Efficacy and residual effects of Topramezone and Dicamba herbicide on weed control in selected crops.

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A Dissertation Submitted to the University of Zambia in Partial Fulfillment of the Requirement for the Degree of Master of Science in Agronomy (Plant Science)

The University of Zambia, School of Agricultural Sciences

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DECLARATION

I, Siabusu Largewell, hereby declare that all the work presented in this dissertation is my own and has never been submitted for a degree at this or any other University.

Signature: …………………

Date: ………………….

APPROVAL

This dissertation is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy (Plant Science) by the University of Zambia.

Examiner	Signature	Date
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DEDICATION

This dissertation is dedicated to my wife, Siabusu M. Nchimunya, my two sons, Chileleko and Chaabilo and my parents Mr and Mrs Siabusu.

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I wish to thank the Almighty God for seeing me through this far by grace in my studies. God has indeed given a definition to my life.

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ABSTRACT

Numerous plants are considered weeds in agriculture and reduce crop yield and quality. Eliminating the deleterious effects of weeds is the goal of weed management. Herbicides are one of the methods of weed management despite some being persistent in the soil. Herbicides such as Stellar star whose active ingredients are Topramezone and Dicamba are considered effective selective, systemic post-emergence herbicide in maize. This study was carried out to evaluate the efficacy of Topramezone and Dicamba herbicide and its residual effect on selected succeeding crops. Field and green house experiments laid out as Split-Split Plot (SSP) and Completely Randomized Designs (CRD) were conducted. Stellar star was applied at 1 L/ ha, 2 L/ ha, 4 L/ ha and a no Stellar star Control. Planting of selected crops was done at residual periods of 0, 30, 60, 90 and 120 days. Plant height, biomass weight, number of leaves, grain yield, 100 seed weight, phytotoxicity, damaged and undamaged weeds and weed species present were monitored. Results showed controlled weeds, reduced plant height, bleached leaves and lower yields. Similarities in efficacy was observed; 89.9% between 2 L/ ha and 4 L/ ha treatments and 74.2% between 1 L/ ha and 4 L/ ha. There were highly significant differences ($p \leq 0.01$) amongst the treatment means for all parameters. Phytotoxicity effects were highest at 0, 30 and 60 days residual periods. 4 L/ ha had the worst average phytotoxicity score of 8.5 out of 9 (98%) and with the control having the lowest (0%).

Chapter 1

INTRODUCTION

1.1 Background

Numerous plant species are considered weeds in agronomic cropping systems (Hager, 2000). Weeds can be categorized by their life cycle; annual, biennial and perennial. The major undesirable feature of weeds is the reduction of crop yields and quality through competition for resources such as sunlight, water, nutrients and space (Gallandt and Weiner, 2015). Weeds also harbor insect pests and provide a host for certain plant pathogens (Capinera, 2005). Reducing the deleterious effects of weeds in agronomic crops is the goal of weed management. Successful weed management requires accurate identification of species and understanding their biological characteristics so that control measures can be done to the weeds present in individual fields (Norsworthy *et al.*, 2012). Integrated weed management includes all practices that enhance a crop's competitive ability and decrease weeds' ability to reduce yield (Ayodele and Olubunmi, 2017). These weed control methods can be preventive, cultural, mechanical, biological and chemical (herbicide use). The scope of the study was on herbicides.

Herbicides control unwanted plants and can be selective, non-selective, pre-or post-emergence (Ware and Whitacre, 2004; Rana 2018). Selective herbicides control specific weed species, leaving the desired crop relatively unharmed, while non-selective herbicides kill all plant material they are exposed to (Vats, 2015). Pre-emergence herbicides are applied before weeds emerge to have any real effect. They work by preventing weed seeds from germinating or kill off the germinating seedlings whereas post-emergence herbicides are applied after weed seeds have germinated. Herbicides can also be classified based on the means of uptake (whether it is absorbed by above-ground foliage only or through the roots) and mechanism of action. Another important feature to be considered in the use of herbicides include persistence herbicide or residual action herbicide, describing how long the product stays in the field and remains active. These herbicides continue to control weeds for some time after application (Vencill, 2002). In Zambia, the use of residual herbicides is common in crop production especially where you have persistent weeds. Residual herbicide activity often describes the unintended stay of the chemical in the environment even when the effect is no longer wanted, thereby causing phytotoxicity to the subsequent crops (Raeder *et al.,* 2015). Residual herbicides activity extends the period of weed control, increasing the efficacy of weed management efforts. However, they may persist longer than desired and injure or kill subsequent rotational crops (Helling, 2005). Most herbicide labels include crop rotation guidelines, but rotational restrictions are often not listed for many crops. The length of time the herbicide remains in the soil, varies greatly with climatic conditions, soil type, and cultural practices. It is important to distinguish between herbicide persistence and herbicide activity. Some herbicides persist for a long time in the soil but are not available for plant uptake and therefore are not active as herbicides. Given the difficulty in predicting herbicide persistence because of several factors involved, it is important to know the factors that lead to persistence. Incorporating these factors into crop planning can reduce herbicide phytotoxicity risk (Colquhoun, 2006).

Herbicides have different trade names but may have the same active ingredients. Agrochemical companies sometimes make combinations of herbicides, especially the selective ones so that they more effectively deal with the range of weed problems faced by the farmers (Damalas *et al.,* 2015). In this study, Stellar Star was used, the active ingredients are Topramezone (pyrazolone) and Dicamba (benzoic acid compound).

1.2 Statement of the Problem

In Zambia, herbicide use by smallholder farmers is increasing partly driven by the adoption of conservation agriculture (CA) (Nkhoma *et al.,* 2017). Studies done have shown that the residual herbicides used for controlling weeds in maize crops can sometimes persist in the soil (Rahman *et al.,* 2014). Herbicide persistence in the soil is a negative aspect of chemicals because it adversely affects the follow up crops.

1.3 Justification

The findings of this study will establish whether the selected crops in question could be rotated with maize where Stellar star was previously used and at what residual period would be ideal for planting each of the crop and attain optimal yields. Information obtained will help make decisions around benefits (efficacy) or drawbacks (phytotoxicity) of using Stellar star.

1.4 Objectives

1.4.1 Overall Objective

To evaluate the efficacy of Topramezone and Dicamba herbicide and its residual effect on subsequent crops involved in the rotation with maize.

1.4.2 Specific Objectives

i). To assess the efficacy of Topramezone and Dicamba herbicide at different application rates.

ii). To evaluate the residual phytotoxicity effect caused by Topramezone and Dicamba herbicide on subsequent crops.

1.5 Research hypothesis

There is a variation in residual effect of Topramezone and Dicamba herbicide at different application rates at varying residual period on selected subsequent crops.

1.6 Statistical hypotheses

i) For specific objective 1

Ho: There is no correlation in efficacy of Topramezone and Dicamba herbicide when applied at different application rates.

Ha: There is a correlation in efficacy of Topramezone and Dicamba herbicide when applied at different application rates.

ii) For specific objective 2

Ho: There is no relationship between residual phytotoxicity effect and Stellar Star herbicide on subsequent crops.

Ha: There is a relationship between residual phytotoxicity and Stellar Star herbicide on subsequent crops.

Chapter 2

LITERATURE REVIEW

2.1 Weeds

Weeds are a major threat to crop production in many cropping systems. Losses due to weeds have been estimated to be even more than those caused by insect pests and diseases (Oerke, 2006). Comparatively, diseases cause 16.4 % and pests 11.2 % of the yield loss, the losses caused by weeds can be as high as 24 % (Kadioglu and Yanar, 2004). At the global level, the major contributors of crop loss are weeds, followed by animals and pathogens (Oerke, 2006). According to Zimdahl, (2007), often complete crop failure (100 % loss of marketable yield) can occur if weeds are not controlled. It has been observed that weeds may cause a reduction of 25-30 % in yield of wheat (Chaudhary *et al*., 2008; Marwat *et al*., 2008), 35-40 % reduction in rice yield (Oerke and Dehne, 2004), 35-80 % reduction in maize (Dangwal *et al*., 2010) and 20-40 % reduction in sugarcane yield (Ibrahim, 2006), depending on the weed density, types of weeds, duration of competition, management practices and weather conditions. Weeds cause a reduction in the growth and yield of crops by interfering with different metabolic processes (Hajizadeh and Mirshekari, 2011). The interference of weeds with crops may be the consequence of competition or allelopathy.

Allelopathy refers to the biological phenomenon where one plant inhibits the growth of another through the release of biochemicals, known as allelochemicals (Tilley, 2016) from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes in both natural and agricultural systems. Allelochemicals are a subset of secondary metabolites not required for metabolism (growth and development) of the allelopathic organism. Allelochemicals with negative allelopathic effects are an important part of plant defense against herbivory (i.e., animals eating plants as their primary food) (Stamp, 2003). Plant allelopathy is used as a means of survival in nature, reducing competition from nearby plants (Tilley, 2016).

Vats, (2015) showed that weeds influence the produce of farmers in several ways:

i. Compete for light, moisture and nutrients affecting quality and quantity of produce;
ii. Interfere with and damage harvesting equipment;

iii. Harbors pests and diseases;
iv. Toxic properties of weeds cause health problems to humans and animals;
v. Contaminate aquatic resources; and
vi. Interferes and adversely affects natural ecosystem.

2.2 Methods of Weed Control

Controlling weeds in crop production may involve a wide range of techniques. Weed control methods may be classified into five main categories:

i. Preventative Weed Control
ii. Cultural Weed Control.
iii. Mechanical Weed Control.
iv. Biological Weed Control.
v. Chemical Weed Control.

2.2.1 Preventative Weed Control

Preventative weed control refers to any control method that prevent weeds from being established in a cultivated crop, a pasture, or a greenhouse (Rana and Rana, 2016). Examples of preventative weed control would be using certified weed free seed, only transporting seed that is weed free, making sure farm equipment is cleaned before moving from one location to another and screening irrigation water to prevent weed seeds from traveling along irrigation ditches.

2.2.2 Cultural Weed Control

Cultural weed control refers to any technique that involves maintaining field conditions such that weeds are less likely to become established or increase in number (Rana and Rana, 2016). Examples of cultural weed control would be crop rotation, field preparation, planting method, planting density, mulching, and fertilizer application/ maintaining good soil fertility. Preventative and cultural methods should be done before crop sowing to lower the density of the weeds in the field during the cropping season (Melander *et al.*, 2005).

2.2.3 Mechanical Weed Control

Mechanical weed control refers to any technique that involves the use of equipment to control weeds. The two mechanical control techniques most often used are tillage and mowing (Ayala *et al.*, 2010). Besides, many cultural control methods are mechanical.

2.2.4 Biological Weed Control

Biological weed control includes any technique that involves the use of natural enemies of weed plants to control the germination of weed seeds or the spread of established plants (Rana and Rana, 2016). The objective of these methods is not eradication of weeds but the reduction of the weed population to economically low levels (Harris, 2009). In fact, for biological control to be continuously successful, small numbers of the weed host must always be present for assured survival of the natural enemy. This method is also not suitable for all weed problems.

2.2.5 Chemical Weed Control

Chemical weed control refers to any technique that involves the application of a chemical (herbicide) to weeds or soil to control the germination or growth of the weed species. In economic terms, chemical control of weeds is a very large industry and there are scores of examples of chemical weed control products. Examples of chemicals used to control weeds in crops are; Atrazine, Glyphosate, Topramezone and Dicamba. However, some herbicides have a problem of being persistent in the soil (Curran, 2001). Topramezone and Dicamba herbicide mixture (Stellar Star) is widely used by smallholder farmers in Zambia because of its efficacy and selectivity in maize. However, the herbicide does not guarantee efficacy and residual effect on maize and the crops involved in rotation due to different environmental factors involved (BASF, 2016) hence the need to carry out a study.

2.3 Topramezone and Dicamba mixture herbicide- Stellar Star

Topramezone and Dicamba is a soluble liquid herbicide used to control early post-emergent grasses and broadleaf weeds (as specified), in maize.

According to Herbicide Resistance Action Committee (HRAC), Stellar Star herbicide is classified under group codes F2 and O (HRAC, 2006). The global HRAC group classification system for herbicides is according to their target sites, modes of action, similarity of induced symptoms or chemical classes. Group code F2 herbicides Inhibit 4-hydroxyphenyl-pyruvatedioxygenase (4-HPPD), a key enzyme in the biosynthesis of prenylquinones, plastoquinone and tocopherols (Chipomho *et al.*, 2019) whereas O herbicides show indole acetic acid (synthetic auxins) like action (Kramer and Schirmer, 2007).

Benefits of Topramezone and Dicamba herbicide (BASF, 2016) include;

i. Consistent broadest spectrum control of annual grasses and annual broadleaf weeds and perennial broadleaf weeds
ii. Synergistic effects with Atrazine and Terbuthylazine.

2.3.1 Topramezone

Schonhammer *et al*., (2006) describe Topramezone as the first selective, systemic, post-emergence herbicide belonging to a chemical class called pyrazolones. Topramezone chemical structure is shown in Figure 1.0 below.

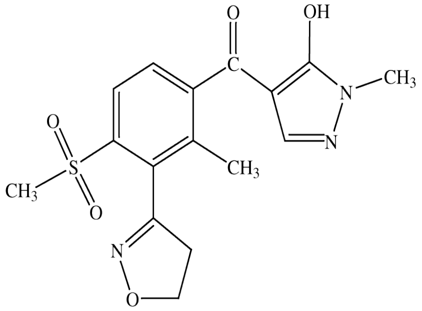


Figure 1.0: Chemical structure of Topramezone

Scientific Name: [3-(4, 5-dihydro-isoxazol-3-yl)-4-methylsulfonyl-2-methylphenyl] (5- hydroxy-1-methyl-1H-pyrazol-4-yl) methanone. ($C_{16}H_{17}N_3O_5S$)

In sensitive plant species Topramezone inhibits the enzyme 4-Hydroxy-phenyl-pyruvate-dioxygenase (4-HPPD). Wolf and Rust (2005), states that this mode of action is shared with isoxaflutole a cyclopropylisoxazole family and mesotrione, a triketone belonging to the benzoylcyclohexanedione family. As a result, the biosynthesis of plastochinones/ carotinoides discontinues, leading to a disruption of the synthesis and function of chloroplasts. Consequently, chlorophyll is destroyed by oxidation. This effect is seen as a pronounced bleaching of the growing shoot tissue and subsequent necrosis of the above ground plant matter.

A key observation associated with the use of the herbicide in maize is a lower sensitivity of the enzymatic target and a faster metabolic decomposition compared to sensitive plant species (Grossmann and Ehrhardt, 2007). According to Schonhammer *et al.,* (2006), Topramezone is taken up by the shoot and the roots, the distribution within the plants is both acro- and basipetally. Uptake by and distribution within the shoot is significantly increased with a suitable adjuvant.

Topramezone has favorable toxicological und eco-toxicological properties. Water solubility and persistency in the soil are in a medium range, which results in weed control also through soil uptake (Schonhammer *et al.,* 2006). However, due to the strongly pronounced foliar activity of this compound even against advanced weed growth stages and the very good crop safety, Topramezone is intended to be used post-emergence of the crop in a range from 1- to 8-leaf-stage of maize. In comparison to other 4-HPPD-inhibiting herbicides Topramezone is characterized by a highly effective control of the whole spectrum of important annual warm season grasses (EPA, 2005).

