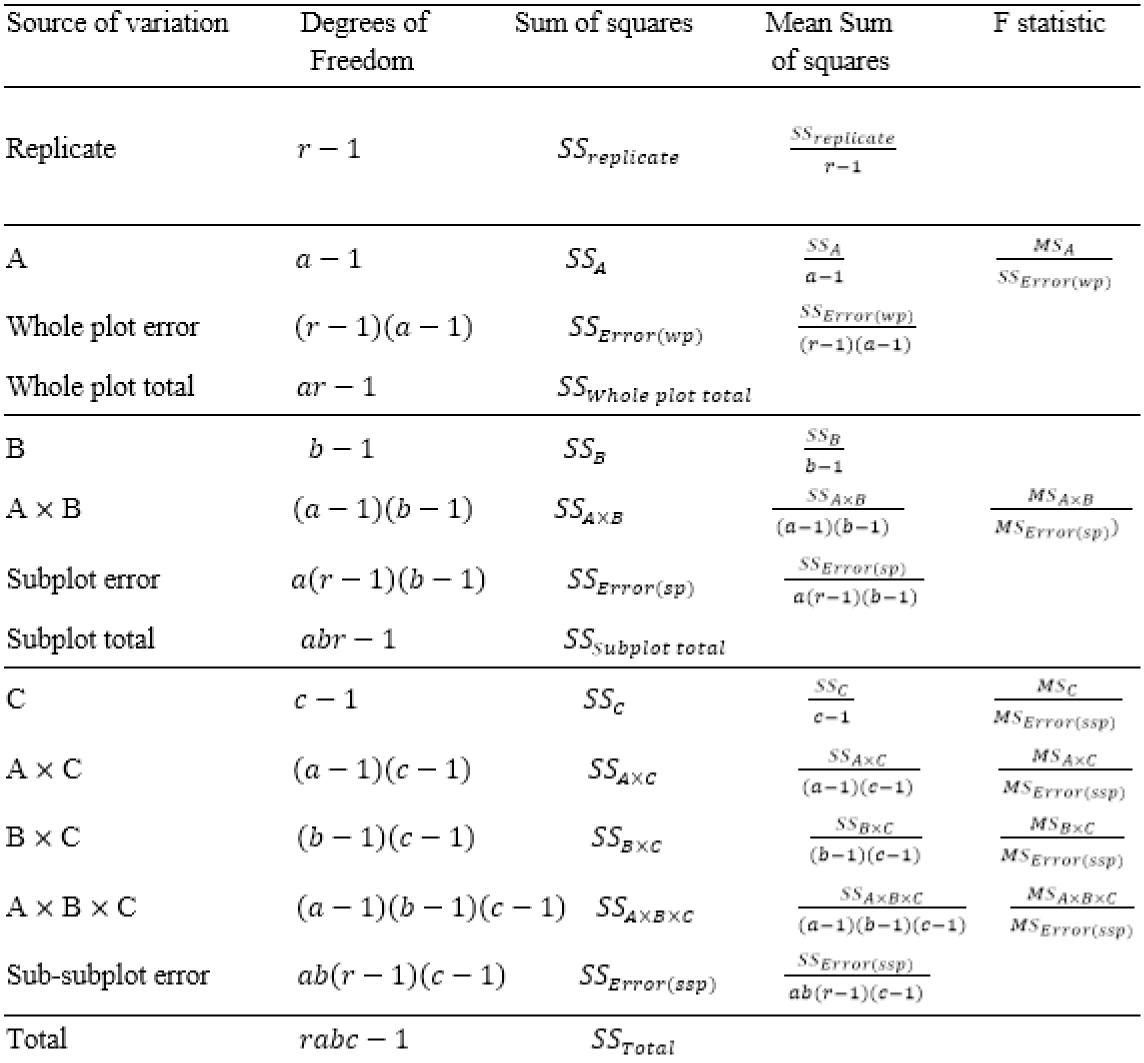
Where: α_i, β_j and τ_k represent the factor levels i, j and k of whole plot, subplot and sub-subplot respectively for, $\begin{cases} i = 1,2 \\ j = 1,2 \\ k = 1,2 \ldots 6 \end{cases}$

2.2.3.1 Analysis of variance (ANOVA)

Logic behind the analysis of variance is to decide whether the differences among the sample are enough to imply that the corresponding treatment means are different. Combining the thoughts of

Montgomery, (2013), Gomez and Gomez, (1984) and Fisher (1925), the analysis of variance for a split-split plot arrangement is represented in table 3

Table 3: The analysis of variance for split-split plot arrangement



Source of variation	Degrees of Freedom	Sum of squares	Mean Sum of squares	F statistic
Replicate	$r-1$	$SS_{replicate}$	$\frac{SS_{replicate}}{r-1}$	
A	$a-1$	SS_A	$\frac{SS_A}{a-1}$	$\frac{MS_A}{SS_{Error(wp)}}$
Whole plot error	$(r-1)(a-1)$	$SS_{Error(wp)}$	$\frac{SS_{Error(wp)}}{(r-1)(a-1)}$	
Whole plot total	$ar-1$	$SS_{Whole\ plot\ total}$		
B	$b-1$	SS_B	$\frac{SS_B}{b-1}$	
A × B	$(a-1)(b-1)$	$SS_{A\times B}$	$\frac{SS_{A\times B}}{(a-1)(b-1)}$	$\frac{MS_{A\times B}}{MS_{Error(sp)})}$
Subplot error	$a(r-1)(b-1)$	$SS_{Error(sp)}$	$\frac{SS_{Error(sp)}}{a(r-1)(b-1)}$	
Subplot total	$abr-1$	$SS_{Subplot\ total}$		
C	$c-1$	SS_C	$\frac{SS_C}{c-1}$	$\frac{MS_C}{MS_{Error(ssp)}}$
A × C	$(a-1)(c-1)$	$SS_{A\times C}$	$\frac{SS_{A\times C}}{(a-1)(c-1)}$	$\frac{MS_{A\times C}}{MS_{Error(ssp)}}$
B × C	$(b-1)(c-1)$	$SS_{B\times C}$	$\frac{SS_{B\times C}}{(b-1)(c-1)}$	$\frac{MS_{B\times C}}{MS_{Error(ssp)}}$
A × B × C	$(a-1)(b-1)(c-1)$	$SS_{A\times B\times C}$	$\frac{SS_{A\times B\times C}}{(a-1)(b-1)(c-1)}$	$\frac{MS_{A\times B\times C}}{MS_{Error(ssp)}}$
Sub-subplot error	$ab(r-1)(c-1)$	$SS_{Error(ssp)}$	$\frac{SS_{Error(ssp)}}{ab(r-1)(c-1)}$	
Total	$rabc-1$	SS_{Total}		

Table 3 is showing analysis of variance (ANOVA) table, with factor A as the whole plot factor, factor B as the subplot factor, and factor C as the sup-subplot factor. Factors A, B, and C will be considered random effects.

Calculations of sum of squares

1 First calculate the correction factor (CF): $CF = \frac{Y_{....}^2}{rabc}$

2 Total sum of squares (SS_{Total}): $SS_{Total} = \sum_{i=1}^{r}\sum_{j=1}^{a}\sum_{k=1}^{b}\sum_{l=1}^{c} Y_{ijkl}^2 - CF$

3 Replicate sum of squares: $SS_{replicate} = \frac{\sum_{i=1}^{r} Y_{i...}^2}{abc} - CF$

4 **A** sum of squares: $SS_A = \frac{\sum_{j=1}^{a} Y_{.j..}^2}{rbc} - CF$

5 Whole plot sum of squares: $SS_{Wholeplot\ total} = \frac{\sum_{i=1}^{r}\sum_{j=1}^{a} Y_{ij}^2}{bc} - CF$

6 Whole plot error (Error (wp)) sum of squares

$$SS_{Error(wp)} = SS_{Wholeplot\ total} - SS_{replicate} - SS_A$$

7 **B** sum of squares: $SS_B = \frac{\sum_{k=1}^{b} Y_{..k.}^2}{rac} - CF$

8 **A × B** sum of squares: $SS_{A\times B} = \frac{\sum_{j=1}^{a}\sum_{k=1}^{b} Y_{.Jk.}^2}{rc} - CF - SS_A - SS_B$

9 Subplot sum of squares: $SS_{Subplot\ total} = \frac{\sum_{k=1}^{b} Y_{ijk.}^2}{c} - CF$

10 Subplot error (Error(sp)) sum of squares

$$SS_{Error(sp)} = SS_{Subplot\ total} - SS_{A\times B} - SS_B - SS_{Error(wp)} - SS_A - SS_{replicate}$$

11 **C** sum of squares: $SS_C = \frac{\sum_{l=1}^{a} Y_{...l}^2}{rab} - CF$

12 ***A* × *C*** sum of squares: $SS_{A\times C} = \frac{\sum_{j=1}^{a}\sum_{l=1}^{c} Y_{.j.l}^2}{rb} - CF - SS_A - SS_C$

13 ***B* × *C*** sum of squares: $SS_{B\times C} = \frac{\sum_{k=1}^{b}\sum_{l=1}^{c} Y_{..kl}^2}{ra} - CF - SS_B - SS_C$

14 $\boldsymbol{A} \times \boldsymbol{B} \times \boldsymbol{C}$ sum of squares:

$$SS_{A\times B\times C} = \sum_{j=1}^{a}\sum_{k=1}^{b}\sum_{l=1}^{c} Y_{.jkl}^{2} - CF - SS_A - SS_B - SS_C - SS_{A\times B} - SS_{A\times C} - SS_{B\times C}$$

15 Sub-subplot (Error(ssp)) sum of squares:

$$SS_{Error(ssp)} = SS_{Total} - SS_{A\times B\times C} - SS_{B\times C} - SS_{A\times C} - SS_C - SS_{Error(sp)} - SS_{A\times B} - SS_B - SS_{Error(wp)} - SS_{replicate}$$

2.2.6 Comparisons of Treatments

If significant differences in treatment means are determined from the F-test, the experimenter have to compare pairs of treatments (Gomez and Gomez, 1984). A protected Fisher's Least Significant Difference (LSD) which is a pairwise comparisons among pairs of treatments and can only be applied if significant differences in treatment means are determined from the F-test can be used.

In a split-split plot design there are 12 different kinds of pair wise comparisons and each requiring a set of its own sets of LSDs values.

Where: $LSD = t_{\frac{\alpha}{2}}^{Err(p).df} \times SED$; $t_{\frac{\alpha}{2}}^{Err(p).df}$ is the tabular value from the student t table at $\frac{\alpha}{2}$ significant level and $Err(p).df$ represent the error degrees of freedom corresponding to each portion of the design. In this case p represent either whole plot (wp) or subplot (sp) or sub-subplot (ssp).

Gomez and Gomez, (1984) stated the pair comparisons, together with their appropriate formulas for computing Least significant differences (LSD) are as follows:

1. To compare the two whole plot means at an average of all subplot and sub-subplot treatments and the following hypothesis is tested.

$$H_0: \mu_{.i..} = \mu_{.i_{\square}..} \; versus \; H_1: \mu_{.i..} \neq \mu_{.i_{\square}..}$$

Where, μ_1 and μ_2 are means estimated by $\bar{Y}_{.i..}$ and $\bar{Y}_{.i_{\square}..}$ respectively. The computational formula for LSD is given in equation 2.1

$$LSD = t_{\frac{\alpha}{2}}^{Err(wp).df} \sqrt{\frac{2MS_{Error(wp)}}{rbc}} \qquad \ldots\ldots \text{equation (2.1)}$$

We reject H_0 if $\left|\bar{Y}_{.i..} - \bar{Y}_{.i_{\square}..}\right| > LSD$

2. To compare the two subplot means at an average of all whole plot and sub-subplot treatments and the following hypothesis is tested.

$$H_0: \mu_{..j.} = \mu_{..j_{\square}.} \; versus \; H_1: \mu_{..j.} \neq \mu_{..j_{\square}.}$$

$$LSD = t_{(\frac{\alpha}{2}, Err(sp).df)} \sqrt{\frac{2Error(sp)MS}{rac}} \qquad \ldots\ldots \text{equation (2.2)}$$

We reject H_0 if $\left|\bar{Y}_{..j.} - \bar{Y}_{..j_{\square}.}\right| > LSD$

3. To compare the two sub-subplot means at an average of all whole plot and subplot treatments and the following hypothesis is tested.

$$H_0: \mu_{...k} = \mu_{...k_{\square}} \; versus \; H_1: \mu_{...k} \neq \mu_{...k_{\square}}$$

$$LSD = t_{(\frac{\alpha}{2}, Err(ssp).df)} \sqrt{\frac{2Error(ssp)MS}{rab}} \qquad \ldots\ldots \text{equation (2.3)}$$

We reject H_0 if $\left|\bar{Y}_{...k} - \bar{Y}_{...k_{\square}}\right| > LSD$

4. To compare the subplot means at an average of all sub-subplot treatments at the same levels of whole plot, the following hypothesis is tested.

$$H_0: \mu_{.ij.} = \mu_{.ij_{\square}.} \; versus \qquad H_1: \mu_{.ij.} \neq \mu_{.ij_{\square}.}$$

$$LSD = t_{(\frac{\alpha}{2},Err(sp).df)}\sqrt{\frac{2Error(sp)MS}{rab}} \qquad \text{… … equation (2.4)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.ij_{\square}.}\right| > LSD$

5. To compare the two whole plot means at an average of all sub-subplot treatments at the same or different levels of subplots the following hypothesis is tested.

$$H_0: \mu_{.ij.} = \mu_{.i_{\square}j.}\ versus\ \ H_1: \mu_{.ij.}\ \neq\ \mu_{.i_{\square}j.}$$

$$LSD = t_{\alpha\beta}\sqrt{\frac{2[(b-1)Error(sp)MS + Error(wp)Ms]}{rbc}} \qquad \text{… … equation (2.5)}$$

Where:

$$t_{\alpha\beta} = \frac{(b-1)Error(sp)MS\left(t_{(\frac{\alpha}{2},Err(sp).df)}\right) + Error(wp)MS\left(t_{(\frac{\alpha}{2},Err(wp).df)}\right)}{(b-1)Error(sp)MS + Error(wp)MS} \qquad \text{… equation (2.5.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.i_{\square}j.}\right| > LSD$

6. To compare the two sub-subplot means at an average of all subplot treatments at the same levels of whole plot, the following hypothesis is tested.

$$H_0: \mu_{.i.k} = \mu_{.i.k_{\square}}\ versus\ \ H_1: \mu_{.i.k}\ \neq\ \mu_{.i.k_{\square}}$$

$$LSD = t_{(\frac{\alpha}{2},Err(ssp).df)}\sqrt{\frac{2Error(ssp)MS}{rb}} \qquad \text{… … equation (A2.6)}$$

We reject H_0 if $\left|\bar{Y}_{.i.k} - \bar{Y}_{.i.k_{\square}}\right| > LSD$

7. To compare the two whole plot means at an average of all sub-subplot treatments at the same or different levels of subplots the following hypothesis is tested.

$$H_0\colon \mu_{.ij.} = \mu_{.i_\square j_\square .}\ versus\ \ H_1\colon \mu_{.ij.}\ \neq\ \mu_{.i_\square j_\square .}$$

$$LSD = t_{\alpha\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(wp)Ms]}{rbc}} \qquad \text{… … equation (2.7)}$$

Where:

$$t_{\alpha\beta} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+Error(wp)MS\left(t_{\left(\frac{\alpha}{2},Err(wp).df\right)}\right)}{(c-1)Error(ssp)MS+Error(wp)MS} \qquad \text{… equation (2.7.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.i_\square j_\square .}\right| > LSD$

8. To compare the two sub-subplot means at an average of all whole plot and at the same level of the subplot treatments the following hypothesis is tested.

$$H_0\colon \mu_{..jk} = \mu_{..j_\blacksquare k_\square}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{..j_\blacksquare k_\square}$$

$$LSD = t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\sqrt{\frac{2Error(ssp)MS}{ra}} \qquad \text{… … equation (2.8)}$$

We reject H_0 if $\left|\bar{Y}_{.jk} - \bar{Y}_{..j_\blacksquare k_\square}\right| > LSD$

9. To compare the two subplot means at an average of all whole plot treatments at the same or different levels of sub-subplots the following hypothesis is tested.

$$H_0\colon \mu_{..jk} = \mu_{..j_\square k_\blacksquare}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{..j_\square k_\blacksquare}$$

$$LSD = t_{\beta\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(sp)Ms]}{rac}} \qquad \text{… … equation (2.9)}$$

Where:

$$t_{\beta\tau} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)}{(c-1)Error(ssp)MS+Error(sp)MS} \qquad \text{… equation (A2.9.1)}$$

We reject H_0 if $\left|\bar{Y}_{.jk} - \bar{Y}_{..j_{\square}k_{\blacksquare}}\right| > LSD$

10. To compare the sub-subplot means at the same combination of whole plot and subplot treatments, the following hypothesis is tested.

$$H_0\colon \mu_{.ijk} = \mu_{.i_{\blacksquare}j_{\blacksquare}k_{\square}}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{.i_{\blacksquare}j_{\blacksquare}k_{\square}}$$

$$LSD = t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\sqrt{\frac{2Error(ssp)MS}{r}} \qquad \text{… … equation (2.10)}$$

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_{\blacksquare}j_{\blacksquare}k_{\square}}\right| > LSD$

11. To compare the subplot means at the same combination of whole plot and sub-subplot treatments, the following hypothesis is tested.

$$H_0\colon \mu_{.ijk} = \mu_{.i_{\blacksquare}j_{\square}k_{\blacksquare}}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{.i_{\blacksquare}j_{\square}k_{\blacksquare}}$$

$$LSD = t_{\alpha\beta\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(sp)Ms]}{rc}} \qquad \text{… … equation (11)}$$

Where: $$t_{\alpha\beta\tau} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)}{(c-1)Error(ssp)MS+Error(sp)MS} \qquad \text{… equation (11.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_{\blacksquare}j_{\square}k_{\blacksquare}}\right| > LSD$

12. To compare the two whole plot means at the same combination of subplots and sub-subplot treatments, the following hypothesis is tested.

$$H_0: \mu_{.ijk} = \mu_{.i_\square j_\blacksquare k_\blacksquare} \; versus \;\; H_1: \; \mu_{..jk} \neq \mu_{.i_\square j_\blacksquare k_\blacksquare}$$

$$LSD = t_{\alpha\beta\tau}\sqrt{\frac{2[b(c-1)Error(sp)MS + (b-1)Error(sp)Ms + Error(wp)Ms]}{rbc}}$$

… equation (12)

Where:

$$t_{\alpha\beta\tau} = \frac{b(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+(b-1)Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)+Error(wp)MS\left(t_{\left(\frac{\alpha}{2},Err(wp).df\right)}\right)}{b(c-1)Error(ssp)MS+(b-1)Error(sp)MS+Error(wp)MS}$$

… equation (12.1)

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_\square j_\blacksquare k_\blacksquare}\right| > LSD$

Note: The subscripts □ and ■ represents the difference between terms and the same level (terms) respectively.

2.2.7 Diagnostic Checking

Inferences concerning relationships of an experimental design must be based on a satisfactory model. That is a model, which seems to fit the data well. A model is plausible or satisfactory if none of its assumptions are (grossly) violated. Thus, before a model is used to make inference it must be subjected to diagnostic checking for adequacy.

The split-split plot experimental design has a model with three experimental errors and the adequacy of the model can be diagnosed for its fitness, using methods such as the coefficient of determination (R^2), coefficient of variation (CV), and graphical approach. The manner in which the measures of R^2 is obtained from a design with one type of error in its model is quite different from that of the split-split plot design with three types of errors in its model, which are whole plot or main plot error, the split-plot or sub-plot error and split-split plot error (Web, Lucas and Borkowski, 2002).

2.2.4.1 Procedures for diagnostic checking for adequacy:

(i) Plot of Residuals against Fitted Values if linearity, independence, equal variance and normality assumptions of the General Linear Model are held, then it implies that a plot of residuals against fitted values should show a good fit characterized by small residuals with no apparent structure or pattern.

(ii) Plot of residuals against each predictor: A plot of residuals against each predictor should show a random pattern.

(iii) Plot of residuals against time or index: The plot should not show any trend or pattern.

(iv) The assumption of normality can be checked by constructing and examining the Histogram of residuals. The assumption can be checked more carefully by plotting the residuals against normal scores. If the data are normally distributed then a plot of the residuals against the corresponding normal scores should produce an approximate straight line.

2.2.4.2 Goodness of model fit

After the estimation of parameters and the determination if linear regression line, we need to know the goodness of the fit of this line to the sample observations of Y_{ijkl} and factors, that is we need to measure the dispersion of observation around the regression line.

(i) Coefficient of Determination (R^2)

$$R^2 = \frac{SSR}{SS_{total}} \times 100\%$$

Determines proportion of variation that is due to changes in Y explained by the variation in X. An R^2 value greater than 0.80 is deemed to mean good fit.

(i) Coefficient of Variation (C.V)

The coefficient of variation (CV) measures the spread of noise around the regression line. It is given by

$$CV = {}^{SED}\!/_{\bar{y}} \times 100\%$$

That is coefficient of variation is an estimate of the residual error standard deviation (SED) as a percentage of the average of the responses. A small value of coefficient of variation (< 20%) suggest good fit that is there is not much noise around the regression line.

Chapter 3 Methodology

Introduction

The strategy and methods employed to carry out this study are presented in this chapter. It seeks to fulfil the objectives of the study stated earlier on in the first chapter.

This chapter will be laid in different sections whose discussion ensues:

3.1 The Experimental Design

The research was carried out during the rainy season of 2015-2016 at Midlands State University (MSU) main campus. Midlands State University is located south-east of the Midlands provincial capital city, Gweru in Zimbabwe. Midlands State University falls in region three where average rainfall is between 600 and 750 mm and the mean temperature ranges from 20℃ to25℃. The location is semiarid characterised by dry season that covers from May to September and a rainy season that extends from October to April. The soils in the area are formed from Gneissic granite, thus are infertile or less fertile.

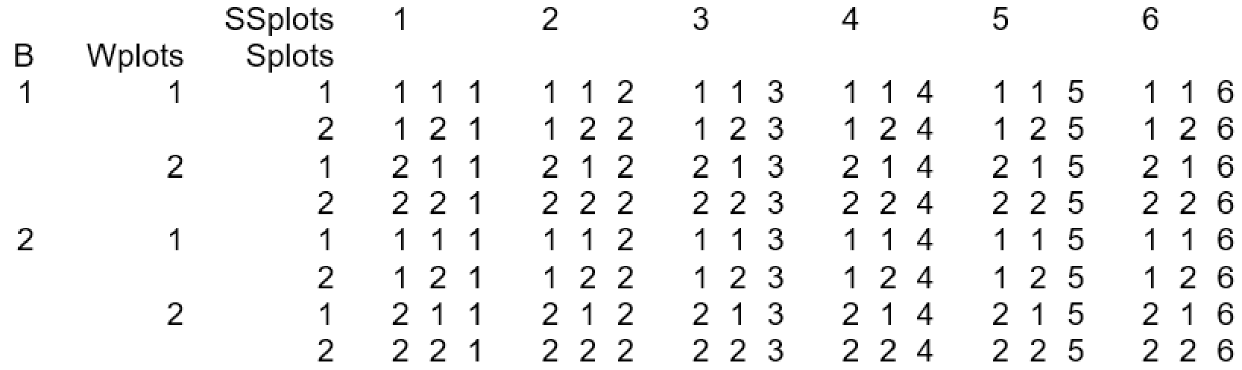
A $2 \times 2 \times 6$ factorial design in the form of a split-split plot design was used with two nitrogen levels as whole plot factor (0kg/ha and 100kg/ha), two varieties of maize as subplot factor (SC627 SeedCo and Pioneer 30G95) and six levels maize stem borer control method as sub-subplot factor (Lantana camara leaves extract, Lantana camara flowers extract, Euphorbia flesh extract, Euphorbia fruit extract, Dipterex 25% granular, and nothing applied). Soil pH (6.5 acid and 7.8 alkaline) was used as a blocking factor. Ten meter lines were used as plots and plants were equally spaced at 30cm.