2.3.2 Dicamba

Dicamba is primarily either a benzoic acid or chlorophenoxy herbicide. It is a selective herbicide used to control a wide spectrum of broadleaf weeds and woody plants (Bunch *et al.,* 2012).

Dicamba is a methoxybenzoic acid that is O-methylsalicylic acid substituted by chloro groups at positions 3 and 6. It has a role as a xenobiotic, an environmental contaminant, herbicide, synthetic auxin and an agrochemical. It is a methoxybenzoic acid and a dichlorobenzene. It is a conjugate acid of a 3, 6-dichloro-2-methoxybenzoate. Figure 2.0 shows the chemical structure of dicamba.

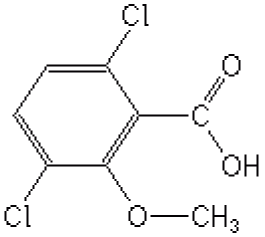


Figure 2.0: Chemical structure of Dicamba

Scientific name: 3, 6-dichloro-2-methoxybenzoic acid ($C_8H_6Cl_2O_3$)

Dicamba is resistant to hydrolysis and oxidation under normal environmental conditions and may remain in soils for 7–10 months (Harp, 2010). It should not be applied to soils classified as sands with less than 3 percent organic matter and where groundwater depth is shallow (York and Culpepper, 2003). The active ingredient is soluble in water (solubility of 6.1 g/ l at 25°C) and will readily leach into runoff water. It is often combined with other herbicides and is used to control a wide spectrum of weeds (Harp, 2010).

Dicamba takes effect through stimulating the outgrowth of plant, which causes the exhaustion of nutrients supplies and plant death. This is based on the nature of Dicamba, which is a synthetic mimic of natural auxin (a plant hormone used for stimulating plant growth). Upon response to this kind of herbicide, the plant develops abnormalities such as leaf epinasty, leaf abscission and growth inhibition of the root and shoots. Overall, the effects of auxinic herbicides can be divided into three consecutive phases in the plant: first, stimulation of abnormal growth and gene expression; second, inhibition of growth and physiological responses, such as stomatal closure; and third, senescence and cell death.

2.4 Herbicide Classification

Herbicides are classified/ grouped in various ways e.g. according to the chemical family, activity, method of application, site of action or timing of application (Sheewani *et al.,* 2015).

2.4.1 Classification Based on Translocation

2.4.1.1 Systemic/ Translocated

These herbicides are extensively translocated in the plant through its vascular system along with water, nutrients and other materials from site of absorption to sites of action. Systemic herbicides are more effective on perennial weeds than contact herbicides. Unlike contact herbicides which are fast acting, systemic herbicides require longer time (days or weeks) to kill weeds. Glyphosate and glufosinate are nonselective systemic herbicides. 2,4-D and dicamba are examples of selective systemic herbicides (Klaus, 2000).

2.4.1.2 Non-systemic/ Contact

These herbicides kill only the portion of plant tissue that is in contact. These are not translocated through the plant. Uniform spray coverage and particle size are essential for adequate application. They are less effective on perennial plants, which can regrow from rhizomes, roots or tubers. Repeated application of contact herbicide is needed to kill regrowth of underground plant parts. These are comparatively fast acting herbicides e.g. bromoxynil and bentazon are contact herbicides (Vats, 2015).

2.4.2 Classification Based on Time of Application

2.4.2.1 Pre-plant

Pre-plant herbicides are non-selective herbicides applied to soil before planting and gets mechanically incorporated into the soil. The objective for incorporation is to prevent dissipation through photo-decomposition or volatility. The herbicides kill weeds as they grow through the herbicide treated zone. Volatile herbicides must be incorporated into the soil before planting the pasture. Agricultural crops grown in soil treated with a pre-plant herbicide include tomatoes, maize, soybeans and strawberries. Soil fumigants like metam-sodium and dazomet are in use as pre-plant herbicides (Hanson and Shrestha, 2006).

2.4.2.2 Pre-emergence

Pre-emergence herbicides are applied before the weed seedlings emerge through the soil surface. Herbicides do not prevent weeds from germinating, but they kill weeds as they grow through the herbicide treated zone by affecting the cell division in the emerging seedling. Dithopyr and Pendimethalin are Pre-emergence herbicides. Weeds that have already emerged before application or activation are not affected by pre-herbicides as their primary growing point escapes the treatment (Brosnan *et al.*, 2014).

2.4.2.3 Post emergence

These herbicides are applied after weed seedlings have emerged through the soil surface and generally require multiple applications for adequate control. They can be foliar, or root absorbed, selective or nonselective, contact or systemic. Liquid formulations of herbicides are more effective than granular formulations. Application of these herbicides is avoided during rain because the problem of being washed off to the soil makes it ineffective. 2,4-D is a selective, systemic, foliar absorbed post-emergence herbicide (Sherwani *et al.,* 2015).

2.4.3 Classification Based on Method of Application

2.4.3.1 Soil Applied

Herbicides applied to the soil are usually taken up by the root or shoot of the emerging seedlings and are used as pre-plant or pre-emergence treatment. There are several factors that influence the effectiveness of soil-applied herbicides. Weeds absorb herbicides by both passive and active mechanism. Herbicide adsorption to soil colloids or organic matter often reduces its amount available for weed absorption.

Positioning of herbicide in correct layer of soil is very important, which can be achieved mechanically and by rainfall. Herbicides on the soil surface are subjected to several processes that reduce their availability. Volatility and photolysis are two common processes that reduce the availability of herbicides. Many soil applied herbicides are absorbed through plant shoots while they are still underground leading to their death or injury. Thiocarbamates (e.g. EPTC) and dinitroanilines (e.g. trifluralin) are soil applied herbicides (Vats, 2015).

2.4.3.2 Foliar Applied

These are applied to portion of the plant above the ground and are absorbed by exposed tissues. These are generally post-emergence herbicides and can either be translocated (systemic) throughout the plant or remain at specific site (contact). External barriers of plants like cuticle, waxes, cell wall affect herbicide absorption and action. Glyphosate, 2,4-D and dicamba are foliar applied herbicide.

2.4.4 Classification Based on Specificity

2.4.4.1 Selective herbicides

They control or suppress certain plants without affecting the growth of other plants species. Selectivity may be due to translocation, differential absorption, physical (morphological) or physiological differences between plant species (Sherwani *et al.,* 2015). 2, 4-D, mecoprop, dicamba control many broadleaf weeds but remains ineffective against turf grasses.

2.4.4.2 Non-selective herbicides

These herbicides are not specific in acting against certain plant species and kill all plant material with which they come into contact. They are used to clear industrial sites, waste ground, railways and railway embankments. Paraquat, glufosinate, glyphosate are non-selective herbicides (Vats, 2015).

2.4.5 Classification Based on Site of Action

Herbicides are often classified according to their site of action, because as a rule, herbicides within the same site of action class will produce similar symptoms on susceptible plants. Classification based on site of action of herbicide is comparatively better as herbicide resistance management can be handled more properly and effectively). They proposed herbicide classification according to site of action with a view that it would help in dealing with herbicide resistance management.

To differentiate herbicides with the same site of action each class was given a group number. The International Herbicide Resistance Action Committee (HRAC) also published a classification system based on letters for each group (Smith and Retzinger, 2003).

2.5 Herbicide Persistence

Herbicides are applied to the soil to manage weeds. While it is desirable for the chemicals to control weeds during the season of application, it is not desirable for them to persist and affect subsequent crop growth. The length of time herbicides remain active in the soil is called 'soil persistence', or 'soil residual life'. For some herbicides, there may be a fine line between controlling weeds for the entire growing season and then planting a sensitive rotation crop. Anything that affects the disappearance or breakdown of herbicides affects persistence. Herbicides vary in their potential to persist in the soil. Herbicide families that have persistent members include the triazines, uracils, phenylureas, sulfonylureas, dinitroanilines, isoxazolidinones, and certain plant growth regulators belonging to the pyridine family (Curran, 2001).

Several factors determine the length of time herbicides persist. These factors fall into three categories: soil factors, climatic conditions, and herbicidal properties. Factors from each category strongly interact with one another (Curran, 2001).

2.5.1 Soil Factors

Soil factors affecting herbicide persistence include soil composition, soil chemistry and microbial activity (Arikan *et al.,* 2015). Soil composition is a physical factor determined by the relative amounts of sand, silt and clay in the soil (the soil texture), as well as by the organic-matter content. An important chemical property of soil that can influence herbicide persistence is pH (Raeder *et al.,* 2015). The microbial aspects of the soil environment include the types and abundance of soil microorganisms present in the soil.

Soil composition affects herbicidal activity and persistence through soil-herbicide binding (adsorption), leaching, and vapor loss (volatilization). Generally, soils high in clay, organic matter or both have a greater potential for carryover because of increased binding of the herbicide to soil particles, with a corresponding decrease in leaching and loss through volatilization. This ‘tie-up’ results in decreased initial plant uptake and herbicidal activity. More herbicide is held in reserve, potentially injuring susceptible crops in the future.

In general, medium- and fine-textured soils with an organic matter content of more than 3 percent have the greatest potential to bind or hold herbicides and to injure sensitive rotation crops. Coarse- to medium-textured soils with a lower organic matter content (less than 3 percent), are less likely to retain herbicides and to have carryover problems. Under the right circumstances, however, herbicide carryover can occur in any type of soil.

Chemical and microbial breakdown, two ways herbicides degrade in soil, often are slower in higher-pH soils. In addition, in higher-pH soils, lesser amounts of these herbicides are bound to soil particles, making more available for plant uptake (Ritchey and Lee, 2011). In higher-pH soils, Topramezone and Dicamba herbicide persist longer and more is available for plant uptake. Low pH also can affect the persistence of both the triazine and sulfonylurea herbicides. Soil pH levels below 6.0 allow a more rapid dissipation of both these herbicide families.

Degradation processes by soil microorganisms probably are the most important pathways responsible for the breakdown of herbicides. The types of microorganisms (fungi, bacteria, protozoans) and their relative numbers determine how quickly decomposition occurs. Microorganisms require certain environmental conditions for optimal growth and utilization of any pesticide. Factors that affect microbial activity are moisture, temperature, pH, oxygen, and mineral nutrient supply. Usually, a warm, well-aerated, fertile soil with a near-neutral pH is most favorable for microbial growth and, hence, for herbicide breakdown (Ritchey and Lee, 2011).

2.5.2 Climatic Factors

The climatic variables involved in herbicide breakdown are moisture, temperature, and sunlight. Herbicide degradation rates generally increase as temperature and soil moisture increase, because both chemical and microbial degradation. Carryover problems are always greater the year following a drought. If winter and spring conditions are wet and mild following a previously dry summer, the lower the likelihood of herbicide carryover. Sunlight is sometimes an important factor in herbicide degradation.

Photodecomposition or degradation catalyzed by sunlight (photolysis) has been reported for many herbicides, especially in liquid solution (i.e. water) or on plant leaf surfaces. But for most of the more persistent soil-applied herbicides, once soil contact is made, losses due to photolysis are small (Ritchey and Lee, 2011).

2.5.3 Herbicide Properties

Herbicide chemical characteristics determine their properties such as persistence. These characteristics include water solubility, vapor pressure and the molecule's susceptibility to chemical or microbial alteration or degradation.

Leaching is one mechanism responsible for herbicide dissipation. The solubility of the herbicide in water helps determine its leaching potential. Leaching occurs when the herbicide is dissolved in water and moves down through the soil profile. Herbicides that readily leach may be carried away from crop and weed germination zones. Herbicide leaching is determined by other factors as well. These include herbicide-soil binding properties, soil physical characteristics, rainfall frequency and intensity, herbicide concentration, and time of herbicide application. In general, herbicides that are less soluble in water and strongly attracted to soil particles are less likely to leach, particularly in dry years.

The vapor pressure of the herbicide determines its volatility. Volatilization is the process whereby the herbicide changes from a liquid or solid to a gas. Volatile herbicides (those with higher vapor pressures) generally dissipate more rapidly than herbicides with lower vapor pressures. Volatilization increases with temperature and moisture. Most herbicides are relatively nonvolatile under normal field-use conditions.

Herbicide chemical structure dictates how the herbicide will degrade in soil. Some herbicides are rapidly decomposed by microorganisms if the right kind and number are present and if soil conditions are favorable for their growth. But herbicides vary greatly in their susceptible to microbial decomposition. The chemical structure of 2,4-D, for example, allows microbes quickly to detoxify the molecule into inactive metabolites, whereas atrazine is not as prone to microbial attack; hence degradation is slower.

The amount of tillage following herbicide application can affect persistence. Tillage encourages herbicide decomposition indirectly through increased microbial and chemical breakdown. Minimum-till and no-till tend to leave a greater concentration of herbicide near the surface zone. Persistent herbicides present in this concentrated zone may affect shallow-planted susceptible crops.

Herbicides generally target essential metabolic processes in plants e.g. photosynthesis, mitosis or amino acid biosynthesis. These processes are common in both crops and weeds (Vats, 2015).

The term 'residual' applies to many herbicides that have a long-lasting activity in the soil. These herbicides are often applied directly to the soil prior to planting crops, pre-emergent. Herbicides rely on moisture and microbial activity to break down. Therefore, one of the consequences of a drier than average growing season is that the herbicides applied may still be active in the following season. In addition, residual herbicides can be applied in advance of dry sown crops and still be expected to have enough weed control activity when the season breaks.

And residues, from the previous season may affect crop emergence or even kill sensitive crops or crop cultivars in the next season. The main factors contributing to residue carryover are poor uptake of herbicides by crop plants and limited microbial or chemical degradation of herbicides in dry soil conditions.

Curran (2001), stated that it is important to apply the correct rate of any pesticide for specific soil types and weed problems. This means applying the lowest rate of the chemical consistent with obtaining the desired effect. Higher rates of more persistent products certainly carry a greater risk of injury to subsequent crops. Accurate acreage determination, chemical measurement, proper sprayer calibration, and uniform application are essential for avoiding misapplication problems (Curran, 2001). It is recommended to always read the label before applying any herbicide *(*Wilen *et al.*, 2017).

2.6 Crop Rotation

Crop rotation should be an integral component of a weed management program. Crop rotation generally leads to healthier crops that are more competitive with weeds. According to Loux *et al.*, 2015, certain weeds are more easily or more economically managed in one crop than in another. In general, most weeds are more easily managed in maize or soybeans than in other agronomic or horticultural crops. Good control in maize can reduce weed problems in rotational crops. Additionally, crop rotation allows use of different herbicide chemistries on the same field in different years. This can prevent weed population shifts (changes in the species composition), avoid evolution of herbicide resistance, and help to keep the overall weed population at lower levels (York and Culpepper, 2003).

Some herbicides may be carried over and damage rotational crops. Before using any herbicide, consider your rotational plans and check the rotational restrictions on the label (York and Culpepper, 2003).