3.1.1 Randomisation Procedure

The following randomisation process was done:

- Two levels of nitrogen namely 0kg/ha and 100kg/ha were randomly to whole plots as whole plot treatment levels,
- Two varieties of maize (SC627 SeedCo and Pioneer 30G95) were randomly assigned to subplots as subplot treatments levels,
- Lantana camara leaves extract, lantana camara fruits extract, euphorbia flesh extract, euphorbia fruits extract, dipterex 25% grounded and control with nothing were randomly assigned to sub-subplots as sub-subplot treatment levels

Table 4: Treatment combinations on each unit of the design



		SSplots	1	2	3	4	5	6
B	Wplots	Splots						
1	1	1	1 1 1	1 1 2	1 1 3	1 1 4	1 1 5	1 1 6
		2	1 2 1	1 2 2	1 2 3	1 2 4	1 2 5	1 2 6
	2	1	2 1 1	2 1 2	2 1 3	2 1 4	2 1 5	2 1 6
		2	2 2 1	2 2 2	2 2 3	2 2 4	2 2 5	2 2 6
2	1	1	1 1 1	1 1 2	1 1 3	1 1 4	1 1 5	1 1 6
		2	1 2 1	1 2 2	1 2 3	1 2 4	1 2 5	1 2 6
	2	1	2 1 1	2 1 2	2 1 3	2 1 4	2 1 5	2 1 6
		2	2 2 1	2 2 2	2 2 3	2 2 4	2 2 5	2 2 6

Where:

B-represent blocks with soil pH 1 and 2 which are 6.5 and 7.8 respectively, Wplots-are whole plot factors (nitrogen rate) 1 and 2 (0kg/ha and 100kg/ha respectively),

Splots- are split plot factors (maize seed varieties) 1 and 2 which are SC627 SeedCo and Pioneer 30G95 in that order and SSplots- are maize stem borer control pesticides 1, 2,3,4,5, and 6 which are lantana camara leaves extracts, lantana camara fruits extracts, euphorbia flesh extracts, euphorbia fruits extracts, dipterex 25% grounded and a control (with nothing) respectively.

3.1.1 Preparation of Biocides

Lantana flowers, leaves extracts and euphorbia flesh, fruits extracts were dried and burnt to ashes. Lantana (leaves and flowers) and euphorbia (flesh and fruits) took three and five weeks respectively to dry up. Soils were tested for acidity and alkalinity and it was observed that the adjacent lands have pH 6.6 and 7.8 for block 1and 2 respectively. A chemical pesticide (dipterex 25% grounded) was bought and for easy identification labels were put on all the prepared treatments and for easy allocation of biocides to plots.

3.1.2 Measurements

Ten plants from each plot were examined for the efficacy of maize stem borer pesticides. The following crop damage parameters were assessed, exit holes per plant, leaf damage scores and dry stem cumulative tunnelling length. Maize grain yields were measured in tonnes per hectare. A visual leaf-damage rating score on a scale of 1 to 9 based on Munyini et al (2012) was used on individual plants of the ten sampled plants per plot. To determine the leaf damage score, the scores were averaged for each plot. The twelve plants were further examined for exit holes and dead hearts counts which was also averaged per plot. The tunnelling length was measured after splitting the stems and the averaged cumulative measure was recorded in centimetres. For further information about the visual leaf damage score rating see Appendix 1 of this paper.

3.2 Approach that was used for Analysis.

GenStat version, 14 was used for ANOVA and separation of means was done using the least significant difference (LSD) at 5%. The approach that was used for data analysis involves, testing for the significance of interactions and main effects of the fixed factors, diagnostic checking for model assumptions and model adequacy. Formulae for Fisher's least significant difference that was used in this study were presented in appendix 2.

3.2.1 The Split-Split-Plot Model

The split-split plot model is given as:

$$Y_{ijkl} = \mu + \alpha_i + b_l + (wp)_{il} \qquad \text{Whole plot portion}$$

$$+\beta_j + (\alpha\beta)_{ij} + (sp)_{ijl} \qquad \text{Split plot portion}$$

$$+\tau_k + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\alpha\beta\tau)_{ijk} + (ssp)_{ijkl} + \varepsilon_{(ijkl)} \qquad \text{Split-split plot portion}$$

For, $\begin{cases} i = 1,2 \\ j = 1,2 \\ k = \overline{1,6} \\ l = 1,2 \end{cases}$

Where: Y_{ijkl} – is the response from the whole plot i, block j, split plot k, split-split plot l;

μ- is the grant mean level;

α_i- is effect of the i^{th} level of nitrogen (whole plot factor) which is fixed;

b_l- is effect of l^{th} level of soil pH (block factor) which is random;

β_j- is effect of j^{th} maize seed variety (split plot factor) which is fixed,

τ_k- is effect of k^{th} maize stem borer pesticide (split-split plot factor) which is fixed,

$(\alpha\beta)_{ij}$- is interaction between the i^{th} level of nitrogen and j^{th} maize seed variety (Whole plot factor and Split plot factor),

$(\alpha\tau)_{ik}$- is the interaction between the i^{th} level of nitrogen and k^{th} maize stem borer pesticide (Whole plot factor and Spit-split plot factor),

$(\beta\tau)_{jk}$- is the interaction between the j^{th} maize seed variety and k^{th} maize stem borer pesticide (Split plot factor and split-split plot),

$(\alpha\beta\tau)_{ijk}$- is the interaction between the i^{th} level of nitrogen, j^{th} maize seed variety and k^{th} maize stem borer pesticide (Whole plot factor, Split plot factor and Split-split plot factor),

$(wp)_{il}$- is the random error corresponding to whole plot elements in block *l* where whole plot *i* is applied,

$(sp)_{ijl}$- is the random error corresponding to split plot elements in whole plot *i* and in block *l* where split plot factor *j* is applied and

$(ssp)_{ijkl}$- Random error corresponding to split-split plot elements in split plot *j*, whole plot *i* and in block *l* where split-split plot factor *k* is applied. The resultant random error for the whole model will be the summation of all the random error corresponding to the three proportions, that is $\varepsilon_{(ijkl)} = (wp)_{il} + (sp)_{ijl} + (ssp)_{ijkl}$.

3.2.2 Model Assumptions

Analysis of data was done while basing on the following assumptions

- $\alpha_i's$, $\beta_j's$ and $\tau_k's$ (that is treatments) are assumed to be fixed real constants satisfying the constraints that $\sum_{i=1}^{2}\alpha_i = \sum_{i=1}^{2}\beta_j = \sum_{i=1}^{6}\tau_k = 0$.
- $b_l's$ (blocks) are assumed to be random variables which are identically and independent normally distributed with mean zero (0) and variance i.e. $b \sim NID(0, \sigma^2{}_b)$
- $(wp)_{il}'s$, $(sp)_{ijl}'s$ and $(ssp)_{ijkl}'s$ (that is errors) are independent random variables that is, $cov\{(wp)_{i_1l_1}, (wp)_{i_2l_2}\} = 0$, $cov\{(sp)_{i_1j_1l_1}, (sp)_{i_2j_2l_2}\} = 0$ and

$$cov\{(ssp)_{i_1j_1k_1l_1}, (ssp)_{i_2j_2k_2l_2}\} = 0, \text{ for} \begin{cases} i_1 \neq i_2 \\ j_1 \neq j_2 \\ k_1 \neq k_2 \\ l_1 \neq l_2 \end{cases}$$

3.2.3 Hypotheses

The following seven pairs of hypotheses were tested using Fisher test (F-test):

1. **Nitrogen level, maize variety and maize stem borer management scheme interaction effect**

   H_o: All the $(\alpha\beta\tau)_{ijk}'s$ are equal to zero, versus

   H_1: Some $(\alpha\beta\tau)_{ijk}'s$ are significantly not equal to zero.

2. **Nitrogen level and maize variety interaction effect**

   H_o: All the $(\alpha\beta)_{ij}'s$ are equal to zero, versus

   H_1: Some $(\alpha\beta)_{ij}'s$ are significantly not equal to zero.

3. **Nitrogen level and maize stem borer management scheme interaction effect**

   H_o: All the $(\alpha\tau)_{ik}'s$ are equal to zero, versus

   H_1: Some $(\alpha\tau)_{ik}'s$ are significantly not equal to zero.

4. **Maize variety and maize stem borer management scheme interaction effect**

   H_o: All the $(\beta\tau)_{jk}{'s}$ are equal to zero, versus

   H_1: Some $(\beta\tau)_{jk}{'s}$ are significantly not equal to zero.

5. **Nitrogen level effect**

   H_o: All the $\alpha_i{'s}$ are equal to zero, versus

   H_1: Some $\alpha_i{'s}$ are significantly not equal to zero.

6. **Maize variety effect**

   H_o: All the $\beta_j{'s}$ are equal to zero, versus

   H_1: Some $\beta_j{'s}$ are significantly not equal to zero.

7. **Maize stem borer management scheme effect**

   H_o: All the $\tau_k{'s}$ are equal to zero, versus

   H_1: Some $\tau_k{'s}$ are significantly not equal to zero.

Chapter 4 Results and Analysis

Introduction

In this chapter, data analysis is presented using the procedures outlined in the preceding chapters. GenStat version 14 was used for analysis which encompassed analysis of variance (ANOVA), pair-wise comparison of treatments, diagnostic checking of model assumptions (homogeneity of variance, independence of residuals and normality) and goodness of fit test. Summary information were presented in the appendices.

4.1 The degree of crop damages for each treatment.

The four damage parameters that are caused by stem borer namely leaf damage score, dead hearts counts, exit holes and the cumulative tunnel length were assessed for each maize stem borer control scheme. Using the results from figure 2, it was noted that the control scheme (with nothing used to control stem borer) had highest figures for all the damage parameters and a low yield of 12.1% (30.39 tonnes per hectare). This is in agreement with Chinwada and Overholt, (2012) who emphasised the need to control maize stem borer by stating that the lepidopteran stem borer's larvae can significantly result in fatal damages of maize hence low yields if uncontrolled. Meanwhile, the schemes with dipterex 25% grounded and lantana camara leaves extracts had highest yields of 19.36% (48.45 tonnes) and 19.342% (48.44 tonnes) respectively as well as less damages.