It is beneficial to have a rotation system that includes crops with different life cycles, growth patterns and management techniques. This will reduce the chance that weeds can proliferate over successive years (Horton *et al.*, 2014). Most of the crops in this study have not be tested under different residual period under various environmental conditions in Zambia hence the need to carry out the study since maize (*Zea mays*) cannot be grown in monoculture if sustainable agriculture was to be upheld.

Most herbicide labels include crop rotation guidelines, but rotational restrictions are often not listed for several crops in Zambia.

2.7 Strategies to reduce crop injury risk from herbicide residue

These methods are not intended to supersede rotational restrictions on the pesticide label but to reduce the risk of carryover (Colquhoun, 2006). Smallholder farmers can adopt these practices to reduce herbicide residue risks.

2.7.1 Tillage

Thorough tillage will distribute residual herbicide evenly and dilute concentration, thus allowing maximum exposure to micro-organisms and clay and inorganic matter that adsorb herbicides. Tillage can also reduce compaction and increase aerobic micro-organism activity. Tillage will not solve all potential carryover issues and in rare cases, can make the situation worse. For example, deep plowing can invert residual herbicides, concentrating the residue at soil depths that remain lower in temperature. The herbicide residue can then be brought back to the plant root zone with subsequent deep plowing, exposing future crops to potential carryover. It is essential to thoroughly distribute any herbicide residue in the soil (Colquhoun, 2006).

2.7.2 Planting more tolerant crops

Curran (2001) states that if crop choice is flexible, consider planting a crop with a shorter rotational restriction in fields where environmental conditions may have extended the length of herbicide carryover e.g. maize.

2.7.3 Conducting herbicide bioassay

With herbicide bioassay, crop seeds are grown in pots using soil from the field. This simple and economical test allows growers to screen for potential herbicide carryover. In the study of Topramezone and Dicamba, greenhouse experiment was done to screen for potential herbicide phytotoxicity under controlled environmental conditions (soil, moisture). Greenhouse experiments are not fail-proof: climatic conditions in the field, such as available moisture, often differ from plants grown indoors in pots (Colquhoun, 2006).

2.8 Phytotoxicity

Soil residual herbicides are those compounds that control plant growth throughout the growing season due to the persistence of phytotoxic residues in the soil (Helling, 2005). Thakur and Rana (2018) defined phytotoxicity as a toxic effect by a compound on plant growth. Phytotoxicity is the degree to which a chemical or other compound is toxic to plants. Herbicides are especially hazardous to plants because they are designed to kill or suppress plants (Thakur and Rana, 2018). Excessive persistence of herbicide in the soil may cause injury to successive crops in the rotation (Curran, 2001).

In summary, Acker (2005) demonstrated that herbicide residues in soils pose four potential problems or hazards: firstly, injury to sensitive plants grown in rotations with sprayed crops, secondly, accumulation of residues from application rates which exceed rates of dissipation, thirdly unlawful residues in crops grown in rotations with treated crops, and lastly, inhibition of beneficial soil microorganisms. Topramezone and Dicamba moderately persistent in the environment, with residual period in the soil of even up to one year at concentrations high enough to damage sensitive crops in the rotation (Schonhammer *et al.*, 2006; Gorsic *et al.*, 2008).

Therefore, farmers who practice crop rotation find it difficult to predict whether herbicide residues in the soil will be a problem for subsequent crops (Acker, 2005). Topramezone and Dicamba herbicide label does not guarantee efficacy and residual effect on maize and the crops involved in rotation due to different environmental factors involved (BASF, 2016).

Chapter 3

MATERIALS AND METHODS

3.1 Experimental site

The study was conducted at Mt. Makulu Central Research Station in Chilanga district during the 2016/ 17 cropping season both in the field and in the green house. Mt. Makulu is in agro-ecological region IIa of Zambia and lies on latitude 15.550˚S, longitude 28.250˚E and elevation 1213 m above sea level. Annual rainfall in Region IIa averages 800-1000 mm, moderately leached sandy loam and the growing season is 100-140 days long (Esser, 2017). The temperature during the season ranged from 14 ^{o}C to 35 ^{o}C as shown in Figure 3. The soils are loamy with moderately to high organic matter and pH that is slightly alkaline with lower available nitrogen content, phosphorus (P) deficient but higher potassium (K). Region IIa support the production of several crops which prompted the choice of these crops (i.e. Maize (*Zea mays* L.), Groundnut (*Arachis hypogaea* L.), Soyabeans (*Gycine max* L.), Common Beans (*Phaseolus vulgaris* L.), Sunflower (*Helianthus annuus* L.) and Sorghum (*Sorghum bicolor* L.) in this study. The objective of having these crops was to test the residue effect of Topramezone and Dicamba to as many crops as possible involved in rotation with maize.

3.2 Experimental Design with treatments

3.2.1 Field experiment

The experimental design used was Split - Split Plot Design (SSP) with herbicide rate laid in the main plot and residual period in the sub plot and was replicated twice because the experimental area carefully chosen was uniform based on the soil test that was done before planting (see Table 1.0). The previous crop grown before this trial was Common Beans (*Phaseolus vulgaris* L.) and no herbicide was used during the growth of this crop. The experimental area was 0.2 ha, plot sizes of 6.0 m x 5.0 m, buffer zones of 1.5 m between blocks and 1.0 m between plots to avoid drift of the herbicide during spraying. The field layout is shown on Appendix 1.0. Four treatments were used;

i. Control (no Stellar star)
ii. Stellar star 1.0L/ ha
iii. Stellar star 2.0L/ ha

iv. Stellar star 4.0L/ ha

Each of these treatments were applied at the onset of the experiment. Planting was then staggered at the residual period of 0, 30, 60, 90, 120 days after the herbicide application. At each of these residual periods, all the crops (Maize (*Zea mays* L.), Groundnut (*Arachis hypogaea* L.), Soyabeans (*Gycine max* L.), Common Beans (*Phaseolus vulgaris* L.), Sunflower (*Helianthus annuus* L.) and Sorghum (*Sorghum bicolor* L.) were planted to assess the phytotoxicity effect of Topramezone and Dicamba. For crop spacing, each crop was planted according to the recommended intra-row spacing and at planting depth not exceeding 0.05 m.

3.2.2 Cultural practices

The land was tilled at a depth of 15-20 cm to control weeds and improve soil structure in readiness for crop production. Weeds were controlled at this stage to correctly evaluate which of the types of emerged weeds were eliminated by Stellar star. This was to ensure uniform seed bed preparation and uniform weed growth stages at the time the herbicide was to be applied. Thereafter, harrowing was done to break clods and produce a fine tilth. Soil samples were collected from all points of the experimental area to determine the state of the soil in terms of its acidity, alkalinity and chemical elements and compounds present as shown in Table 1.0. The field was then mapped and pegged according to different blocks and plots. Rows were then made per plot and followed by basal dressing using compound D at planting. Topramezone and Dicamba herbicide was applied at different rates before planting the crop. First planting was done on 29th November 2016 and then every after 30 days at a depth not exceeding 5 cm. Top-dressing was done 3 - 4 weeks after planting. It should be stated that soybean was also top dressed as no inoculation was done.

3.2.3 Meteorological data

Agro-meteorological data on rainfall, maximum and minimum temperatures for 2016/ 17 growing season was obtained from Mt Makulu Meteorological Station. The data was used to determine if the year during which the experiment was conducted experienced normal seasonal weather pattern (Figure 3.0).

MONTH	Dekad (10 days	Rainfall Data (mm) Mean	(mm) Total	Temperature (°C) Max	Min
October	1	0.4	4	33.14	18.6
	2	0	0	34.81	19.91
	3	0	0	34.67	20.04
November	1	0.12	1.2	35.45	21.73
	2	1.38	13.8	31.73	18.98
	3	5.35	53.5	28.44	18.69
December	1	0	0	31.04	18.94
	2	5.67	56.7	27.17	18.54
	3	19.06	190.6	28.85	17.57
January	1	9.81	98.1	27.43	18.75
	2	4.3	43	25.46	18.12
	3	16.74	167.4	27.56	17.81
February	1	5.76	57.6	27.1	18.12
	2	7.96	79.6	28.06	18.3
	3	7.27	72.7	26.73	17.95
March	1	5.82	58.2	26.66	18.01
	2	0	0	26.85	15.65
	3	0.92	9.2	25.41	16.89
April	1	0.14	1.4	26.17	15.25
	2	0.38	3.8	26.48	14.93
	3	0.64	6.4	23.62	15.4

Figure 3.0: Agro-meteorological data for the 2016/ 17 growing season obtained from Mt. Makulu meteorological station**.**

3.3 Green house experiment

The experimental design used was Complete Randomized Design (CRD) and was replicated three times. There were four treatments under study;

i. Control (no Stellar star)
ii. Stellar star 1.0L/ ha

iii. Stellar star 2.0L/ ha
iv. Stellar star 4.0L/ ha

Each of these treatments were applied at the beginning of the experiment. Planting was then staggered at the residual period of 0, 30, 60, 90, 120 days after the herbicide application. At each of these residual periods, all the crops (Maize (*Zea mays*), Groundnut (*Arachis hypogaea*), Soyabeans (*Gycine max*), Common Beans (*Phaseolus vulgaris*), Sunflower (*Helianthus annuus*) and Sorghum (*Sorghum bicolor*) were planted to assess the phytotoxicity effect of Topramezone and Dicamba.

3.3.1 Potting mixture

Soil was collected from within Mt Makulu and samples were drawn for soil analysis and the results were presented on Table 1.0.

Table 1.0 Physical and chemical properties of the soil sample

Sample source	pH	OM %	P mg/kg	N %	K cmol/kg	Sand %	Clay %	Silt %	USDA Class
G/ house	7.52	2.4	0.62	0.81	0.96	55.6	26	18.4	Loam
Field	7.64	1.6	11.68	0.67	0.9	51.6	28	20.4	Loam

Soil was placed in plastic pots and planting of the crops in the green house was done on 10th February 2017 and every after 30 days. All the agronomic practices were the same as for the field practices stated earlier.

3.4 Data collection and analysis

To assess the efficacy of Topramezone and Dicamba herbicide and its residual effect, several parameters were collected, namely; Undamaged weeds per plot, damaged weeds per plot, weed species present, weed species damaged, Damage score (1-No phytotoxicity, 9-highest phytotoxicity i.e. 1-Green health plant leaves (Not bleached), 5-Bleached but not all leaves are whitish, 9-bleached (albinism) plant leaves followed by death of plants). Stand count (7, 14, 28 days from planting), plant height, biomass weight, number of leaves, yield (total yield, 100 seed weight).

3.4.1 Data collection

Plant stand was collected by counting the number of seedlings that emerged in each sub-plot at 7, 14 and 28 days after planting and expressed as a percentage of the total number of seeds that were planted in that plot. Apart from stand count, plant height was also determined by measuring the length (cm) from the soil surface to the top of the plant, at 2,4, and 8 weeks before harvesting. This was done on a sample of ten plants in each sub-plot.

The number of leaves was another parameter that was collected, and it was done by counting all leaves on ten randomly selected plants per sub-plot. Dry biomass was collected by carefully digging up selected plants, getting the fresh weight and drying them under an oven. The oven dried plants were weighed and recorded in kilograms. Total biomass weights were collected on three representative samples per sub-plot.

Grain yield was calculated by weighing the total produce or grain per sub-plot in kilograms whereas hundred seed weight was done by drawing 100 seeds from the total grain yield of each sub-plot and weighed in grams.

For phytotoxicity effect, visual score of levels of damage from 1 to 9 where 1 indicated absence of phytotoxicity and 9 showed highest level of phytotoxicity. 1 for a Green health plant leaves (Not bleached), 5 for bleached but not all leaves are whitish and 9 for bleached (albinism) of plant leaves followed by death of plants). In terms of herbicide efficacy, a square metre area (quadrant) was marked in all the main treatment blocks and weeds were removed and identified. Undamaged weeds/ plot, damaged weeds/ plot, weed species present and weed species damaged

3.4.2 Data analysis

The data collected was analyzed using R statistical computing version 3.6.3 software by calculating the Analysis of Variance (ANOVA) to determine whether there were significant differences among the treatments means in terms of the efficacy of Topramezone and Dicamba herbicide on weeds and it's phytotoxicity effect on subsequent crops. A comparison was done between rates of application of herbicide and weed control (undamaged or damaged weeds).

The coefficient of determination or R^2 was also calculated to predict a dependent variable (plant stand) from independent variables (days). R-squared is the percentage of the dependent variable variation that a linear model explains.

$$R^2 = \frac{\text{Variance explained by the model}}{\text{Total variance}}$$

R-squared is always between 0 and 100%. Generally, the higher the R-squared the better the model fits the data.

Chapter 4

RESULTS

4.1 Field Experiment

4.1.1 Herbicide residual effect

Different parameters were analyzed to determine the residual effect of Topramezone and Dicamba, results were summarized in Table 2.0.

Table 2.0: Summary of Analysis of variance (ANOVA) for the different parameters

Source	Degree of Freedom	Stand count (7days)	Stand count (14days)	Stand count (28day)	Plant height	Number of plant leaves	Dry biomass	Hundred Seed Weight	Grain yield
Rep	1	242.98**	69.07**	1.55^{ns}	27.05**	3.29^{ns}	639.80**	2.94^{ns}	2.54^{ns}
Herbicide Rate (R)	3	8.1^{ns}	13.67*	4.61^{ns}	25.48**	18.27*	13.76*	44.76**	91.69**
Error a	3								
Residual period (P)	4	14.43**	56.19**	20.77**	14.15**	92.06**	4.12*	47.55**	73.15**
R x P	12	0.42^{ns}	2.39*	1.30^{ns}	4.85**	16.87**	0.34^{ns}	12.74**	8.77**
Error b	16								
Crop (C)	5	172.36**	255.42**	81.50**	186.88**	477.16**	17.37**	475.62**	154.54**
C x R	15	0.62^{ns}	0.57^{ns}	0.55^{ns}	1.20^{ns}	2.67**	0.26^{ns}	9.04**	4.64**
C x P	20	14.22**	19.41**	7.74**	7.92**	30.65**	1.19^{ns}	15.08**	32.78**
C x R x P	60	0.7^{ns}	1.40^{ns}	0.53^{ns}	1.15^{ns}	3.70**	0.15^{ns}	2.11**	1.56*
Error c	100								

** highly significant at $p \leq 0.01$, * significant at $p \leq 0.05$, ^{ns} not significant at $p > 0.05$.

i. Stand count

The ANOVA Table 2.0 showed that there were highly significant differences ($p \leq 0.01$) among the treatment means for crops, herbicide residual period and on the two-way interaction between herbicide residual period and the crop in terms of stand count, plant height, number of leaves, hundred seed weight and grain yield. However, no significant difference ($p > 0.05$) was seen on herbicide rate, herbicide rate and crop interaction, herbicide rate and residual period interaction on stand count at 7 days from planting and dry biomass. No significant difference was seen among the three-way interaction of herbicide rate, residual period and the crop in terms of stand count, plant height and dry biomass but the difference was significant at number of plant leaves, hundred seed weight and grain yield.

Figure 4.0 shows the similar trend of polynomial among the three crops (soybeans, groundnuts and beans) in terms of low stand count at 7 days, high at 14 days and low at 28 days. For sorghum and sunflower, a linear trend was seen, high stand count at 7 days, low at 14 days and lowest at 28 days. For maize the polynomial trend was relatively low stand count at 7 days, high at 14 days and highest at 28 days. This was seen in the coefficient of determination (R^2) which indicated 96 - 100% variation in the relationship between days and plant stand count. Therefore, we could most likely predict what would happen to plant stand count after 28 days for each crop.

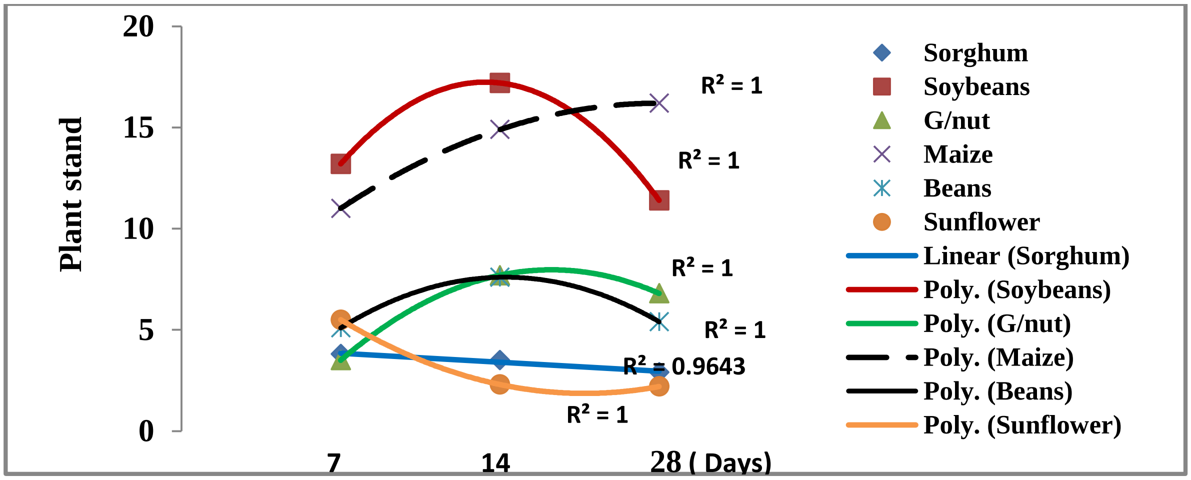


Figure 4.0: Plant stand count at zero-day residual period

ii. Plant height

Table 2.0 on plant height showed that there were no significant differences ($p > 0.05$) among the treatment means for the interaction between herbicide rate and the crop and the three-way interaction of the herbicide rate, residual period and the crop. However, highly significant differences ($p \leq 0.01$) were seen on herbicide rate, herbicide residual period, crop and the interaction between residual period and the crop.

iii. Number of leaves

There were highly significant differences ($p \leq 0.01$) among all the treatment means.

iv. Dry biomass

The summarized ANOVA Table 2.0, results indicated that there were no significant differences in dry biomass among the treatment means for all the two- and three-way interactions. Significant differences were seen on herbicide rate, herbicide residual period and highly significant differences for crop.

v. Hundred Seed weight

In Table 2.0, all the sources of variation indicated highly significant differences among the treatment means.

vi. Grain yield

All the sources of variation showed highly significant differences amongst the treatment means apart from the three-way interaction which only showed significant difference. Grain yields of all crops were subjected to further analysis to demonstrate where the significant differences of the interactions existed. Figures 5.0 to 9.0 showed the interaction of these treatments

Figure 5.0 highlighted that there were highly significant differences amongst the treatment means and this was seen in grain yield between the control and the rest of the three treatments and even between 1L/ ha and 4L/ ha. Maize seems to be affected by Topramezone and Dicamba as the herbicide rate increases, this was seen in grain yield of the 4L/ ha treatment. The effect of the herbicide tends to be more after 60 days.

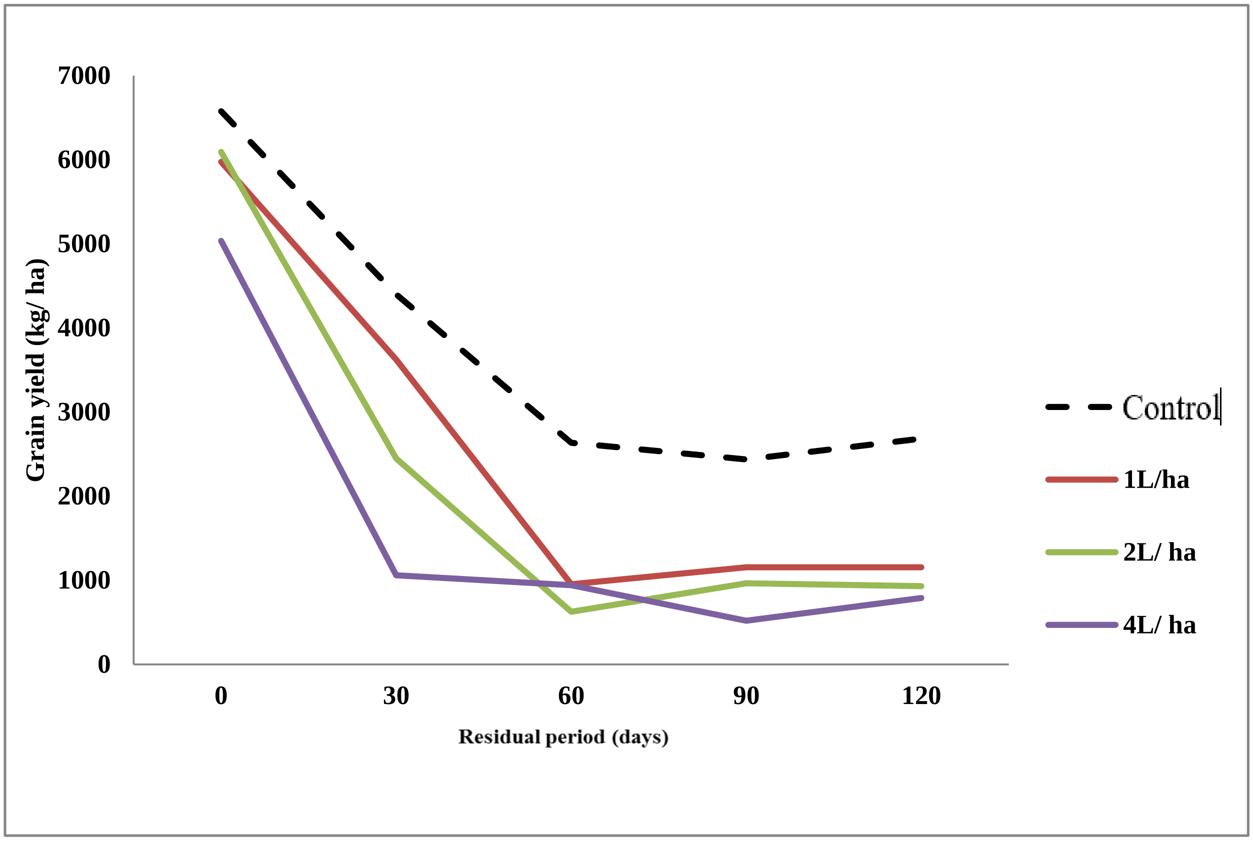


Figure 5.0: Effect of herbicide application rate and residual period on grain yield of Maize

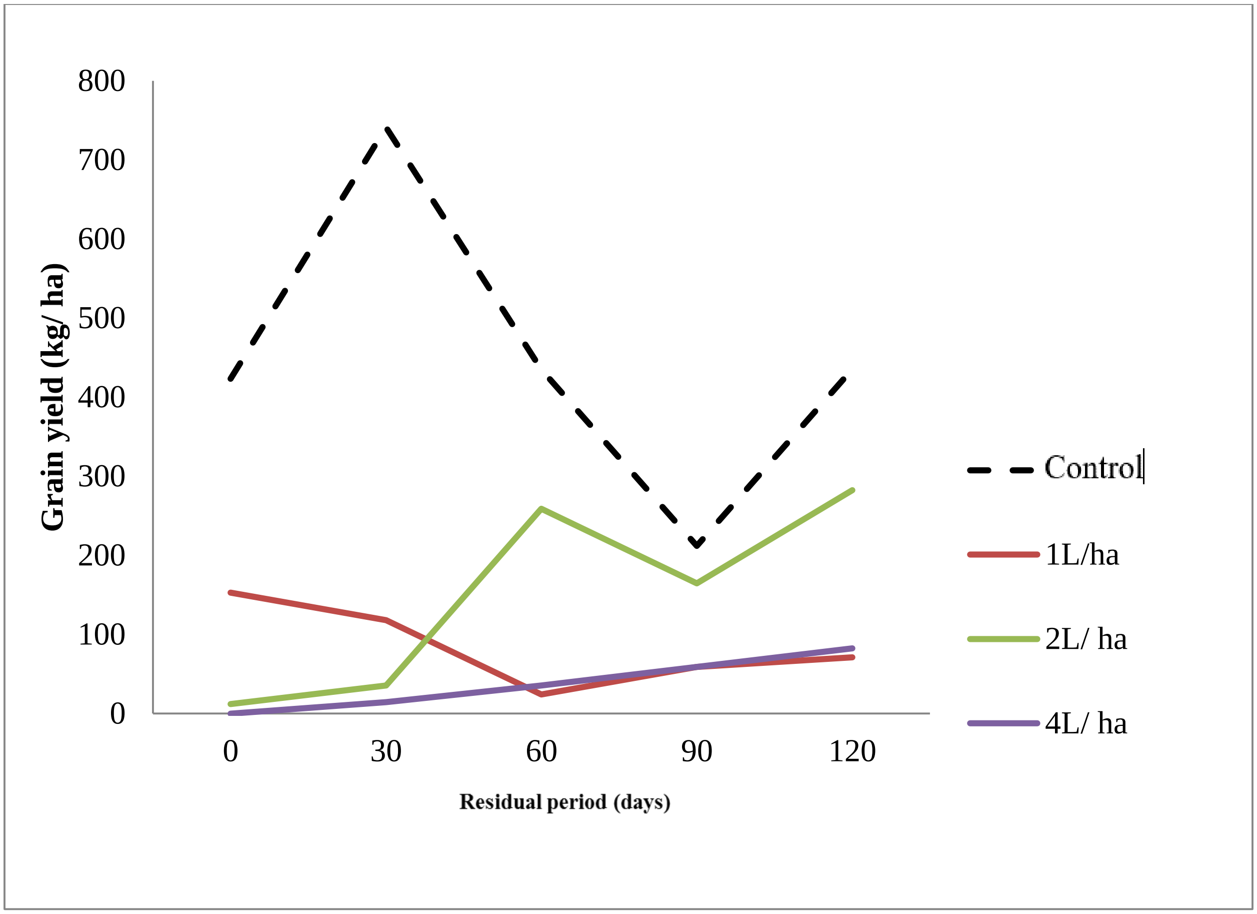


Figure 6.0 Effect of herbicide application rate and residual period on grain yield of Sorghum.

In Figure 6.0, the interaction between herbicide rate and residual period showed that there were highly significant differences in grain yield of sorghum due to the high yield difference between the control and the other treatments and between the 2L/ ha and the other herbicide rates. Sorghum is affected by residual effect of Topramezone and Dicamba herbicide. 2L/ ha herbicide application rate had less effect especially after 30 days of residual period. However, no significant differences between 1L/ ha and 4L/ ha. Using 4L/ ha of the herbicide was wasteful and uneconomical.

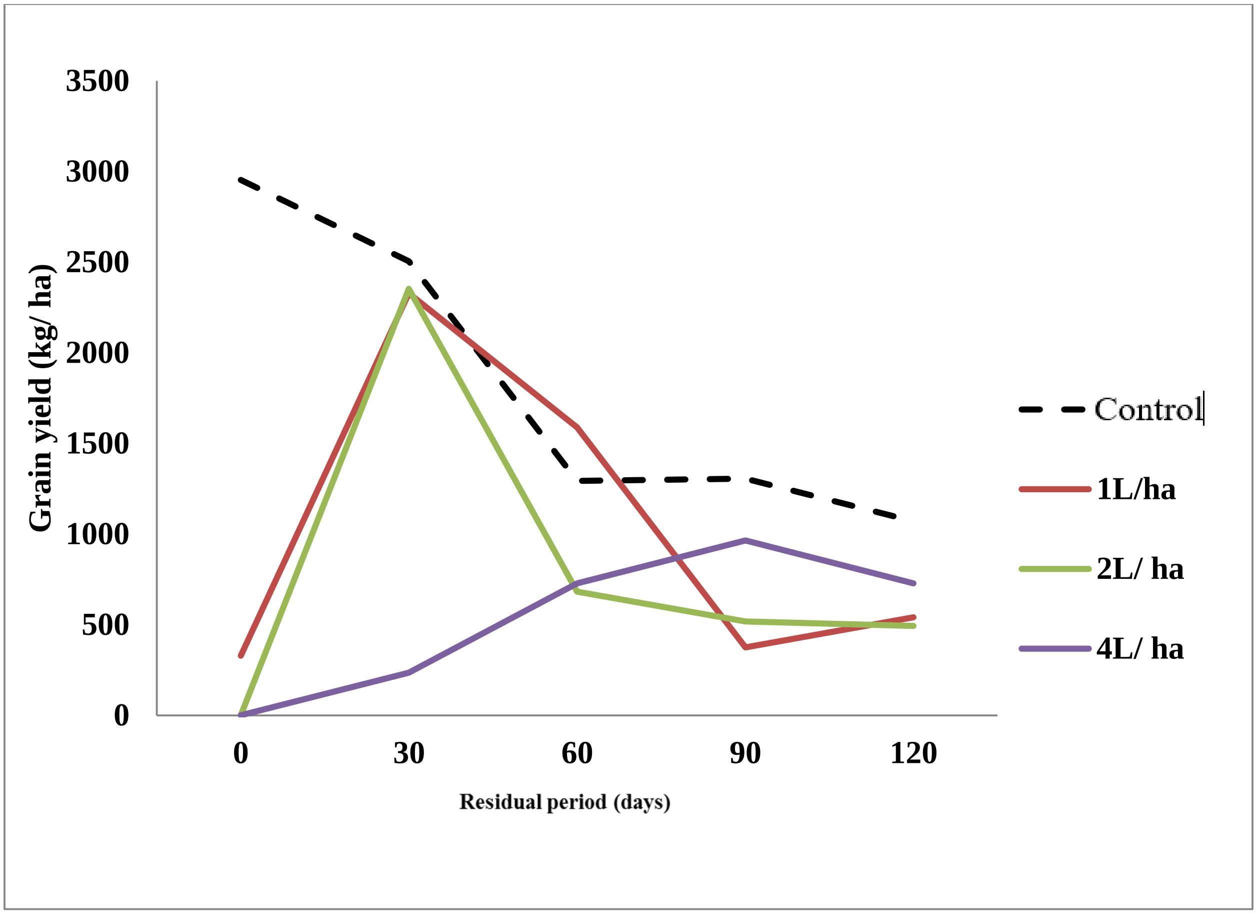


Figure 7.0 Effect of Herbicide rate and residual period on grain yield of Soybeans

On Figure 7.0, the graph showed highest yield of soybeans at 30 days residual period. In the first 30 days residual period, there were highly significant differences in soybeans grain yield, but this was not the case after 30 days.