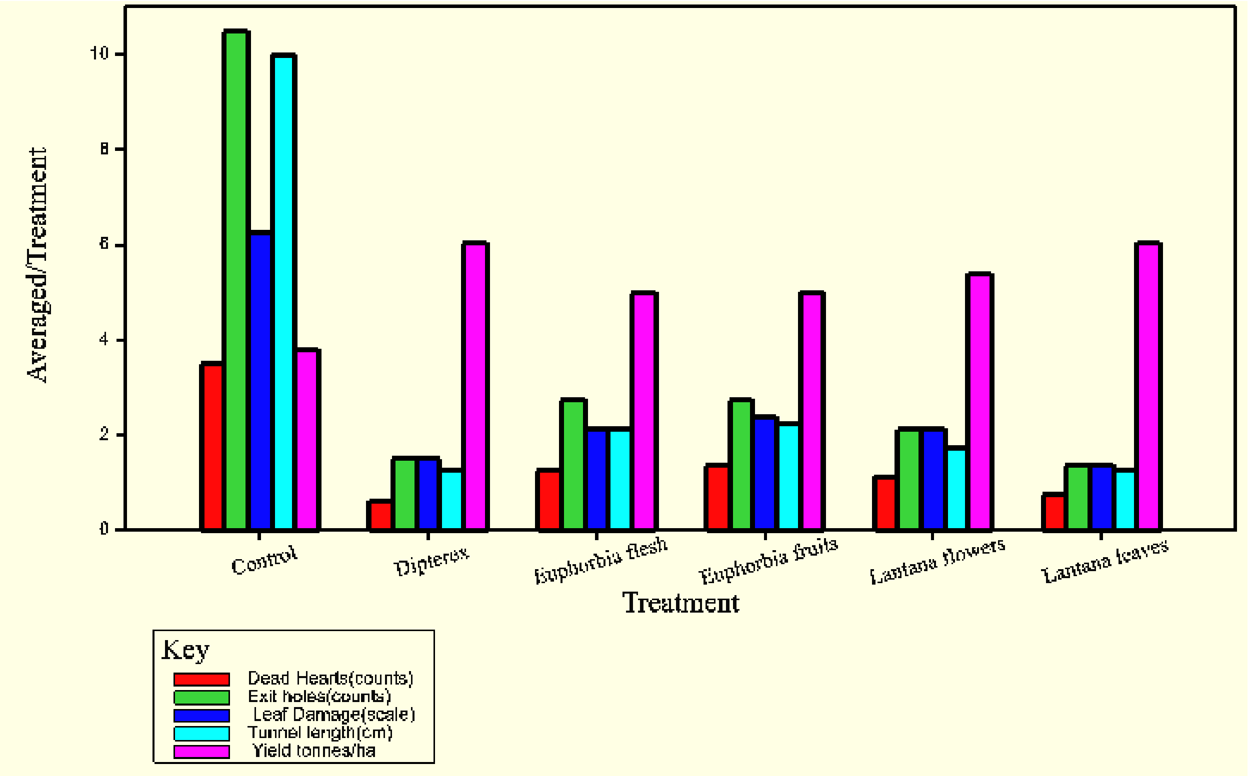


Figure 2: Effect of crop damages on grain yield for each maize stem borer control scheme

4.2 The impact of maize stem borer damages on maize grain yield subject to methods of stem borer control

Information about which pest management scheme lessens different crop damage parameters is very important to farmers as it helps in identifying which treatment to use at each stage of infection. The following subsections explores the effect of each control plan on damages that are caused by maize stem borer. Table 5 shows the effect of stem borer management schemes on exit holes, leaf damage, tunnel length and dead hearts.

Table 5: The effect of stem borer management schemes on exit holes, leaf damage, tunnel length and dead hearts

	Average/plot			
Treatment	Exit holes	Leaf damage	Tunnel length	Dead hearts
Dipterex 25% grounded	1.50^a	1.50^a	1.25^a	0.62^a
Lantana camara Leaves	1.38^a	1.38^a	1.25^a	0.75^a
Lantana camara flower	2.12^a	2.12^b	1.75^a	1.12^a
Euphorbia flesh	2.75^a	2.12^b	2.12^a	1.25^a
Euphorbia fruits	2.75^a	2.12^b	2.25^a	1.38^a
Nothing	10.50^c	6.25^c	10.00^b	3.50^b
F-Prob	<.001	<.001	<.001	<.001
F-value	42.48	28.48	45.88	17.16
SED	0.755	0.482	0.711	0.359
LSD	1.524	0.972	1.434	0.724

Note: Means with different superscripts are significantly different at 5% level of significance.

4.2.1 The effect of methods of stem borer control on exit holes

From table 5, the F-value of 42.48 ($p<0.001$) for the treatments on exit holes implies that the treatments are significantly different. The mean of performance of plots with nothing applied on exit holes, were the highest (10.50). Figure 3, shows the performance of each maize stem borer control on exit holes.

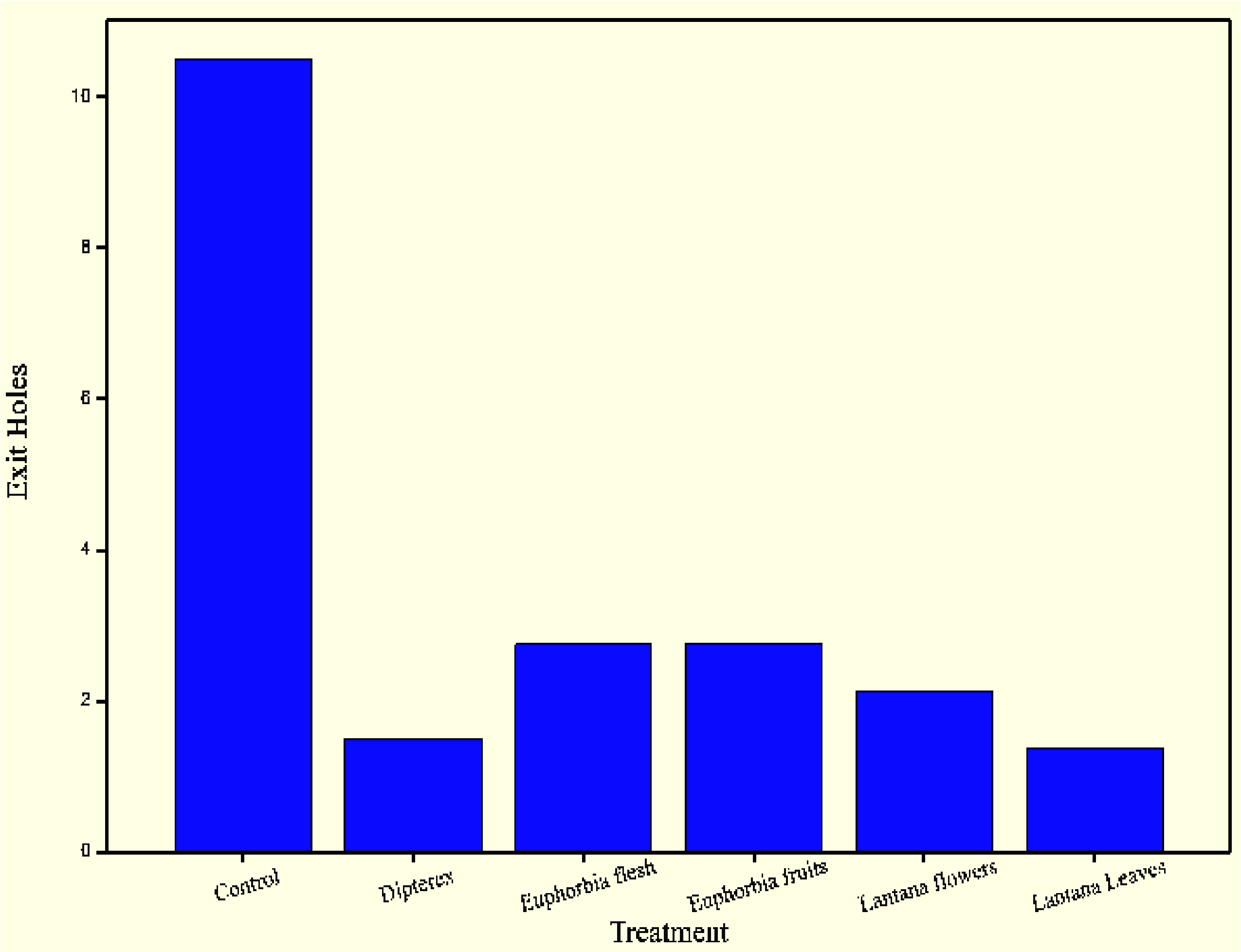


Figure 3: The performance of each maize stem borer control on exit holes

The absolute differences between the means compared against least significance difference (LSD) of 1.524, indicated that the difference between dipterex 25% grounded and all the biocides (Lantana leaves, lantana flowers, euphorbia flesh and euphorbia fruits extracts) were insignificant. The variation in exit holes increased from dipterex (1.50), lantana leaves (1.38), lantana leaves (2.12), euphorbi*a* flesh (2.75), euphorbia fruits (2.75) to control with nothing (10.50).

4.2.2 The effect of methods of stem borer control on leaf damage

Table 5 is showing the F-value of 28.48 and p-value <0.001. This implies that the performance of treatments on controlling leaf damage is significantly different. Least leaf damage scores were noted on plots that received actions (treatments) in comparison with plots that received nothing and this is illustrated Figure 4

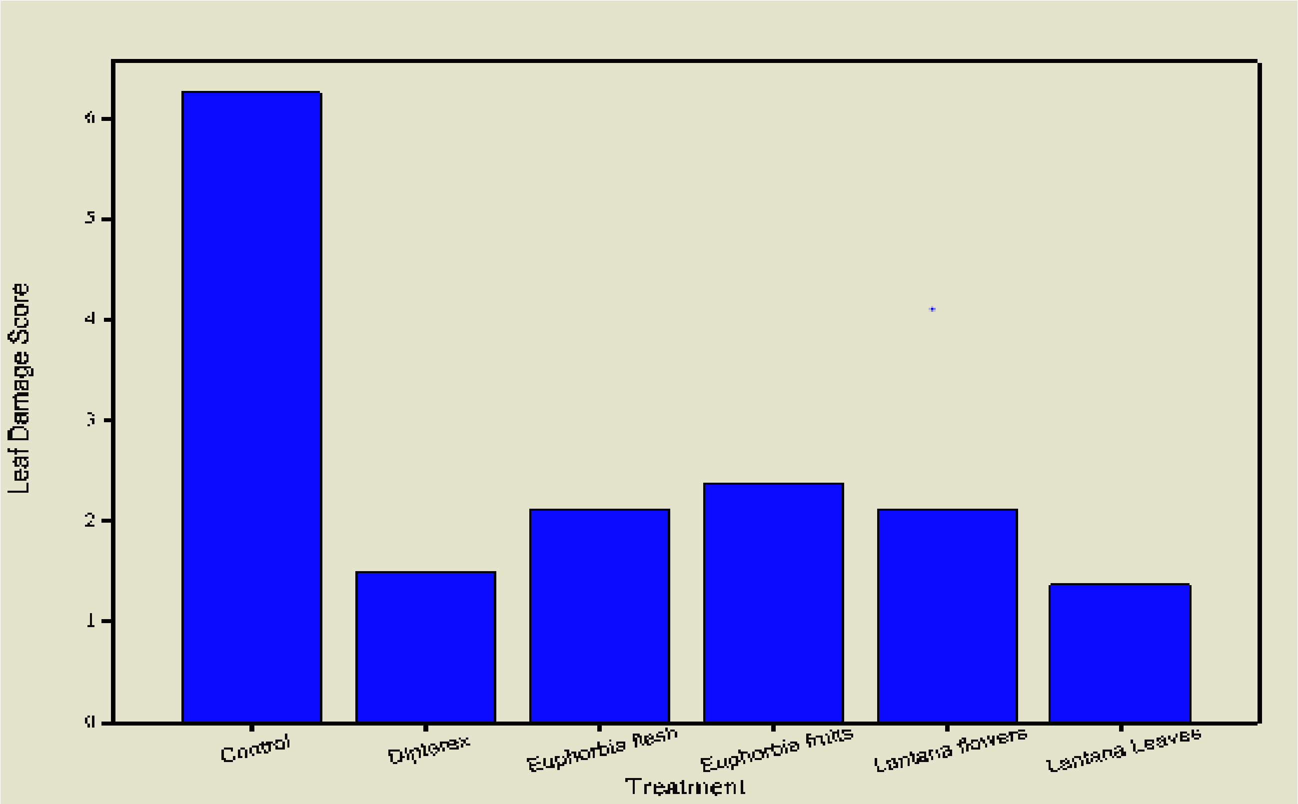


Figure 4: The performance of each maize stem borer control on leaf damage

From table 5, we established that there were significant differences among treatments except for only two pairs namely dipterex 25% grounded and lantana camara leaves; euphorbia flesh and euphorbia fruit. Thus, we established that the performance of two pairs namely dipterex 25% grounded and lantana camara leaves; euphorbia flesh and euphorbia fruit were the same.

4.2.3 The effect of methods of stem borer control on tunnel length

Table 5, is showing that the variance ratio (42.48) on tunnel length for each maize stem borer control is significantly different ($p<0.001$) and LSD = 1.343. From table 5, we noted that all the treatments were significantly different from the plots where nothing was applied. Figure 5 shows the effect of each maize stem borer control measure on tunnel length.