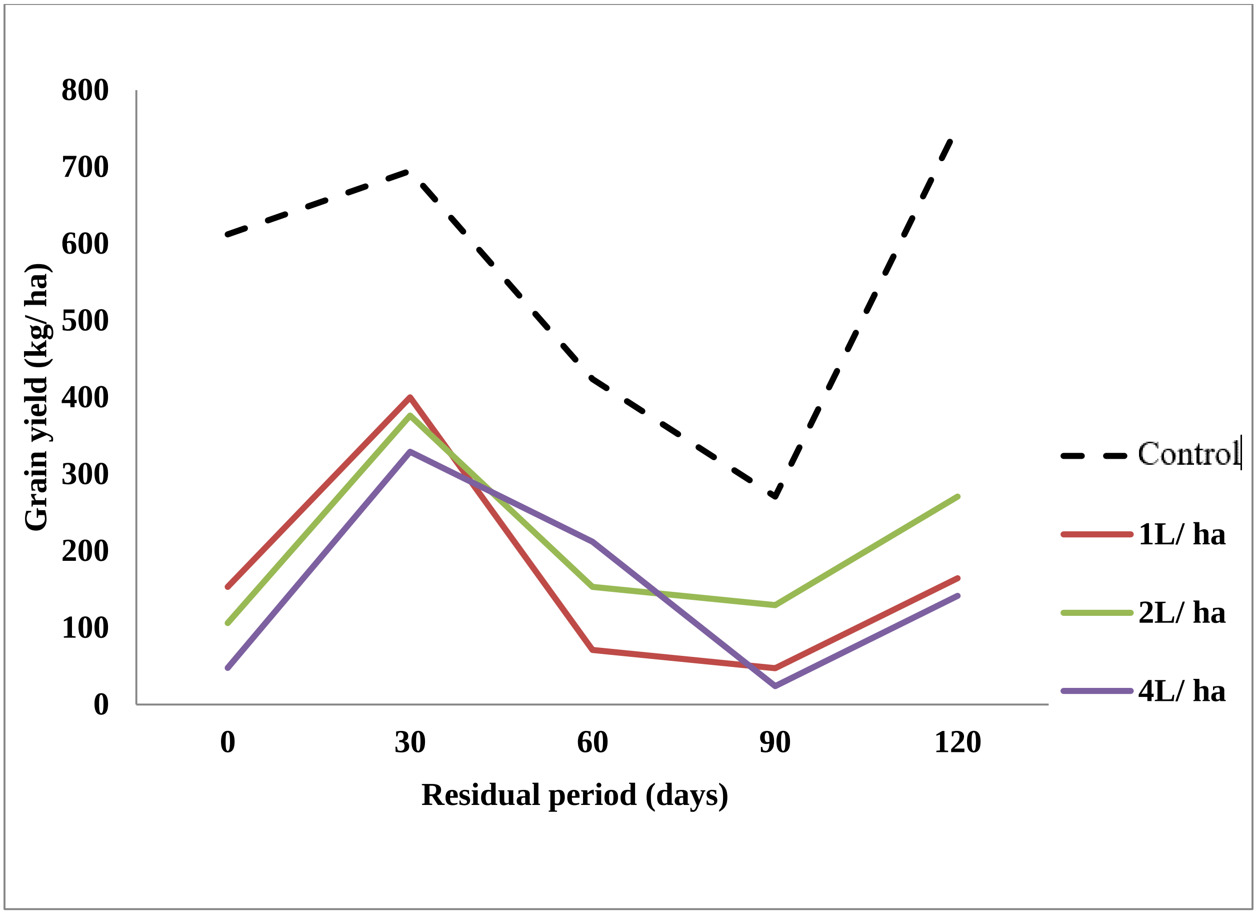


Figure 8.0 Effect of herbicide application rate and residual period on grain yield of Groundnut.

The graph in Figure 8.0 indicated that there were highly significant differences in grain yield of groundnuts between the control and the other treatments with various herbicide rates. Residual effect of Topramezone and Dicamba was highest at 0, 60 and 90 days residual period. Highest yield was obtained at 30 days residual period.

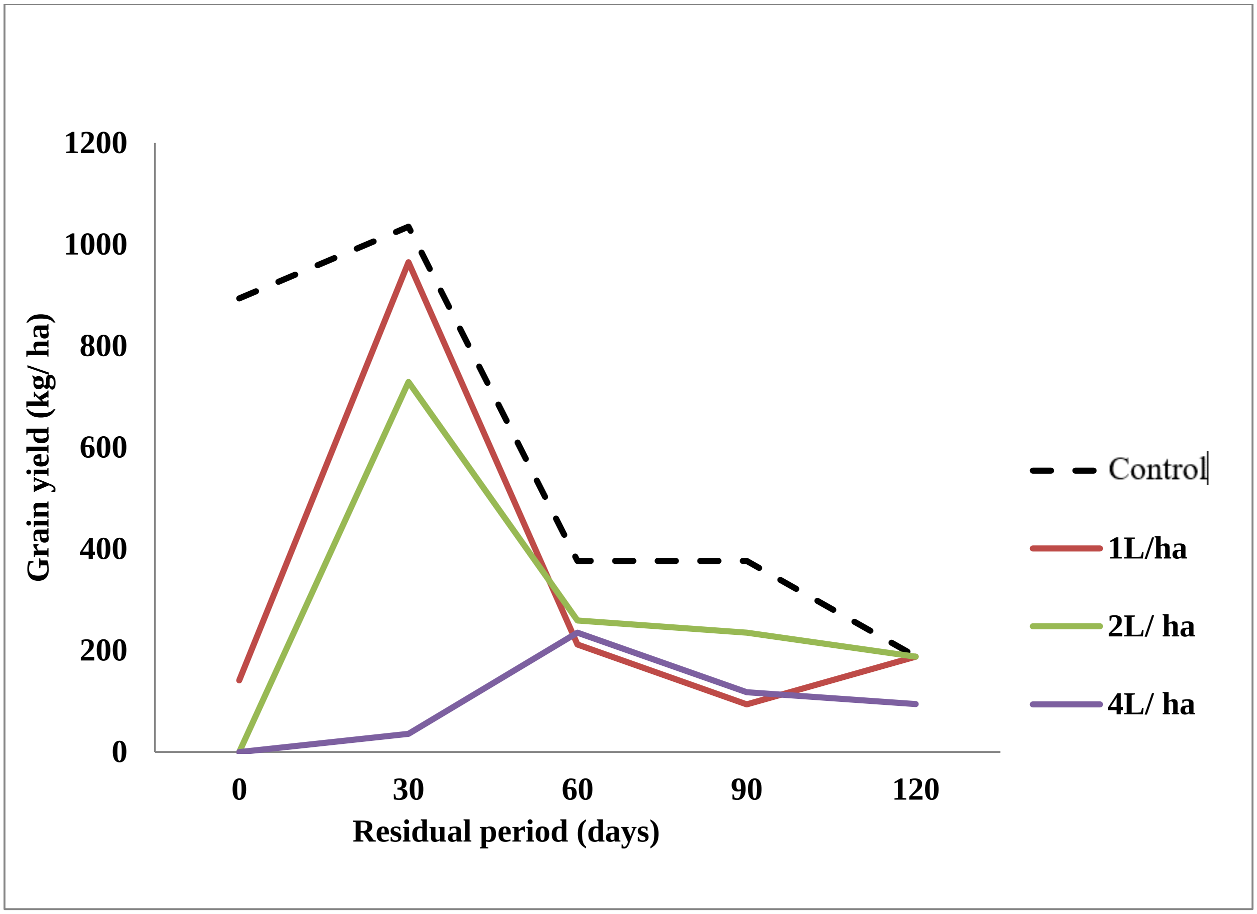


Figure 9.0 Effect of Herbicide rate and residual period on grain yield of beans

Figure 9.0 showed that highest grain yield of beans was obtained on 30 days residual period apart from the 4L/ ha treatment which caused 100% damage on beans at 0-day residual period.

4.1.2 Herbicide efficacy

Table 3.0. shows the efficacy of Topramezone and Dicamba herbicide at different application rates

Table 3.0 Average mean weight (g) of undamaged weeds per treatment

Treatment	***Cyperus rotundus***	***Eleucine indica***	***Nicandra physaloides***	***Euphorbia heterophyla***	***Portulaca oleracea***	***Sida alba***	***Tridax procumbens***	***others***	***Bidens pilosa***	***Trichodesma zeylenicum***	***Sonchus sp***
Control	2.5	7.0	37.7	7.0	16.0	1.6	2.7	2.1	0.0	0.0	0.0
1L/ ha	3.5	0.0	0.0	1.3	2.5	1.3	0.0	0.0	5.7	1.7	0.0
2L/ ha	96.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4L/ ha	2.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0

Table 3.0 illustrated that the control treatment had most of the weed species compared to the other treatments in the field. 2L/ ha was the most effective weed control herbicide rate as it controlled most of the weed species however, it promotes vigorous growth of *Cyperus rotundus.* Despite the herbicide rate of 4L/ ha, *Cyperus rotundus, Euphorbia heterophyla* and *Bidens pilosa* still thrived hence a wasteful and uneconomical practice. It was therefore deduced that Topramezone and Dicamba was an effective selective weed control method in maize regardless of the rate used. From Table 3.0, average mean weight of weeds per treatment was replaced by either presence (1) or absence (0) of the weed species in Table 4.0.

Table 4.0: Presence (1) and absence (0) of weed species per treatment

Treatment	***Cyperus rotundus***	***Eleucine indica***	***Nicandra physaloides***	***Euphorbia heterophyla***	***Portulaca oleracea***	***Sida alba***	***Tridax procumbens***	***others***	***Bidens pilosa***	***Trichodesma zeylenicum***	***Sonchus sp***
Control	1	1	1	1	1	1	1	1	0	0	0
1L/ ha	1	0	0	1	1	1	0	0	1	1	0
2L/ ha	1	0	0	0	0	0	0	0	0	0	0
4L/ ha	1	0	0	1	0	0	0	0	1	0	0

Table 4.0 showed that the control had diverse weed species, followed by 1L/ ha treatment. 4L/ ha had the same number of weed species as 1L/ ha treatment, but 2L/ ha had only one weed specie. The lesser the number and diversity of weeds in the field the better the weed control treatment rate. Table 5.0 shows the similarities amongst the weed treatment rates in terms of weeds control.

Table 5.0: Similarity matrix of the Herbicide treatments

	Control	**1L/ ha**	**2L/ ha**	**4L/ ha**
Control	----			
1L/ ha	33.1	----		
2L/ ha	37.4	62.3	----	
4L/ ha	48.4	74.2	88.9	----

In Table 5.0, the similarity between the same treatment rates is 100 % hence it was left blank. There was 88.9 % similarity in weed control between 4 L/ ha and 2 L/ ha and 74.2 % similarity between 1 L/ ha and 4 L/ ha and 62.3 % similarity between 2 L/ ha and 1 L/ ha. This suggests that using 1 L/ ha and 2 L/ ha would give similar weed control results to that of 4 L/ ha. Therefore, using 4 L/ ha treatment would be wasteful.

4.2 Green House Experiment

The results for the different parameters of the study are illustrated in Table 6.0.

Table 6.0: Summary of the analysis of variance (ANOVA) for the different parameters

Source	DF	(plant stand)	(Phytotoxicity)	(% dead)
Herbicide Rate	3	1400.8**	1030.2**	1490.1**
Residual period	4	673.3**	194.5**	708.1**
Crop	5	165.0**	143.1**	174.5**
Herb Rate*Res period	12	42.8**	21.8**	43.7**
Herb Rate*Crop	15	33.8**	32.4**	36.4**
Res period*Crop	20	18.9**	7.0**	20.3**
Herb Rate*Res per*Crop	60	5.6**	3.4**	5.8**

Key: *** highly significant at $p \leq 0.01$, * significant at $p \leq 0.05$, ^{ns} not significant at $p > 0.05$.*

The ANOVA Table 6.0 showed that there were highly significant differences ($p \leq 0.01$) among all the sources of variation for all the parameters (plant stand, phytotoxicity and percent dead plants).

Results for phytotoxicity effects caused by herbicide rate and residual period on crops were further analyzed to determine exactly where the significant differences existed.

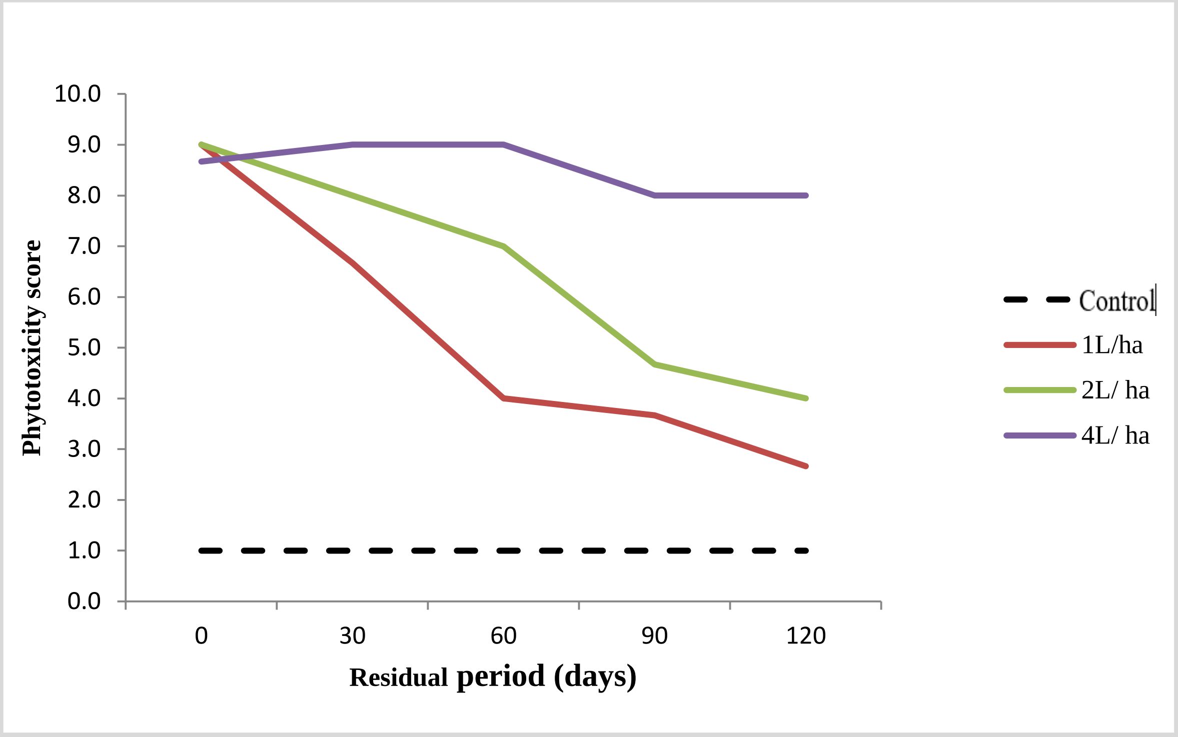


Figure 10.0 Phytotoxicity effect caused by herbicide rate and residual period on sorghum.