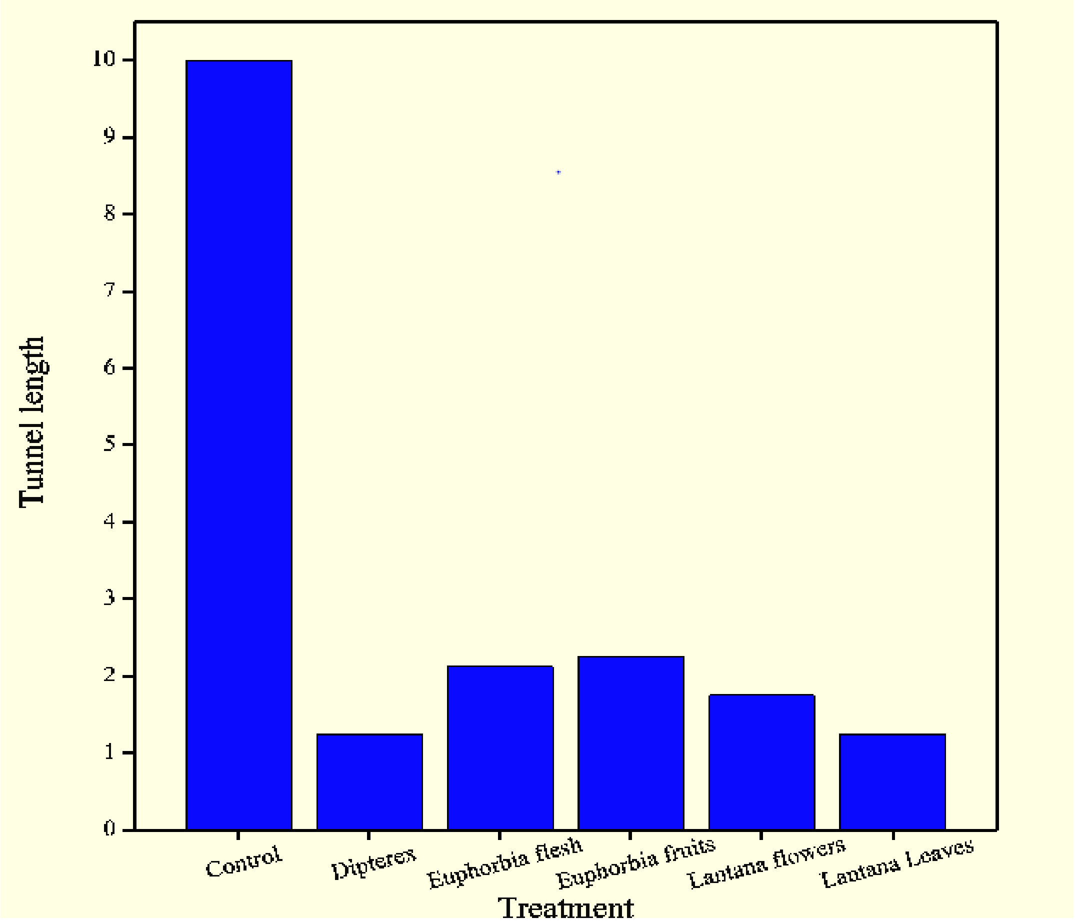


Figure 5: The performance of each maize stem borer control on tunnel length

The highest mean tunnel length was noted on where nothing was applied (10) followed by euphorbia fruit (2.25), euphorbia flesh (2.12), lantana flowers (1.75 and lantana leaves (1.25). A recording of (1.25) was realized on dipterex 25% granular.

4.2.4 The effect of methods of stem borer control on dead hearts

From table 5, we noted that there was no significant difference among the following treatments, dipterex 25% grounded, lantana leaves, lantana flowers, euphorbia fruits and euphorbia flesh. Figure 6, is an illustration of the performance of maize stem borer control measure on dead hearts.

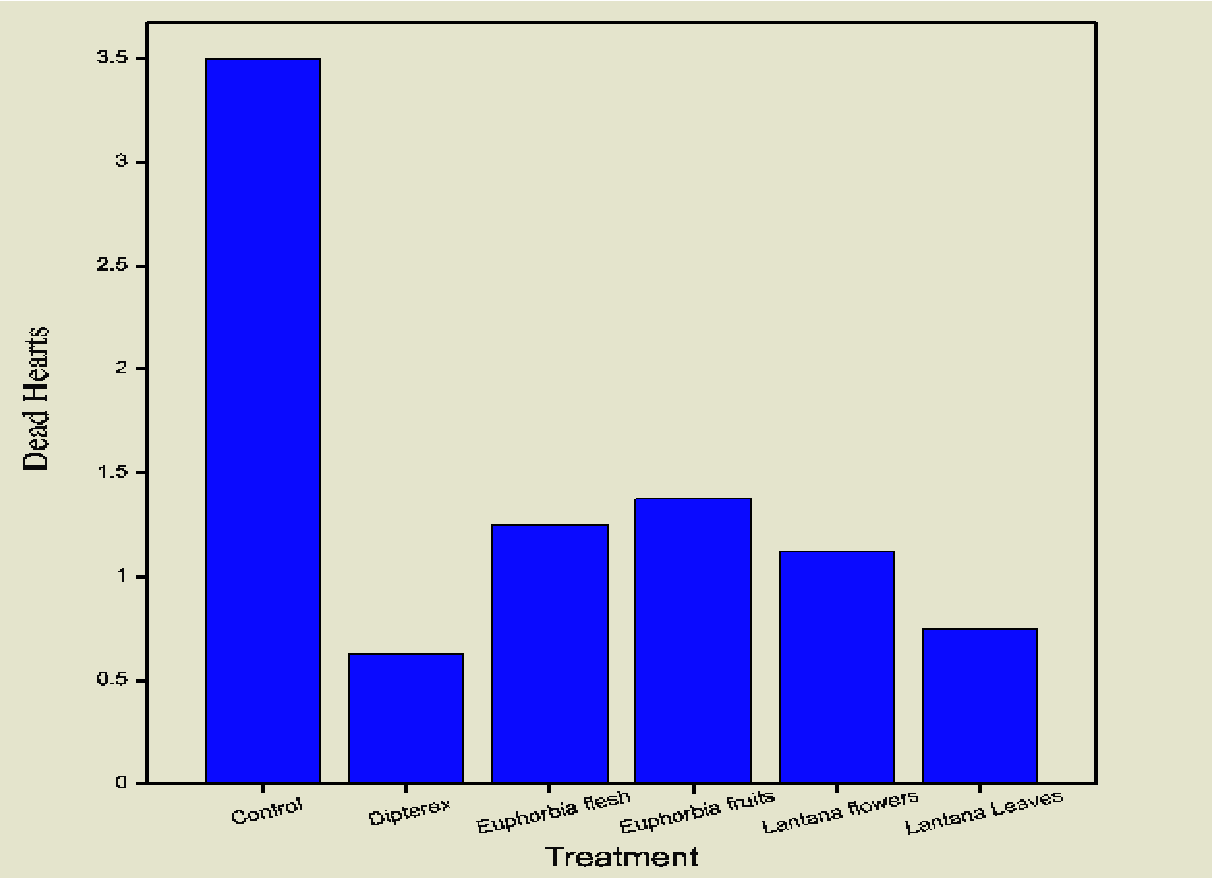


Figure 6: The performance of each maize stem borer control on dead hearts

The least counts of dead hearts was noted on dipterex 25% grounded with (1.62) followed by lantana leaves (0.75), lantana flower (1.12), euphorbia flesh (1.25) and euphorbia fruits (1.350). A recording of (3.50) was recognised where nothing was applied.

4.3 The effect of factors in the experiment

ANOVA was used to compare the performance of the biocides (lantana leaves, lantana fruits, euphorbia flesh, and euphorbia fruits) and dipterex 25% grounded at a reference level of the control (with nothing) on two levels of nitrogen and two varieties of seeds. The results are shown in table 6.

Table 6: ANOVA of yield data due to plant damage resulting from maize stem borer under different control methods.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	1	0.206719	0.206719	2.72	
Block. Nitrogen stratum					
Nitrogen	1	0.478002	0.478002	6.29	0.242
Whole plot error	1	0.076002	0.076002	2.62	
Block.Nitrogen.Variety stratum					
Variety	1	5.789352	5.789352	199.22	0.005
Nitrogen. Variety	1	0.861352	0.861352	29.64	0.032
Subplot error	2	0.058121	0.029060	4.86	
Block.Nitrogen.Variety. Treatment stratum					
Treatment	5	28.353285	5.670657	947.41	<.001
Nitrogen. Treatment	5	0.468735	0.093747	15.66	<.001
Variety. Treatment	5	0.809585	0.161917	27.05	<.001
Nitrogen.Variety.Treatment	5	0.326535	0.065307	10.91	<.001
Sub-subplot error	20	0.119708	0.005985		
Total	47	37.547398			

The results in table 6 indicate that maize variety, treatment (with the following levels Lantana camara leaves extracts, lantana camara flowers extracts, euphorbia fruits extracts, euphorbia flesh extracts, dipterex 25% grounded and control with nothing) and all the interaction effects are significantly different with p-values of <0.05. The difference in effects of nitrogen alone is insignificant with a p-value of 0.242. The results obtained from the $2 \times 2 \times 6$ replicated split-split plot experimental design showed that nitrogen rates (0kg/ha and 100kg/ha) were not significantly different in controlling maize stem borer. Dropping this factor from the model will not be a right decision since its interactions with other factors showed some significant difference. The reasons for this insignificance can be attributed to the fact that enhancing soil fertility alone is not effective in controlling maize stem borer. This then contradicts to Ogah and Ogbodo, (2011) who suggested that enhancing soil fertility is helpful in controlling pests.

Pairwise comparison of the treatment means was done based on the summary information in Appendix 9 and Appendix 10 respectively.

4.3.2 Effect of Factors without Interactions

In this section we present a comparison of treatment means of the main factor effects. Note that F-test from table 6 showed that the effect of the two nitrogen levels are not significantly different, thus pairwise comparison of the treatment means for the whole plot factor (nitrogen) will not be done.

4.3.2.1 Testing whether Maize variety has an effect in the experiment

The F-value (F.Pr) is <0.001, so the two maize varieties are significantly different. In this case we say that the effects of SC627 SeedCo and Pioneer 30G95 as two maize varieties on maize stem borer management are significantly different. Pioneer 30G95 (5.566) had the highest mean of grain yields compared to SC627 SeedCo (4.871) see Appendix 9.

4.3.2.2 Testing whether maize stem borer control measure has an effect in the experiment

In order to assess the effectiveness of each plant extracts, dipterex 25% grounded and a scheme with no pesticides (with nothing), Appendix 11 was used for values of absolute difference of estimated means and LSD=0.0807. The means $\mu_{\dots k}$ and $\mu_{\dots k_{\square}}$ are significantly different if $\left|\bar{Y}_{\dots k} - \bar{Y}_{\dots k_{\square}}\right| > LSD$.

The effect of the treated plots were significantly different from the untreated plots since $|\bar{Y}_{\dots k} - \bar{Y}_{\dots 6}|$ >LSD=0.0807 for $k \neq 6$. Where k represent the k^{th} method of stem borer control. Pairing each of the four biocides with dipterex 25% grounded we established that they were significantly different except for lantana camara leaves. The results 0.004=$\left|\bar{Y}_{\dots 1} - \bar{Y}_{\dots k_6}\right|$<LSD=0.0807 implies that Lantana camara leaves and dipterex 25% grounded were not significantly different. The performance of extracts from different parts of the euphorbia plants were the same since 0.006=$\left|\bar{Y}_{\dots 3} - \bar{Y}_{\dots k_4}\right|$<LSD=0.0807.

4.3.3 Effect of Factors with Interactions

To compare the means of different treatment combinations, Appendix 9 was used to calculate the absolute differences of the expected means. The results were compared with respective least significant differences.

1) To compare the two maize variety means at an average of all sub-subplot treatments on the same levels of whole plot, LSD=0.4540. For both levels of nitrogen (0kg/ha and 100kg/ha) we established that SC627 SeedCo and Pioneer 30G95 had the following results, 0.962=

$\left|\bar{Y}_{.ij.}-\bar{Y}_{.ij_{\square}.}\right|$>LSD=0.4540 and 0.427= $\left|\bar{Y}_{.ij.}-\bar{Y}_{.ij_{\square}.}\right|$>LSD=0.4540 respectively. Thus, the effect of maize varieties are significantly different irrespective of nitrogen level.

2) To compare the two nitrogen rates at an average of all subplot treatments on the same levels of sub-subplot, 66 pairs were compared and LSD=0.2994. For both nitrogen rates (0kg/ha and 100kg/ha), we established that all the control measure were significantly different except for a pair of interaction which involved lantana leaves and dipterex 25% grounded whose absolute difference are 0.227 and 0.225 respectively. For means corresponding to each control measure, the interactions were not significantly different. The rest, from the 66 pairs were significantly different.

3) To compare two maize stem borer control level means at an average of all subplot treatments on the same levels of whole plot, 30 pairs were compared and LSD=0.4191. For nitrogen rate of 0kg/ha, pairs of lantana leaves and dipterex 25% grounded; euphorbia flesh and euphorbia fruits were not significantly different with mean absolute differences of 0.227 and 0.225 respectively. For nitrogen rate of 100kg/ha, lantana leaves and dipterex 25% grounded were significantly different with absolute difference of 0.225 and lantana flowers, euphorbia flesh and euphorbia flowers were not significantly different. The rest were significantly different.

4) To compare the two nitrogen means at an average of all sub-subplot treatments on the same or different levels of subplots, 6 pairs of interactions were compared and LSD=0.2994. The interaction of nitrogen (0kg/ha) and maize variety (Pioneer 30G95) compared with the interaction of nitrogen (100kg/ha) and maize variety (Pioneer 30G95) showed no significant difference with an absolute difference of 0.068. Also the interaction of nitrogen (100kg/ha) and maize variety (SC627 SeedCo) compared with the interaction of nitrogen (100kg/ha) and

maize variety (Pioneer 30G95) showed no significant difference with an absolute difference of 0.213. The other interactions were significantly different.

5) To compare the two maize stem borer control means at an average of all whole plot treatments on the same levels of the subplot treatments, 30 pairs were assessed and LSD=0.1638. For both maize varieties, (SC627 SeedCo and Pioneer 30G95), the interactions that involve lantana leaves and dipterex 25% grounded (with respective absolute differences of 0.037 and 0.04); euphorbia flesh and euphorbia fruit (with respective absolute differences of 0.068 and 0.07) were not significantly different. The interaction of SC627 SeedCo and lantana flowers compared with the interaction of Pioneer 30G95 and lantana flowers indicated no significant difference (absolute difference of 0.037). Also interaction of SC627 SeedCo and lantana flowers compared with the interaction of Pioneer 30G95 and euphorbia fruits indicated no significant difference (absolute difference of 0.163). The rest of the interactions were significantly different.
6) To compare the two maize varieties means at an average of all whole plot treatments on the same or different levels of sub-subplots, 66 pairs were compared and LSD=0.114. . For both maize varieties, (SC627 SeedCo and Pioneer 30G95), the interactions that involve lantana leaves and dipterex 25% grounded (with respective absolute differences of 0.037 and 0.04); euphorbia flesh and euphorbia fruit (with respective absolute differences of 0.068 and 0.07) were not significantly different. The interaction of SC627 SeedCo and lantana flowers compared with the interaction of Pioneer 30G95 and lantana flowers indicated no significant difference (absolute difference of 0.037). The rest of the interactions were significantly different.

7) To compare the two maize variety means at an average of same combination of whole plot and sub-subplot treatments 12 pairs were assessed and LSD=0.1614.. For the interactions that involve nitrogen at 0kg/ha, the two maize varieties (SC627 SeedCo and Pioneer 30G95) were significantly different. For the interactions that involve nitrogen at 100kg/ha, absolute differences of corresponding to lantana flowers (0.07), euphorbia fruits (0.032) and euphorbia flesh (0.230) implies no significant difference. The other pairs corresponding to lantana leaves, dipterex 25% grounded and the control were significantly different.
8) To compare two nitrogen means at an average of same combination of subplot and sub-subplot treatments, 6 pairs were compared and LSD=0.2316. The absolute differences of the pairs corresponding to lantana leaves (0.494) and euphorbia fruit (0.44) indicates significant difference between the interactions. The absolute differences of the pairs corresponding to lantana flowers (0.037), euphorbia flesh (0.005), and dipterex 25% grounded (0.042) and the control with nothing applied (0.177) implies no significant difference between two nitrogen means.
9) To compare the maize stem borer control means at an average of same combination of whole plot and subplot treatments, 60 pairs were assessed and LSD=0.3177. For all the four interaction groups we noted that all the treated plots are significantly different from the untreated on (the control of the experiment with nothing applied).

- For the combination of nitrogen 0kg/ha and maize variety SC627 SeedCo, we noted that the pairs lantana leaves and dipterex 25% grounded; euphorbia flesh and euphorbia fruits, are not significantly different with absolute difference of 0.255 and 0.075 respectively. The rest are significantly different.

- For the combination of nitrogen 0kg/ha and maize variety Pioneer 30G95, we noted that lantana leaves and dipterex 25% grounded were not significantly different (with absolute difference of 0.260) whilst the rest pairs are significantly different.
- For the combination of nitrogen 100kg/ha and maize variety SC627 SeedCo we noted that lantana leaves and dipterex 25% grounded; lantana flowers and dipterex 25% grounded; euphorbia flesh and euphorbia fruits are not significantly different with absolute differences of 0.27, 0.215 and 0.012 respectively. The rest are significantly different.
- For the combination of nitrogen 100kg/ha and maize variety Pioneer 30G95, we noted that lantana leaves and dipterex 25% grounded; lantana flowers and dipterex 25% grounded; euphorbia flesh and euphorbia fruits are not significantly different with absolute differences of 0.18, 0.215 and 0.21 respectively. All the other comparisons were significantly different.

4.4 Diagnostic Checking

In order to re-define, re-check and re-fit the data if necessary the following diagnostic checks were done:

4.4.1 Diagnostic checking of model assumptions

4.4.1.1 Homogeneity variance Assumption

The plots in figure 7 are from data of noise in yield measured in tonnes per hectare. Based on the plots of residuals against fitted values in figure 4.1, the error variance is equal since the plots are evenly distributed. Thus the residuals are random variables with mean zero $(E\{\mathrm{e}\} = 0)$ and a constant variance (σ^2).

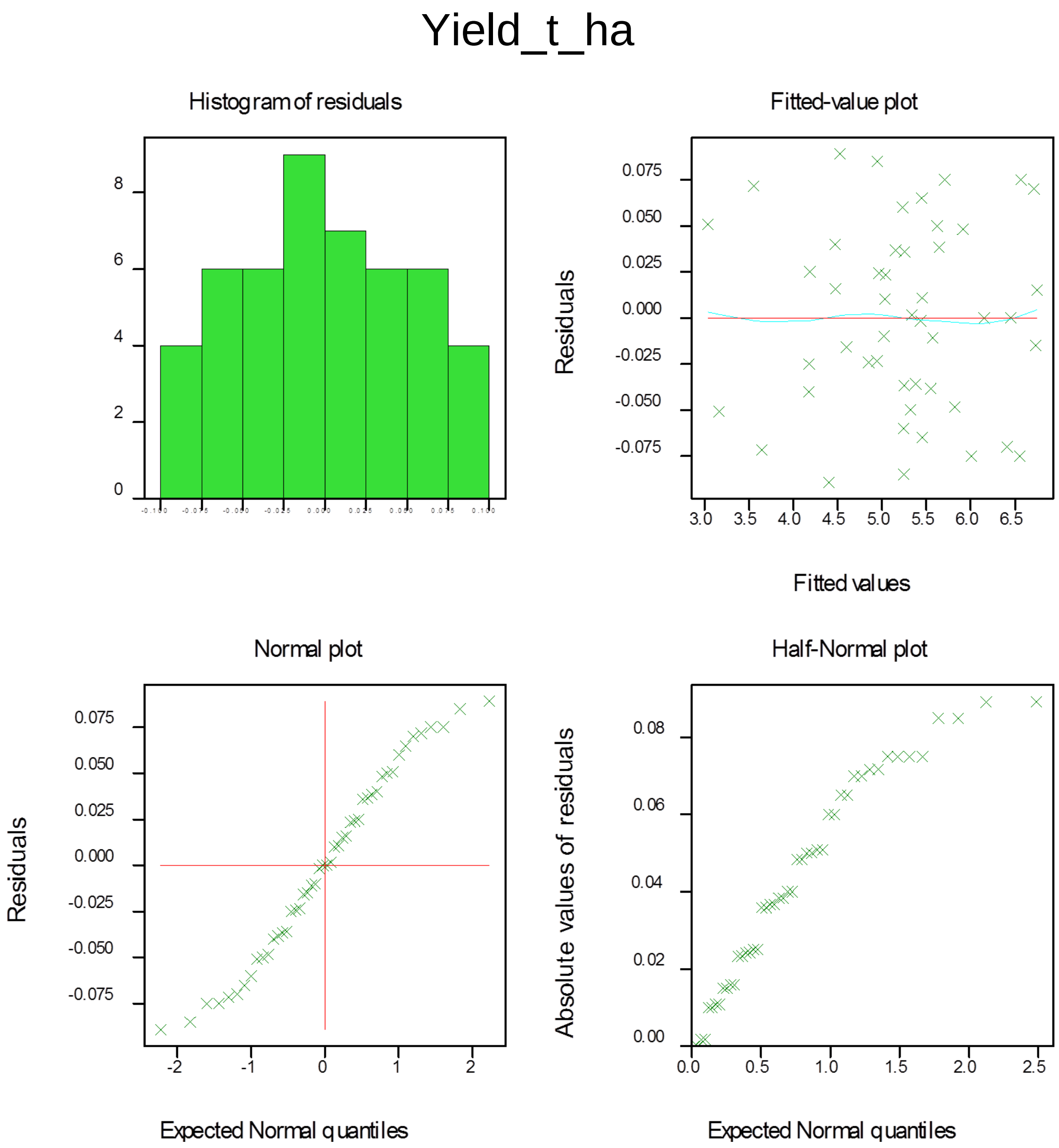


Figure 7: Normal plots and histogram of residuals for maize grain yield data.

4.4.1.2 Independence of error terms Assumption

The scatter plot of error terms against fitted values in figure 2 is shapeless so we can say that the residuals are independent, so are the response variables.

4.4.1.3 Normality Assumption

From figure 7, we can conclude that the data was generated from a normal distribution since the fitted values are evenly distributed, histograms of error terms are bell-shaped and non-skewed and the normal and half-normal plots exhibit approximately straight lines.

Since the model residual assumptions are fulfilled, it means that the data set is sufficiently described by the model. As a result the data need not to be transformed as the model assumptions are not violated.

4.4.2 Test for goodness of fit

1) **Coefficient of determination R^2**

The coefficient of determinations for the whole plot, subplot and sub-sub plots were found to be 0.863, 0.9913 and 0.996 respectively. Their R-squared adjusted were 0.892 for the whole plot, 0.9945 for the sub plot and 0.9986 for the sub-subplot which implies that the proportion of variation in the response data (grain yield per hectare) that is explained by the variation in the factors (nitrogen rates, maize varieties and pesticides) is very significant. Therefore the model fits data well.

2) **Coefficient of Variation**

From the appendix 12, results obtained after using Genstat version 14 we found out that, the coefficient of variation for the whole plot, subplot and sub-sub plots were found to be 1.5%, 1.7% and 2.1% respectively. The coefficient of variation are small meaning that there is little influence from the regression lines, the model fits the data perfectly.