Figure 10.0 showed that there were highly significant differences ($p \leq 0.01$) among the treatment means and was seen in the phytotoxicity score between the control and the other treatments. The control had an average phytotoxicity score of 1.0 which meant that it was not affected by Topramezone and Dicamba as the herbicide was not applied on this treatment. 4L/ ha had the highest score of 8.5 and showed severe plant damage. The recommended rate of 1L/ ha seemed less severe on sorghum.

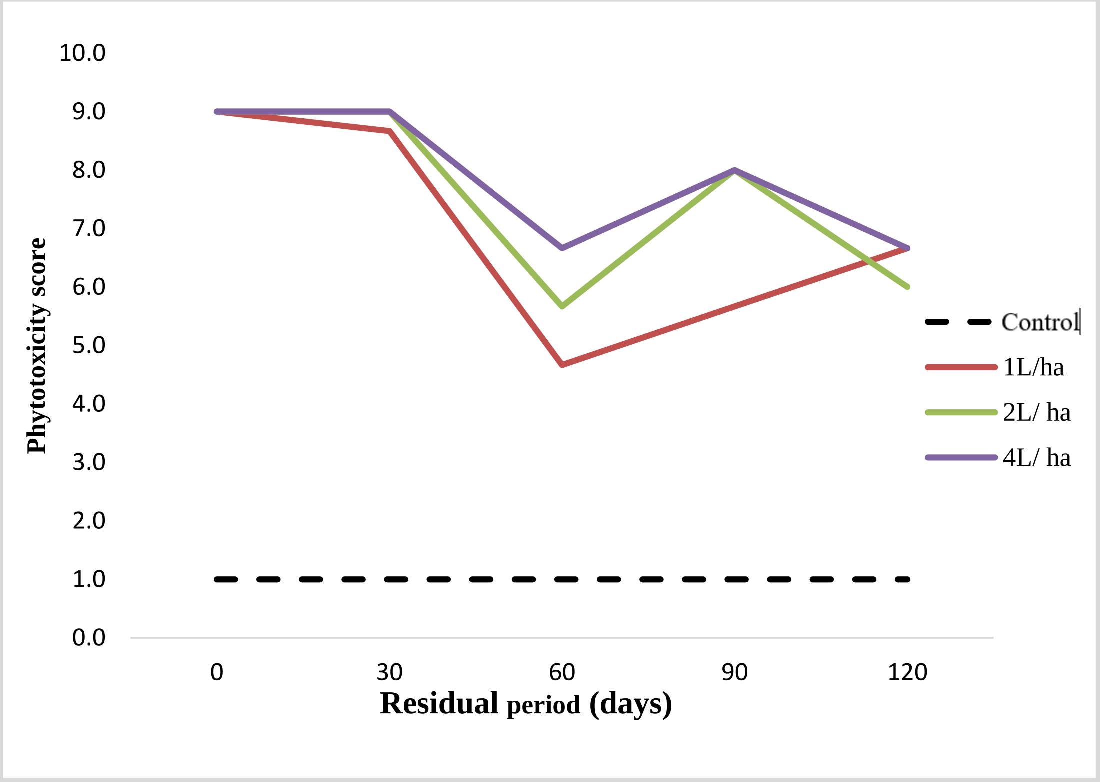


Figure 11.0 Phytotoxicity effect caused by herbicide rate and residual period on sunflower

Highly significant differences ($p \leq 0.01$) among the treatment means resulted from the control having lower phytotoxicity score compared to the other treatments as seen in Figure 11.0. The trend was the same as 4L/ ha treatment had more effect compared to 1L/ ha.

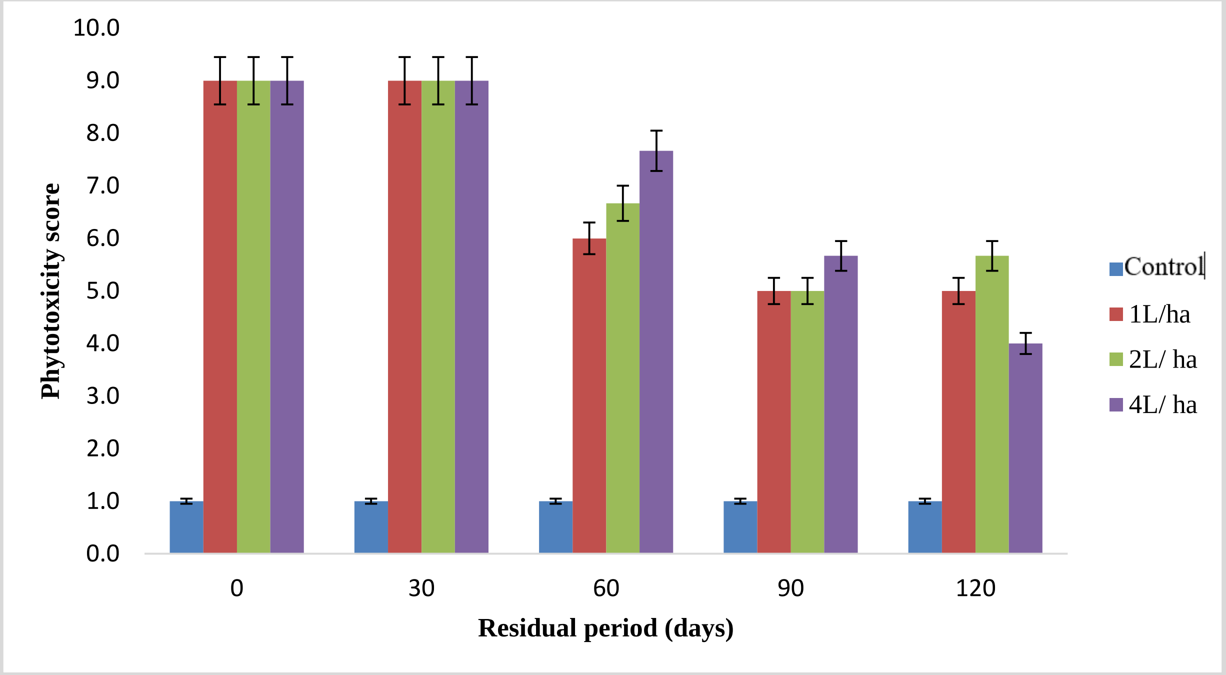


Figure 12.0 Phytotoxicity effect caused by herbicide rate and residual period on soybeans

The control had the lowest phytotoxicity effect whereas 4L/ ha treatment had the highest effect but there was no significant difference among the treatments with herbicides apart from the control. For the other treatments, significance differences were seen at 120 days as shown in Figure 12.0.

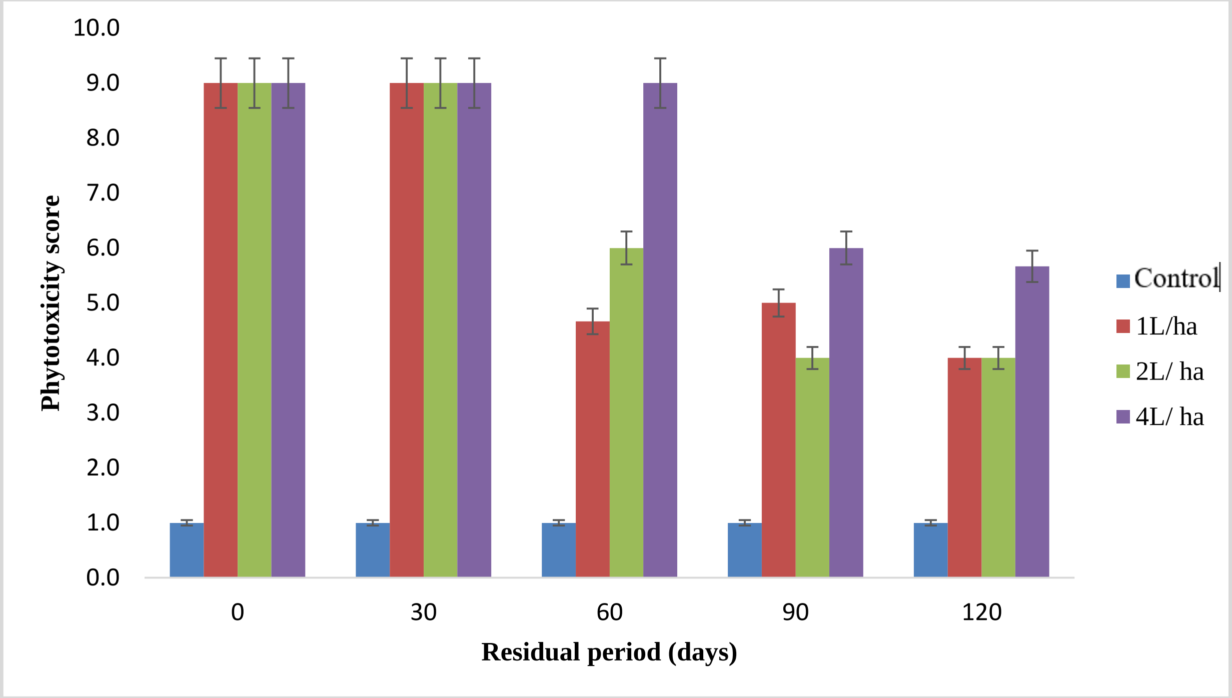


Figure 13.0 Phytotoxicity effect caused by herbicide rate and residual period on groundnuts

A similar trend was seen in Figure 13.0, 4L/ ha showed severe phytotoxicity effect and 1L/ ha was better among the other treatments. Significant difference was seen after 60 days residual period between the 4L/ ha and the other treatments with herbicides (1L/ ha and 2L/ ha).

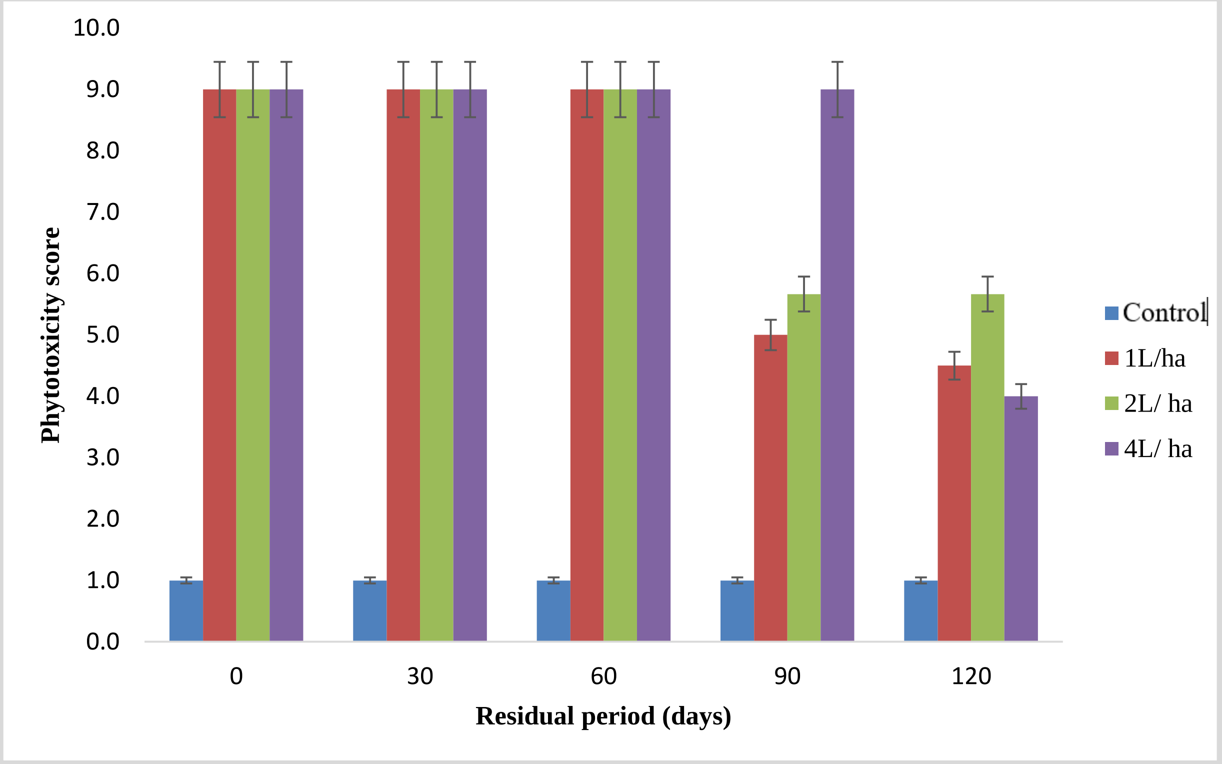


Figure 14.0 Phytotoxicity effect caused by herbicide rate and residual period on beans

For all the treatments with Topramezone and Dicamba, beans had the highest phytotoxicity effect at 0, 30 and 60 days residual period as shown in Figure 14.0. Highly significant differences were seen after 90 days residual period among all the treatment means.

Chapter 5

DISCUSSION

5.1 Efficacy of Topramezone and Dicamba at different application rates

Results obtained showed that the various application rates of Stellar star herbicide whose active ingredients are Topramezone and Dicamba have different effects in terms of weed control. The control treatment where no chemical was applied had many weed species compared to the other treatments. This was because no control measure was done at the time the sample was taken whereas the other treatments had already received the weed control measures. The recommended herbicide rate of Topramezone and Dicamba herbicide was 1 L/ ha but this rate was not the best weed control measure. This rate seems to be unable to eradicate *Cyperus rotundus, Euphorbia heterophyla, Portulaca oleracea, Sida alba, Biden pilosa* and *Tricodesma zeylenicum.*

The 2 L/ ha rate was the most effective weed control herbicide rate as it controls most of the weed species compared to any other rate. However, it promotes vigorous growth of *Cyperus rotundus* with 96 g average mean weight of the weed per treatment. This was even far much higher than that of the control, which might suggest that the herbicide stimulates growth of *Cyperus rotundus* at this rate. Despite not having enough evidence, it can be suggested that the *Cyperus rotundus* is resistant to Topramezone and Dicamba control as all the rates could not eradicate it.

The herbicide rate of 4 L/ ha could not eradicate *Cyperus rotundus, Euphorbia heterophyla* and *Bidens pilosa* despite being one of the most effective rates. This application rate of the herbicide was above normal dose compared to the recommended chemical rate of 1 L/ ha and yet it was as effective in weed control as a 2 L/ ha treatment. Therefore, use of overdose as well as under dose of herbicides is not recommended because it is wasteful and uneconomical practice as seen in this study. According to Bari (2012), farmers are not following dose instructions properly as they tend to overdose as well as under dose herbicides. Herbicides are poisonous chemical compounds. That’s why they obviously have some detrimental effects on main crops (Begum *et al.,* 2008; Scarponi *et al.,* 2005; Islam, 2001; Rahman, 2001), surrounding ecosystems (Panda and Sahu, 2004; Bromilow, 2003; Sannino and Gianfreda 2001) and human health (Gammon, 2009). Therefore, judicious use of herbicides is essential to ensure proper weed control, crop growth and yield and environmental safety. Some researchers suggest that overdose use of herbicides prolong the residual phytotoxicity or carryover effect. Use of under dose is also not recommended. Neve and Powles (2005) demonstrated that by repeatedly using reduced herbicide rates, resistant weed populations increased more compared to when a full, recommended rate of the herbicide was used.