Therefore the model for this study was as follows:

$$\hat{Y}_{ijkl} = 5.219 + \alpha_i + b_l + \qquad \text{Whole plot portion}$$

$$+\beta_j + (\alpha\beta)_{ij} + \qquad \text{Split plot portion}$$

$$+\tau_k + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\alpha\beta\tau)_{ijk} \qquad \text{Split-split plot portion}$$

For, $\begin{cases} i = 1,2 \\ j = 1,2 \\ k = \overline{1,6} \\ l = 1,2 \end{cases}$

Where the terms are as defined in the methodology section 3.2.1 of this paper.

Chapter 5 Conclusion and Recommendations

Overview

The purpose of this chapter is to summarise the main findings and discuss the implications of the experimental design reported in this project. Conclusion and recommendations are presented.

The overriding purpose of this study was to determine the effectiveness of biocides (lantana camara leaves, lantana camara flowers, euphorbia flesh and euphorbia fruits extracts) in comparison to a chemical pesticide (dipterex 25% grounded) in controlling maize stem borer under a control with nothing applied. A split-split plot design and analysis was used in which soil pH (6.5 acid and 7.8 alkaline) as the block (replicate) factor, two nitrogen levels as whole plot factors (0kg/ha and 100kg/ha) and two maize varieties (SC627 SeedCo and Pioneer 30G95) as subplot factor were considered. To accomplish the purpose of the study, it becomes necessary to focus on the analysis of variance (ANOVA), least significant difference and model diagnostic checking. The grain yields for this study were higher where either a chemical pesticide or biocide was used than where nothing was applied. The highest records of exit holes, leaf damages, tunnel length and dead hearts were noted where nothing was applied as a control measure against maize stem borer. The results obtained from the $2 \times 2 \times 6$ replicated split-split plot experimental design showed that nitrogen rates (0kg/ha and 100kg/ha) were not significantly different in controlling maize stem borer. Dropping this factor from the model was not a right decision since its interactions with other factors showed some significant difference. The results of the analysis of subplot portion showed that the effect of the two maize varieties were different. Pioneer 30G95 (4.871) had the highest mean of grain yields compared to SC627 SeedCo (5.566).

5.2 Conclusion

Chemical pesticides can be costly and inaccessible to communal and small scale farmers. Lantana leaves, lantana flowers, euphorbia flesh and euphorbia fruits ashes can be used instead in controlling maize stem borer as shown by the smallest mean total of exit holes, leaf damage, dead hearts and cumulative tunnel length as well as improved grain yields. Other factors such as maize variety resistance and the use of nitrogen as top dressing fertilizer should be considered for integrated stem borer management schemes.

5.3 Recommendations

Small scale farmers and communal farmers in Zimbabwe or even globally are encouraged to alleviate the problem of maize stem borer outbreak by means of biocides. Lantana camara leaves extracts can be used in place of dipterex 25% grounded. In controlling the maize crop damages caused by stem borer, lantana camara leaves, lantana camara flowers, euphorbia flesh and euphorbia fruits extracts can be used with a greater preference to lantana camara leaves. A combined effort of 100kg/ha of nitrogen, Pioneer 30G95 (maize variety) and lantana camara leaves extract, should be considered as one of the best pest management scheme that includes plants which are naturally available.

When analysing data researchers and experimenters in all fields of enquiry especially agronomy should make use of experimental design and analysis such as split plot, split-split plot and their extensions. They are the best when one needs to know the effect of multi-factors and their interactions (combined efforts) in the experiment.

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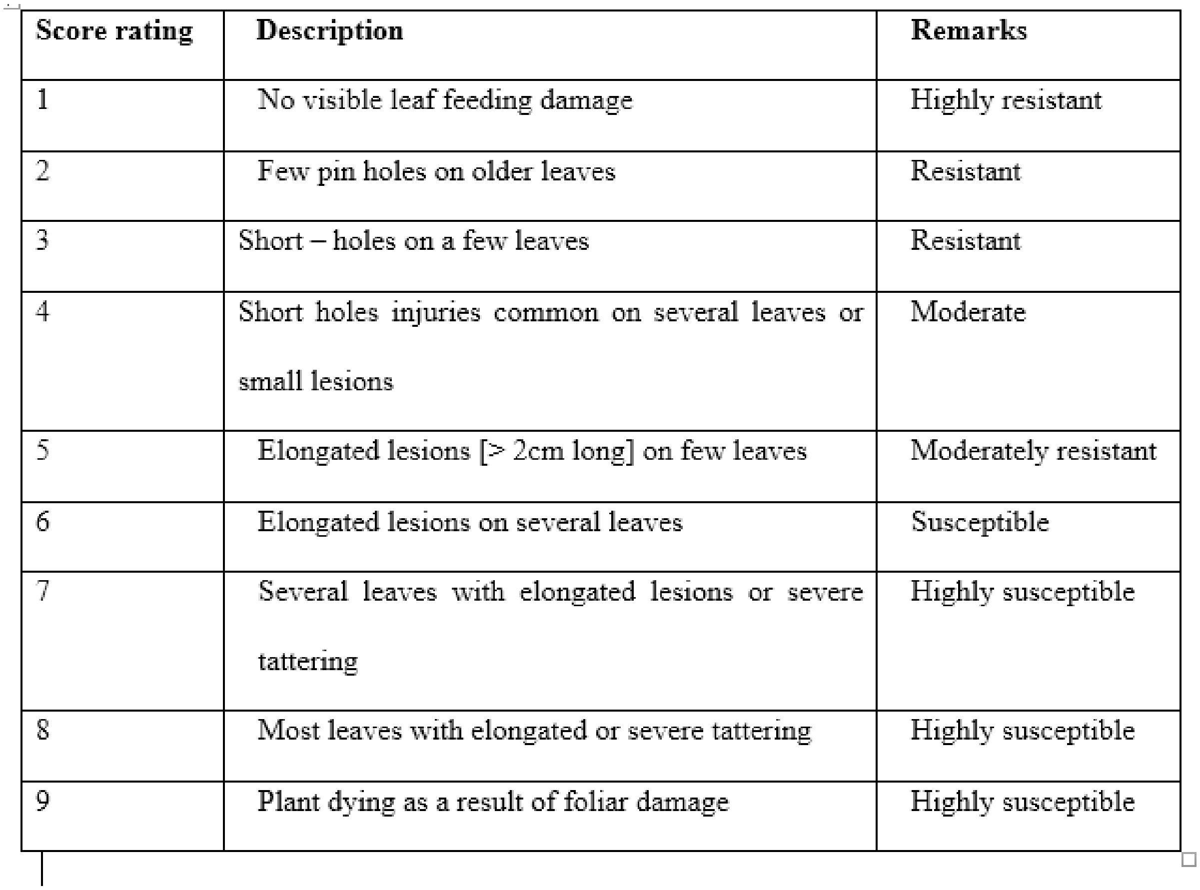
Appendices

Appendix 1: Table of leaf damage score ratings



Score rating	Description	Remarks
1	No visible leaf feeding damage	Highly resistant
2	Few pin holes on older leaves	Resistant
3	Short – holes on a few leaves	Resistant
4	Short holes injuries common on several leaves or small lesions	Moderate
5	Elongated lesions [> 2cm long] on few leaves	Moderately resistant
6	Elongated lesions on several leaves	Susceptible
7	Several leaves with elongated lesions or severe tattering	Highly susceptible
8	Most leaves with elongated or severe tattering	Highly susceptible
9	Plant dying as a result of foliar damage	Highly susceptible

Source of adaptation Munyini et al (2012)

Appendix 2: List of Least Significance Differences

The following pair-wise comparisons and their respective hypotheses were tested,

1. To compare the two nitrogen level means at an average of all subplot and sub-subplot treatments and the following hypothesis was tested.

$$H_0: \mu_{.i..} = \mu_{.i_{\square}..} \; versus \; H_1: \mu_{.i..} \neq \mu_{.i_{\square}..}$$

   Where, μ_1 and μ_2 are means estimated by $\bar{Y}_{.i..}$ and $\bar{Y}_{.i_{\square}..}$ respectively. The computational formula for LSD is given in equation 3.5.4.1.

$$LSD = t_{\frac{\alpha}{2}}^{Err(wp).df}\sqrt{\frac{2Error(wp)MS}{rbc}} \qquad \text{…… equation (A2.1)}$$

   We reject H_0 if $\left|\bar{Y}_{.i..} - \bar{Y}_{.i_{\square}..}\right| > LSD$

2. To compare the two maize variety level means at an average of all whole plot and sub-subplot treatments and the following hypothesis was tested.

$$H_0: \mu_{..j.} = \mu_{..j_{\square}.} \; versus \; H_1: \mu_{..j.} \neq \mu_{..j_{\square}.}$$

$$LSD = t_{(\frac{\alpha}{2},Err(sp).df)}\sqrt{\frac{2Error(sp)MS}{rac}} \qquad \text{…… equation (A2.2)}$$

   We reject H_0 if $\left|\bar{Y}_{..j.} - \bar{Y}_{..j_{\square}.}\right| > LSD$

3. To compare the two maize stem borer control means at an average of all whole plot and subplot treatments and the following hypothesis was tested.

$$H_0: \mu_{...k} = \mu_{...k_{\square}} \; versus \; H_1: \mu_{...k} \neq \mu_{...k_{\square}}$$

$$LSD = t_{(\frac{\alpha}{2},Err(ssp).df)}\sqrt{\frac{2Error(ssp)MS}{rab}} \qquad \text{…… equation (A2.3)}$$

   We reject H_0 if $\left|\bar{Y}_{...k} - \bar{Y}_{...k_{\square}}\right| > LSD$

4. To compare the two maize variety level means at an average of all sub-subplot treatments at the same levels of whole plot, the following hypothesis was tested.

$$H_0\colon \mu_{.ij.} = \mu_{.ij_{\square}.}\ versus \qquad H_1\colon \mu_{.ij.}\ \neq\ \mu_{.ij_{\square}.}$$

$$LSD = t_{(\frac{\alpha}{2},Err(sp).df)}\sqrt{\frac{2Error(sp)MS}{rab}} \qquad \text{…… equation (A2.4)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.ij_{\square}.}\right| > LSD$

5. To compare the two nitrogen level means at an average of all sub-subplot treatments at the same or different levels of subplots the following hypothesis was tested.

$$H_0\colon \mu_{.ij.} = \mu_{.i_{\square}j.}\ versus\ \ H_1\colon \mu_{.ij.}\ \neq\ \mu_{.i_{\square}j.}$$

$$LSD = t_{\alpha\beta}\sqrt{\frac{2[(b-1)Error(sp)MS + Error(wp)Ms]}{rbc}} \qquad \text{…… equation (A2.5)}$$

Where:

$$t_{\alpha\beta} = \frac{(b-1)Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)+Error(wp)MS\left(t_{\left(\frac{\alpha}{2},Err(wp).df\right)}\right)}{(b-1)Error(sp)MS+Error(wp)MS} \qquad \text{… equation (A2.5.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.i_{\square}j.}\right| > LSD$

6. To compare the two maize stem borer control level means at an average of all subplot treatments at the same levels of whole plot, the following hypothesis was tested.

$$H_0\colon \mu_{.i.k} = \mu_{.i.k_{\square}}\ versus\ \ H_1\colon \mu_{.i.k}\ \neq\ \mu_{.i.k_{\square}}$$

$$LSD = t_{(\frac{\alpha}{2},Err(ssp).df)}\sqrt{\frac{2Error(ssp)MS}{rb}} \qquad \text{…… equation (A2.6)}$$

We reject H_0 if $\left|\bar{Y}_{.i.k} - \bar{Y}_{.i.k_\square}\right| > LSD$

7. To compare the two nitrogen level means at an average of all sub-subplot treatments at the same or different levels of subplots the following hypothesis was tested.

$$H_0: \mu_{.ij.} = \mu_{.i_\square j_\square.} \; versus \;\; H_1: \mu_{.ij.} \neq \mu_{.i_\square j_\square.}$$

$$LSD = t_{\alpha\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(wp)Ms]}{rbc}} \qquad \text{……equation (A2.7)}$$

Where:

$$t_{\alpha\beta} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right) + Error(wp)MS\left(t_{\left(\frac{\alpha}{2},Err(wp).df\right)}\right)}{(c-1)Error(ssp)MS + Error(wp)MS} \qquad \text{…equation (A2.7.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ij.} - \bar{Y}_{.i_\square j_\square.}\right| > LSD$

8. To compare the two maize stem borer control level means at an average of all whole plot and at the same level of the subplot treatments the following hypothesis was tested.

$$H_0: \mu_{..jk} = \mu_{..j_\blacksquare k_\square} \; versus \;\; H_1: \; \mu_{..jk} \neq \mu_{..j_\blacksquare k_\square}$$

$$LSD = t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\sqrt{\frac{2Error(ssp)MS}{ra}} \qquad \text{……equation (A2.8)}$$

We reject H_0 if $\left|\bar{Y}_{.jk} - \bar{Y}_{..j_\blacksquare k_\square}\right| > LSD$

9. To compare the two maize variety level means at an average of all whole plot treatments at the same or different levels of sub-subplots the following hypothesis was tested.

$$H_0: \mu_{..jk} = \mu_{..j_\square k_\blacksquare} \; versus \;\; H_1: \; \mu_{..jk} \neq \mu_{..j_\square k_\blacksquare}$$

$$LSD = t_{\beta\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(sp)Ms]}{rac}} \qquad \ldots\ldots \text{equation (A2.9)}$$

Where:

$$t_{\beta\tau} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)}{(c-1)Error(ssp)MS+Error(sp)MS} \qquad \ldots \text{equation (A2.9.1)}$$

We reject H_0 if $\left|\bar{Y}_{.jk} - \bar{Y}_{..j_\square k_\blacksquare}\right| > LSD$

10. To compare the maize stem borer control level means at the same combination of whole plot and subplot treatments, the following hypothesis was tested.

$$H_0\colon \mu_{.ijk} = \mu_{.i_\blacksquare j_\blacksquare k_\square}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{.i_\blacksquare j_\blacksquare k_\square}$$

$$LSD = t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\sqrt{\frac{2Error(ssp)MS}{r}} \qquad \ldots\ldots \text{equation (A2.10)}$$

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_\blacksquare j_\blacksquare k_\square}\right| > LSD$

11. To compare the maize variety level means at the same combination of whole plot and sub-subplot treatments, the following hypothesis was tested.

$$H_0\colon \mu_{.ijk} = \mu_{.i_\blacksquare j_\square k_\blacksquare}\ versus\ \ H_1\colon\ \mu_{..jk} \neq \mu_{.i_\blacksquare j_\square k_\blacksquare}$$

$$LSD = t_{\alpha\beta\tau}\sqrt{\frac{2[(c-1)Error(ssp)MS + Error(sp)Ms]}{rc}} \qquad \ldots\ldots \text{equation (A2.11)}$$

Where:

$$t_{\alpha\beta\tau} = \frac{(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2},Err(ssp).df\right)}\right)+Error(sp)MS\left(t_{\left(\frac{\alpha}{2},Err(sp).df\right)}\right)}{(c-1)Error(ssp)MS+Error(sp)MS} \qquad \ldots \text{equation (A2.11.1)}$$

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_{\blacksquare}j_{\square}k_{\blacksquare}}\right| > LSD$

12. To compare the two nitrogen level means at the same combination of subplots and sub-subplot treatments, the following hypothesis was tested.

$$H_0\text{: } \mu_{.ijk} = \mu_{.i_{\square}j_{\blacksquare}k_{\blacksquare}} \ versus \ \ H_1\text{: } \mu_{..jk} \neq \mu_{.i_{\square}j_{\blacksquare}k_{\blacksquare}}$$

$$LSD = t_{\alpha\beta\tau}\sqrt{\frac{2[b(c-1)Error(sp)MS + (b-1)Error(sp)Ms + Error(wp)Ms]}{rbc}}$$

... equation (A2.12)

Where:

$$t_{\alpha\beta\tau} = \frac{b(c-1)Error(ssp)MS\left(t_{\left(\frac{\alpha}{2}, Err(ssp).df\right)}\right) + (b-1)Error(sp)MS\left(t_{\left(\frac{\alpha}{2}, Err(sp).df\right)}\right) + Error(wp)MS\left(t_{\left(\frac{\alpha}{2}, Err(wp).df\right)}\right)}{b(c-1)Error(ssp)MS + (b-1)Error(sp)MS + Error(wp)MS}$$

... equation (A2.12.1)

We reject H_0 if $\left|\bar{Y}_{.ijk} - \bar{Y}_{.i_{\square}j_{\blacksquare}k_{\blacksquare}}\right| > LSD$

Note: The subscripts □ *and* ■ *represents the difference between terms and the same level (terms) respectively.*

Appendix 3: Table of the impact of maize stem borer damages on yield

Maize stem borer Control Scheme	Sum of Leaf Damage	Sum of Dead Hearts	Sum of Exit holes	Sum of Tunneling length	Sum of Yield t/ha
Control	50	28	84	80	30.39
Dipterex 25% grounded	11	5	11	10	48.45
Euphorbia flesh	17	10	22	17	39.98
Euphorbia fruits	19	11	22	18	40.04
Lantana Camara flowers	17	9	17	14	43.19
Lantana Camara Leaves	11	6	11	10	48.44
Grand Total	**126**	**69**	**168**	**149**	**250.49**

Appendix 4: Analysis of variance for exit holes

```
Variate: Exit_holes

Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Treatment                       5     484.250      96.850     42.48    <.001
Residual                       42      95.750       2.280
Total                          47     580.000
```

Appendix 5: Analysis of variance for leaf damage score

```
Variate: Leaf_Damage

Source of variation          d.f.        s.s.        m.s.      v.r.    F pr.
Treatment                       5    132.2500     26.4500     28.48    <.001
Residual                       42     39.0000      0.9286
Total                          47    171.2500
```

Appendix 6: Analysis of variance for tunnel length

Variate: Tunnel_length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	463.604	92.721	45.88	<.001
Residual	42	84.875	2.021		
Total	47	548.479			

Appendix 7: Analysis of variance for dead hearts

Variate: Dead_Hearts

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	44.1875	8.8375	17.16	<.001
Residual	42	21.6250	0.5149		
Total	47	65.8125			

Appendix 8: Analysis of variance for mean grain yield for a split-split plot arrangement

Variate: Yield_t_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	1	0.206719	0.206719	2.72	
Block.Nitrogen stratum					
Nitrogen	1	0.478002	0.478002	6.29	0.242
Residual	1	0.076002	0.076002	2.62	
Block.Nitrogen.Variety stratum					
Variety	1	5.789352	5.789352	199.22	0.005
Nitrogen.Variety	1	0.861352	0.861352	29.64	0.032
Residual	2	0.058121	0.029060	4.86	
Block.Nitrogen.Variety.Treatment stratum					
Treatment	5	28.353285	5.670657	947.41	<.001
Nitrogen.Treatment	5	0.468735	0.093747	15.66	<.001
Variety.Treatment	5	0.809585	0.161917	27.05	<.001
Nitrogen.Variety.Treatment	5	0.326535	0.065307	10.91	<.001
Residual	20	0.119708	0.005985		
Total	47	37.547398			

Appendix 9: Table of treatment means for different portions of the experimental design

		Treatment					
Nitrogen	Variety	1 (LL)	2 (LF)	3 (EFL)	4 (EFR)	5 (DIP)	6 (NO)
1	1	5.315	4.905	4.535	4.460	5.570	3.100
	2	6.300	5.855	5.470	5.095	6.560	4.320
2	1	5.865	5.380	4.990	5.002	5.595	3.595
	2	6.740	5.450	5.025	5.235	6.560	4.180
1		5.808	5.380	5.002	4.777	6.035	3.710
2		6.302	5.417	5.007	5.217	6.077	3.887
	1	5.590	5.145	4.762	4.830	5.553	3.347
	2	6.520	5.652	5.240	5.165	6.560	3.799
Treatment		6.055	5.399	5.005	4.999	6.059	3.799

		Variety	
		1	2
Nitrogen	1	4.638	5.600
	2	5.105	5.532
Variety		4.871	5.566
Nitrogen		5.119	5.318
Grand Mean		5.219	

Where, **LL** stands for lantana camara leaves extracts, **LF** stands for lantana camara flowers extracts, **EFR** stands for euphorbia fruits extracts, **EFL** stands for euphorbia flesh extracts, **DIP** stands for dipterex 25% grounded and **NO** is the control of the experiment with nothing. Nitrogen 1 represent 0kg/ha and nitrogen 2 is 100kg/ha. Variety 1 represent SC627 SeedCo and variety 2 is Pioneer 30G95.

Appendix 10: Least significant differences of means (5% level)

```
Table                     Nitrogen       Variety     Treatment      Nitrogen
                                                                     Variety
rep.                            24            24             8            12
l.s.d.                      1.0112        0.2117        0.0807        0.4540
d.f.                             1             2            20          1.78
Except when comparing means with the same level(s) of
Nitrogen                                                              0.2994
d.f.                                                                       2

Table                     Nitrogen       Variety      Nitrogen
                         Treatment     Treatment       Variety
                                                     Treatment
rep.                             4             4             2
l.s.d.                      0.4191        0.1638        0.3177
d.f.                          1.93          7.45          4.26
Except when comparing means with the same level(s) of
Nitrogen                    0.1141                      0.2316
d.f.                            20                        7.45
Variety                                   0.1141
d.f.                                          20
Nitrogen.Variety
                                                        0.1614
d.f.                                                        20
Nitrogen.Treatment
                                                        0.2316
d.f.                                                      7.45
```

Appendix 11: Absolute difference of the means of the Maize Stem Borer control measures averaged over all whole plot and subplot treatments

$\left\|\bar{Y}_{\dots k} - \bar{Y}_{\dots k_{\square}}\right\|$	$\|\bar{Y}_{\dots 1} - \bar{Y}_{\dots 2}\|$	$\|\bar{Y}_{\dots 1} - \bar{Y}_{\dots 3}\|$	$\|\bar{Y}_{\dots 1} - \bar{Y}_{\dots 4}\|$	$\|\bar{Y}_{\dots 1} - \bar{Y}_{\dots 5}\|$	$\|\bar{Y}_{\dots 1} - \bar{Y}_{\dots 6}\|$
Absolute Difference	0.656	1.05	1.056	0.004	2.256
$\left\|\bar{Y}_{\dots k} - \bar{Y}_{\dots k_{\square}}\right\|$	$\|\bar{Y}_{\dots 2} - \bar{Y}_{\dots 3}\|$	$\|\bar{Y}_{\dots 2} - \bar{Y}_{\dots 4}\|$	$\|\bar{Y}_{\dots 2} - \bar{Y}_{\dots 5}\|$	$\|\bar{Y}_{\dots 2} - \bar{Y}_{\dots 6}\|$	$\|\bar{Y}_{\dots 3} - \bar{Y}_{\dots 4}\|$
Absolute Difference	0.394	0.4	0.66	1.6	0.006
$\left\|\bar{Y}_{\dots k} - \bar{Y}_{\dots k_{\square}}\right\|$	$\|\bar{Y}_{\dots 3} - \bar{Y}_{\dots 5}\|$	$\|\bar{Y}_{\dots 3} - \bar{Y}_{\dots 6}\|$	$\|\bar{Y}_{\dots 4} - \bar{Y}_{\dots 5}\|$	$\|\bar{Y}_{\dots 4} - \bar{Y}_{\dots 6}\|$	$\|\bar{Y}_{\dots 5} - \bar{Y}_{\dots 6}\|$
Absolute Difference	1.054	1.206	1.06	1.2	2.26

Note: The subscripts 1,2 3,4,5 and 6 represent lantana leaves, lantana flowers, Euphorbia flesh, Euphorbia fruit, Dipterex 25% grounded and scheme with nothing applied respectively.

Appendix 12: Coefficient of Variation CV%

```
Variate: Yield_t_ha
Covariate: Plot

Stratum                              d.f.          s.e.        cv%
Block.Nitrogen                          1        0.0796        1.5
Block.Nitrogen.Treatment
                                        9        0.0381        0.7
Block.Nitrogen.Treatment.Variety
                                       11        0.1070        2.1
```