Weed diversity is a serious problem in crop production because more weed species present indicates different effects on crops. Various weed species compete differently with crops in terms of nutrients mining and even allelopathy. Smallholder farmers can use 2 L/ ha rate and yet realize results that are 88.9% like that of 4 L/ ha. Therefore, using 4 L/ ha would mean an increase in the cost of production. Regardless of the herbicide rate used, efficacy of Topramezone and Dicamba could be seen in terms of stimulated outgrowth of weeds to whitish leaves and later death of weeds. Topramezone is a 4-Hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor and prevents the biosynthesis of carotenoid that protects chlorophyll molecules from dangerous UV rays and excess light (Grossmann and Ehrhardt, 2007). There is nothing to prevent sunlight from penetrating into the leaves, which results in the photooxidation of chlorophyll molecules (Wang *et al.,* 2018). Consequently, the weed turns white and dies. Dicamba takes effect through stimulating the outgrowth of plant, which causes the exhaustion of nutrients supplies and plant death (Nishimura *et al.*, 2015). This is based on the nature of Dicamba, which is a synthetic mimic of natural auxin (a plant hormone used for stimulating plant growth). Upon response to this kind of herbicide, the plant develops abnormalities such as leaf epinasty, leaf abscission and growth inhibition of the root and shoots (Harp, 2010).

5.2 Effect of Topramezone and Dicamba on subsequent crops at different application rates

5.2.1 Crop responses

Results obtained shows a low stand count at 7 days, followed by the highest stand count at 14 days and later lowest stand count at 28 days in soybeans (*Glycine max* L.), groundnuts (*Arachis hypogaea* L.) and beans (*Phaseolus vulgaris* L.). This may suggest that Topramezone and Dicamba herbicide had some residual effects of delayed germination on beans at 7 days, prevented germination of seeds at 14 days and caused death of some germinated plants at 28 days. This agrees with studies done by Barber (2016), who highlighted that dicamba herbicide affects the germination of soybeans. When seeds were planted in the greenhouse and the field, germination and vigor were greatly reduced as was expected based on the data collected (Barber, 2016). Herbicide residual effects were visible in the whitish plants turning greyish due to bleaching of the chlorophyll (green colour) by the herbicide, disrupting their function and eventually killing them. Apart from maize, all the crops exhibited both temporary and permanent stress as expressed in the discolouration and death of some plants. Studies done by Dragicevic *et al.*, 2010, indicated that the application of herbicides might result in some cases of temporary or permanent stress, depending on the characteristics of the product and environment. The stand count of maize seemed to have increased despite some temporary stress caused by the herbicide.

However, the seeds that did not germinate in the control accounted for the quality of the seed and other soil factors. Field experiment results shows some significant differences among the treatment means on stand count, implying that the herbicide could have some residual effects. The results were also the same for the green house experiment which shows that there were highly significant differences among all the sources of variation for all the parameters (plant stand, phytotoxicity and percent dead plants).

5.2.2 Interactive effects of herbicide rate and residual period

Results showed that maize (*Zea mays* L.) is also affected by Topramezone and Dicamba as the herbicide rate increases, this can be seen in grain yield of the 4 L/ ha treatment. The 4 L/ ha treatment had maize grain yield losses of 1.5 tons/ ha, 3 tons/ ha, 1.5 tons/ ha, 2 tons/ ha and 1.7 tons/ ha at 0, 30, 60, 90 and 120 days residual period respectively when compared to the control where no herbicide was applied.

However, the reduction in maize grain yield especially after the residual period of 60 days could be due to late planting of the crop. However, the effect of the herbicide was seen in all the other treatments applied with the chemical. This agrees with other scholars who deduced that timely planting of full season hybrids allow the maize crop to take full advantage of the available growing season (Coulter, 2012). In most cases studied, results show that maize grain yield potential declines as planting is delayed beyond the optimum planting window for a given geographical location (Farnham, 2001; Myers and wiebold, 2013; Nafziger, 2008).

In this study, it seemed that amongst all the selected succeeding crops used, groundnut (*Arachis hypogaea* L.) was the most sensitive crop. The highest grain yield of the crop was 350 kg/ ha at herbicide residual period of 30 days whereas the control had 700 kg/ ha. Yields of groundnut vary from about 400 kg to several tonnes per hectare, depending on the production system, but on the average, the global yield is 2500–2700 kg per hectare (Aransiola *et al.*, 2019). The lower grain yield was across the entire herbicide application rates throughout the residual periods. There seems to be enough evidence also that all the selected succeeding crops are affected by Topramezone and Dicamba herbicide.

Results from the green house experiment indicated that there were highly significant differences among all the sources of variation for all the parameters (plant stand, phytotoxicity and percent dead plants). It shows that the residual phytotoxicity effect of Topramezone and Dicamba herbicide was high in the 0, 30 and 60 days residual period for all the crops. 4 L/ ha treatment rate had the worst and highest phytotoxicity score of 9 whereas the control had the score of 1(no phytotoxicity effect). The phytotoxicity effect could be seen from the whitish, greyish, pale germinated plants which mostly dried after 3 to 5 days. According to Sondhia (2014), herbicides are chemicals in nature, therefore, excessive and repeated use may pose residue problems, phytotoxicity to crop plants, residual effects on susceptible intercrops or succeeding crops and adverse effects on non-target plants. In this study, it appears that Topramezone and Dicamba herbicide has severe residual phytotoxicity effect on sorghum (*Sorghum bicolor* L.), soybeans (*Glycine max* L.), sunflower (*Helianthus annuus* L.), common beans (*Phaseolus vulgaris*) and groundnuts (*Arachis hypogea* L.) at all residual periods.

Chapter 6

CONCLUSION

Stellar star herbicide comprising of Topramezone and Dicamba herbicide is an effective selective and systemic herbicide in controlling early post-emergence grasses and broadleaf weeds in maize. The herbicide application rate influenced efficacy. The 2 L/ ha treatment was the most effective weed control herbicide rate as it controlled most of the weed species compared to any other rate.

The residual phytotoxicity effect of Topramezone and Dicamba herbicide was high particularly in the 0, 30 and 60 days residual period for all the crops. The 4 L/ ha treatment rate had the worst and highest phytotoxicity score of 9 whereas the control had the score of 1(no phytotoxicity effect).

Topramezone and Dicamba herbicide has effects on follow-up crops both at varying application rate and at varying residual periods with groundnuts being the most affected and sorghum the least affected. Hence, the research hypothesis was accepted which stated that; There is a variation in carryover effects of Topramezone and Dicamba herbicide at different application rates and at different herbicide residual periods on follow-up crops.

REFERENCES

1. Acker R. C. (2005). Soil residual herbicide: Science and management. Department of plant science, University of Monitob, Canada.
2. Aransiola E. F, Ehinmitola E. O, Adebimpe A. I, Shittu T. D, Solomon D. O (2019). Prospects of biodiesel feedstock as an effective eco-fuel source and their challenges. Advances in Eco-Fuels for sustainable Environment. Woodhead publishing series in Energy. Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.
3. Arikan N, Turktemel I, Burcak A. A. and Akbas B. (2015). Persistence of herbicides in soil. Republic of Turkey Ministry of Food, Agriculture and Livestock, General Directorate of Agricultural Research and Policies.
4. Ayala R.V, Rasmussen J, Gerhards R. (2010). Precision crop protection-the challenge and use of heterogeneity. Mechanical weed control. Department of weed sciences. University of Hohenheim, Stuttgart, Germany.
5. Ayodele O. and Olubunmi A. (2017). Weed Management Strategies for Conservation Agriculture and Environmental Sustainability in Nigeria. *Journal of Agriculture and Veterinary Science* (IOSR-JAVS). Volume 10 (8): 1 - 8
6. Barber T. (2016). Dicamba effects on soybeans seed and offspring. Division of Agriculture, Research and Extension. University of Arkansas system.
7. Bari M. N. (2012). Evaluation of herbicide use in Bangladesh agriculture with special reference to wetland rice. Krishi Gobeshona Foundation, Dhaka, Bangladesh.
8. BASF (2016). Stellar star herbicide. Agricultural solutions, South Africa.
9. Begum M, Juraimi A. S, Omar S, A. Rajan and Azmi M. (2008). Effect of Herbicides for the Control of *Fimbristylis miliacea* in Rice. *Agronomy Journal*, 7: 251-257.
10. Bromilow R. H. (2003). Paraquat and sustainable agriculture. *Pest Management Science*, 60: 340-349.
11. Brosnan J. T, Breeden G. K, Thoms A. W and Sorochan J. C. (2014). Effects of pre-emergence herbicides on the establishment rate and tensile strength of hybrid Bermuda grass sod. *Weed technology*, 28: 206-212.
12. Bunch T. R, Gervais, J. A, Buhl K, Stone D. (2012). Dicamba Technical Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services.

13. Capinera J. L. (2005). Relationships between Insect Pests and Weeds: An Evolutionary Perspective. *Weed Science*. Vol. 53, No. 6, pp. 892-901
14. Chaudhary S. U, Hussain M, Ali M. A, Iqbal J. (2008). Effect of weed competition period on yield and yield components of wheat. *Journal of Agricultural Research* 46 (1): 47-54.
15. Chipomho J, Mupeti S, Chipomho C, Mashavakure N, Mashingaidze A. B. (2019). Evaluation of a pre-formulated post-emergence herbicide mixture of topramezone and dicamba on annual weeds and Bermuda grass in maize in a sub-tropical agro-ecology. University of Zimbabwe, College of Agricultural Sciences and Technology, Marondera. *Elsevier Journal*, Vol 5: 1-9.
16. Colquhoun J. (2006). Herbicide persistence and carryover. University of Wisconsin Weed Science-Cooperative Extension Publishing.
17. Coulter J. (2012). Planting date considerations for corn. Minnesota crop news. University of Minnesota Extension.
18. Curran W. S. (2001). Persistence of herbicide in soil. Agronomy facts. College of Agricultural Sciences. The Pennsylvania State Extension.
19. Damalas C. A, Gitsopoulos T. K, Koutroubas S. D and Georgoulas I. (2015). Annual grasses control with topramezone in mixture with ALS-inhibiting herbicides. Democritus University of Thrace.
20. Dangwal R. L, Singh A, Singh T, Sharma C. (2010). Effect of weeds on the yield of wheat crop in Tehsil Nowshera. *Journal of American Science* 6 (10): 405-407.
21. Dragicevic V, Simic M, Stefanovic L and Sredojevic (2010). Possible toxicity and tolerance patterns towards post-emergence herbicides in maize inbred lines. Maize Research Institute, Serbia
22. EPA. (2005). Pesticide fact sheet: Topramezone. Environmental protection agency, USA.
23. Esser K. B. (2017). Water Infiltration and Moisture in Soils under Conservation and Conventional Agriculture in Agro-Ecological Zone IIa, Zambia. *Agronomy Journal*, Vol 7 (2): 40.
24. Farnham, D. (2001). Corn Planting Guide. Iowa State University.
25. Gallandt E. R. and Weiner J. (2015). Crop-Weed Competition. Wiley and Sons Ltd.
26. Gammon C. (2009). Weed-Whacking Herbicide Proves Deadly to Human Cells. Environmental Health Sciences Company, USA.

27. Gorsic M, Baric K, Galzina N, Scepanovic M, Ostojic Z. (2008). Weed control in maize with new herbicide topramezone. *Cereal Research Communications*, 36: 1627-1630.
28. Grossmann K. and Ehrhardt T. (2007). On the mechanism of action and selectivity of the corn herbicide Topramezone: a new inhibitor of 4-Hydroxyphenylpyruvate dioxygenase. *Pest Management Science* 63, 429-439.
29. Hager A. (2000). Weed management. Agronomy handbook. University of Illinois.
30. Hajizadeh R, Mirshekari B. (2011). Interference of wild oat (*Avena fatua*) with wheat cultivars. *Journal of Food, Agriculture and Environment* 9(3-4):398-399.
31. Hanson B. D. and Shrestha A. (2006). Weed control with methyl bromide alternatives. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. University of California, USA.
32. Harp P. R. (2010). Handbook of Pesticide Toxicology (Third Edition). University of California, USA.
33. Harris P. (2009). Biological control of weeds. Weeds biological control. Canada Department of Agriculture. Research institute, Belleville Ontario.
34. Helling C. S. (2005). The science of soil residual herbicides. Soil Residual Herbicides: Science and Management. Canadian Weed Science Society.
35. Horton C. R, Weisz R, York A, Place G, Hamilton M. (2014), Chapter 7: weed management. North Carolina organic grain production guide, NC State Extension Publication.
36. HRAC (2006). Pant protection. Classification of herbicide according to mode of action. Wiley and sons Ltd.
37. Ibrahim A. A. S. (2006). Weed competition and control in sugarcane. *Weed research* 24: 227-231.
38. Islam M. A. (2001). Evaluation of four herbicides in controlling weeds in transplant Aman rice (MSc. Thesis). Bangladesh Agricultural University. Bangladesh.
39. Kadioglu I. and Yanar Y. (2004). Allelopathic effects of plant extracts against seed germination of some weeds. *Asian journal of plant sciences*. Volume 3:472-475
40. Klaus G. (2000). Mode of action of auxin herbicides: a new ending to a long, drawn out story. Germany. *Trends in Plant Science* 5: 506-8.

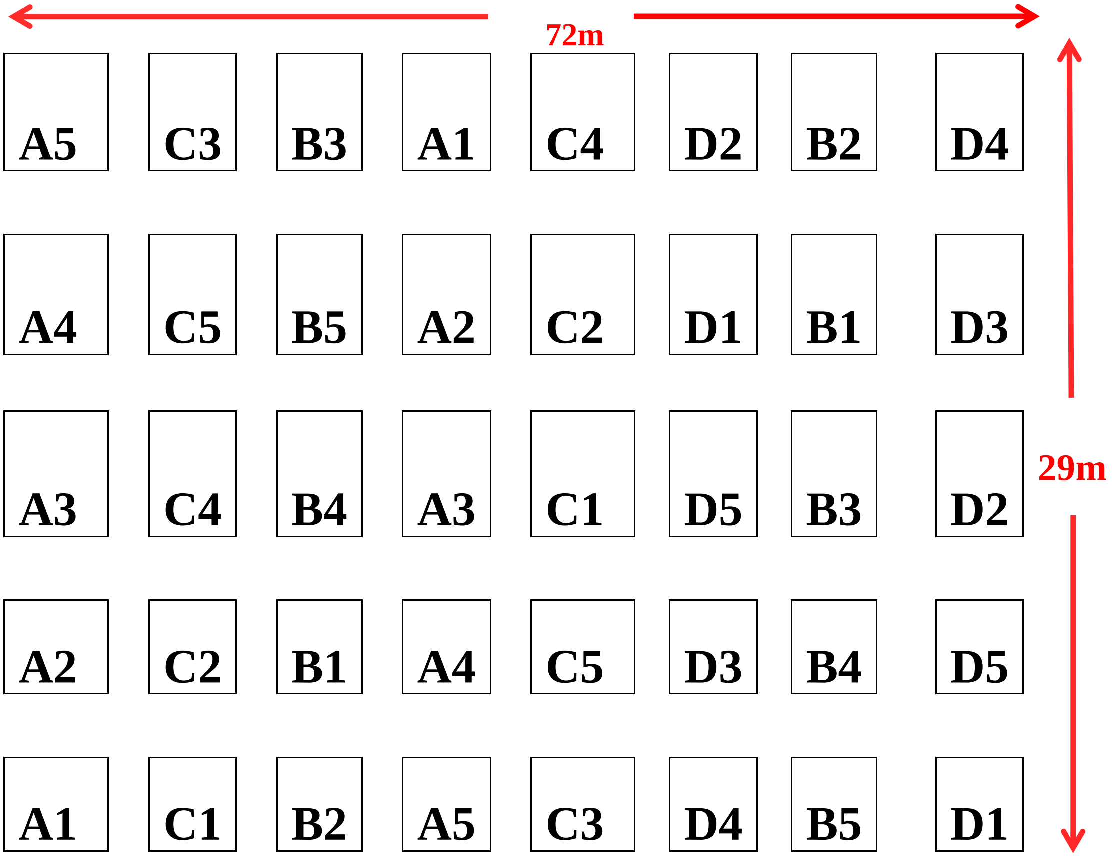
41. Kramer W. and Schirmer U. (2007). Modern crop protection compounds. Wiley and sons Ltd. UK.
42. Loux M. M, Doohan D, Dobbels A. F, Johnson W. G, Young B. G, Legleiter T. R and Hager A. (2015). Weed control guide. The Ohio State University.
43. Marwat K. B, Saeed M, Hussain Z, Gul B, Rashid H. (2008). Study of various herbicides for weed control in wheat under irrigated conditions. *Pakistan Journal of Weed Science Research* 14:1-8.
44. Melander B, Rasmussen I. A. and Barberi P. (2005). Integrating physical and cultural methods of weed control, examples from European research. *Weed Science* 53, 369–381.
45. Myers B. and Wiebold W. J. (2013). Planting date. Integrated Pest and Crop Management. University of Missouri
46. Nafziger E. (2008). Thinking About Corn Planting Date and Population. The Bulletin. University of Illinois Extension.
47. Neve P. and Powles S. B. (2005). Recurrent selection with reduced herbicide rates results in the rapid evolution of herbicide resistance in *Lolium rigidum*. Theoretical and Applied Genetics, 110, 1154-1166.
48. Nishimura J, Gazzo K. and Budd R. (2015). Environmental Fate and Toxicology of Dicamba. Department of Pesticide Regulation, California Environmental Protection Agency. Technical report.
49. Nkhoma S, Kalinda T. and Kuntashula E. (2017). Adoption and Impact of Conservation Agriculture on Smallholder Farmers' Crop Productivity and Income in Luapula Province, Zambia. Department of Agricultural Economics and Extension, University of Zambia. *Journal of Agricultural Science*; 9 (9): 168-170.
50. Norsworthy J. K, Ward S. M, Shaw D. R, Llewellyn R. S, Nichols R. L, Webster T. M, Bradley K.W, Frisvold G, Powles S. B, Burgos N. R, Witt W.W, Barrett M. (2012). Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Science. Special Issue:31–62.
51. Oerke E. C. (2006) Crop losses to pests. *Journal of Agricultural Science* 144:31–43
52. Oerke E. C. and Dehne H. W. (2004). Safeguarding production-losses in major crops and role of crop protection. *Crop Protection* 23(4): 275-285

53. Panda S. and Sahu S. K. (2004). Recovery of acetylcholine esterase activity of Drawida willsi (Oligochaeta) following application of three pesticides to soil. *Chemosphere* 55: 283-290.
54. Raeder A. J, Lyon D, Harsh J. and Burke I. (2015). How soil pH affects the activity and persistence of herbicides. Soil acidification series. WSU Extension.
55. Rahman A, Dowsett C. A, Trolove M. R. and James T. K. (2014). Soil residual activity and plant-back periods for the herbicides saflufenacil and topramezone. AgResearch, Ruakura research centre, Hamilton, New Zealand.
56. Rahman, S. M. (2001). Effect of herbicides on the growth and yields of Aus rice Cv. Iratom-24. Bangladesh Agricultural University. *Journal of science foundation* volume 12 (2): 39-46
57. Rana S. S. (2018). Selectivity of herbicides and factors affecting it. Published by Department of Agronomy. CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, India.
58. Rana S. S. and Rana M. C. (2016). Principles and practices of weed management. Department of Agronomy, Forages and Grassland Management College of Agriculture, CSK Himachal Pradesh Krishi, Vishwavidyalaya, Palampur, India.
59. Ritchey E. and Lee B. (2011). Soil and fertility. University of Kentucky. College of Agriculture, Food and Environment. Cooperative Extension Service
60. Sannino F. and Gianfreda L. (2001). Pesticide influence on soil enzymatic activities. *Chemosphere*, 45: 417-425.
61. Scarponi L, Buono D. and Vischetti C. (2005). Effect of Pretilachlor and Fenclorim on carbohydrate and protein formation in relation to their persistence in rice. *Pest Management Science* 61 (4): 371-376.
62. Schonhammer A, Koch H. and Freitag J. (2006). Topramazone - A new highly selective herbicide compound for control of warm season grasses and dicotyledoneous weeds in maize. *Journal of plant diseases and protection* 20. Pp. 1023-1031.
63. Sherwani S. I, Arif I. A. and Khan H. A. (2015). Modes of Action of Different Classes of Herbicides. Intech Open Limited.
64. Smith M and Retzinger J (2003). Revised classification of herbicides by site of action for weed resistance management strategies. *Weed Technology* volume 17: 605-619

65. Sondhia S. (2014). Herbicides residues in soil, water, plants and non-targeted organisms and human health implications: *Indian Journal of Weed Science* 46 (1): 66-85.
66. Stamp N. (2003). Out of the Quagmire of Plant Defense Hypotheses. *The Quarterly Review of Biology* 78: 23–55.
67. Thakur S. and Rana S. S. (2018). Climatic Factors and Phytotoxicity of Herbicides. Department of Agronomy, CSK Himachal Pradesh Krishi, Vishwavidyalaya, Palampur India.
68. Tilley N. P. (2016). Allelopathy in Plants: What Plants Suppress Other Plants. North Carolina (USA)
69. Vats S. (2015). Herbicides: history, classification and genetic manipulation of plants for herbicide resistance. Springer International Publishing, Switzerland pp. 153–192.
70. Vencill W. K. (2002). Herbicide Handbook. 8th edition. Weed Science Society of America.
71. Wang H, Lui W, Zhao K, Yu H, Zhang J. and Wang J. (2018). Evaluation of Weed control efficacy and crop safety of the new HPPD – inhibiting herbicide. Scientific Report 8, 7910
72. Ware W. G. and Whitacre M. D. (2004). An introduction to herbicides, 2nd edition. University of Minnesota.
73. Wilen C. A, Haver D. L, Flint M. L, Geisel P. M. and Unruh C. L. (2017). Pesticides: Safe and Effective Use in the Home and Landscape. University of California Statewide IPM Program.
74. Wolf J. K. and Rust M. C. (2005). Topramezone Herbicide. Tier II drinking water assessment. US Environmental Protection Agency
75. York A. and Culpepper A. S. (2003). Weed management in corn. NC State Extension Publications.
76. Zimdahl R. L. (2007). Fundamentals of weed science, 3rd edition. Department of Bio-Agricultural sciences and pest management, Colorado State University, Elsevier Inc.

APPENDICES

Appendix 1.0 Field layout



A5	C3	B3	A1	C4	D2	B2	D4
A4	C5	B5	A2	C2	D1	B1	D3
A3	C4	B4	A3	C1	D5	B3	D2
A2	C2	B1	A4	C5	D3	B4	D5
A1	C1	B2	A5	C3	D4	B5	D1

Key: Blocks: A, B, C and D

Herbicide rate	***Residual period (Days)***
A - Control (no herbicide)	*1 – 0 day*
B - Topramezone and Dicamba 1.0l/ ha	*2 – 30 days*
C - Topramezone and Dicamba 2.0l/ ha	*3 – 60 days*
D - Topramezone and Dicamba 4.0l/ ha	*4 – 90 days*
	5 – 120 days

Appendix 2.0: Field experiment

Appendix 2.1: Analysis of Variance (ANOVA) for Plant Stand at 7 days

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	3345	3345.1	242.98	0
Herbicide Rate (R)	3	335	111.6	8.10	0.06
Error a	3	41	13.8		
Residual period (P)	4	15466	3866.5	14.43	0
R x P	12	1344	112	0.42	0.93
Error b	16	4287	267.9		
Crop (C)	5	62421	12484.2	172.36	0
C x R	15	670	44.7	0.62	0.86
C x P	20	20605	1030.2	14.22	0
C x R x P	60	3027	50.4	0.70	0.94
Error c	100	7243	72.4		

Appendix 2.2: Analysis of Variance (ANOVA) for Plant Stand at 14 days

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	992	992.3	69.07	0
Herbicide Rate (R)	3	589	196.3	13.67	0.03
Error a	3	43	14.4		
Residual period (P)	4	17198	4299.6	56.19	0
R x P	12	2198	183.2	2.39	0.05
Error b	16	1224	76.5		
Crop (C)	5	71100	14220	255.42	0
C x R	15	479	32	0.57	0.89
C x P	20	21609	1080.5	19.41	0
C x R x P	60	4669	77.8	1.40	0.07
Error c	100	5567	55.7		

Appendix 2.3: Analysis of Variance (ANOVA) for Plant Stand at 28 days

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	128	127.6	1.55	0.30
Herbicide Rate (R)	3	1136	378.7	4.61	0.12
Error a	3	247	82.2		
Residual period (P)	4	10473	2618.1	20.77	0
R x P	12	1962	163.5	1.30	0.31
Error b	16	2017	126.1		
Crop (C)	5	49702	9940.5	81.51	0
C x R	15	1001	66.7	0.55	0.91
C x P	20	18875	943.8	7.74	0
C x R x P	60	3864	64.4	0.53	1.0
Error c	100	12195	122.0		

Appendix 2.4: Analysis of Variance (ANOVA) for Plant height

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	17185	17185	27.05	0.01
Herbicide Rate (R)	3	48570	16190	25.48	0.01
Error a	3	1906	635		
Residual period (P)	4	45882	11470	14.15	0
R x P	12	47212	3934	4.85	0
Error b	16	12972	811		
Crop (C)	5	819789	163958	186.88	0
C x R	15	15818	1055	1.20	0.28
C x P	20	139051	6953	7.92	0
C x R x P	60	60749	1012	1.15	0.26
Error c	100	87733	877		

Appendix 2.5: Analysis of Variance (ANOVA) for Number of leaves

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	96	96.3	3.29	0.17
Herbicide Rate (R)	3	1606	535.2	18.27	0.02
Error a	3	88	29.3		
Residual period (P)	4	6321	1580.3	92.06	0
R x P	12	3474	289.5	16.87	0
Error b	16	275	17.2		
Crop (C)	5	44117	8823.4	477.16	0
C x R	15	741	49.4	2.67	0
C x P	20	11337	566.8	30.65	0
C x R x P	60	4103	68.4	3.70	0
Error c	100	1849	18.5		

Appendix 2.6: Analysis of Variance for Dry biomass

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	9057839	9057839	639.80	0
Herbicide Rate (R)	3	584364	194788	13.76	0.03
Error a	3	42472	14157		
Residual period (P)	4	3173642	793411	4.12	0.02
R x P	12	776856	64738	0.34	0.97
Error b	16	3082870	192679		
Crop (C)	5	25693910	5138782	17.37	0
C x R	15	1160213	77348	0.26	1.00
C x P	20	7062112	353106	1.19	0.28
C x R x P	60	2670072	44501	0.15	1.00
Error c	100	29585624	295856		

Appendix 2.7: Analysis of Variance for Hundred seed weight

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	31.6	31.6	2.94	0.18
Herbicide Rate (R)	3	1442.8	480.9	44.76	0.01
Error a	3	32.2	10.7		
Residual period (P)	4	1582.3	395.6	47.55	0
R x P	12	1271.7	106	12.74	0
Error b	16	133.1	8.3		
Crop (C)	5	30857.4	6171.5	475.62	0
C x R	15	1760.3	117.4	9.04	0
C x P	20	3914.1	195.7	15.08	0
C x R x P	60	1638.8	27.3	2.11	0
Error c	100	1297.6	13		

Appendix 2.8: Analysis of Variance for Grain yield (kg/ ha)

Source	Degree of Freedom	Sum of squares	Mean Square	F value	P value
Rep	1	351243	351243	2.54	0.21
Herbicide Rate (R)	3	38092686	12697562	91.69	0
Error a	3	415449	138483		
Residual period (P)	4	21296565	5324141	73.15	0
R x P	12	7661571	638464	8.77	0
Error b	16	1164490	72781		
Crop (C)	5	176445800	35289160	154.54	0
C x R	15	15877698	1058513	4.64	0
C x P	20	149715626	7485781	32.78	0
C x R x P	60	21440154	357336	1.56	0.02
Error c	100	22834974	228350		

Appendix 3.0: Green House experiment

Appendix 3.1: Analysis of Variance for Plant stand

Source	DF	SS	MS	F	P
HR	3	2439.8	813.3	1400.8	0
DAH	4	1563.6	390.9	673.3	0
Crop	5	478.9	95.8	165.0	0
HR*DAH	12	298.1	24.8	42.8	0
HR*Crop	15	294.2	19.6	33.8	0
DAH*Crop	20	219.5	11.0	18.9	0
HR*DAH*Crop	60	194.2	3.2	5.6	0
Error	240	139.3	0.6		
Total	359	5627.5			

Appendix 3.2: Analysis of Variance for Phytotoxicity

Source	DF	SS	MS	F	P
HR	3	2000.2	666.7	1030.2	0
DAH	4	503.5	125.9	194.5	0
Crop	5	463.2	92.6	143.1	0
HR*DAH	12	169.5	14.1	21.8	0
HR*Crop	15	314.3	21.0	32.4	0
DAH*Crop	20	90.3	4.5	7.0	0
HR*DAH*Crop	60	133.8	2.2	3.4	0
Error	240	155.3	0.6		
Total	359	3830.1			

Appendix 3.3: Analysis of Variance for percent dead plants

Source	DF	SS	MS	F	P
HR	3	244941.9	81647.3	1490.1	0
DAH	4	155196.3	38799.1	708.1	0
Crop	5	47815.6	9563.1	174.5	0
HR*DAH	12	28723.8	2393.6	43.7	0
HR*Crop	15	29906.9	1993.8	36.4	0
DAH*Crop	20	22231.2	1111.6	20.3	0
HR*DAH*Crop	60	19208.7	320.1	5.8	0
Error	240	13150.0	54.8		
Total	359	561174.4			

Appendix 4.0 Phytotoxicity effect of stellar star herbicide in the Field and Green house