INVESTIGATING THE USE OF LANTANA (*LANTANA CAMARA* L.) IN WEED CONTROL USING COWPEA (*VIGNA UNGUICULATA* L. WALP) AS A TEST CROP

MUCHIMBA LINDA CHIKEYI

A DISSERTATION SUBMITTED TO THE UNIVERSITY OF ZAMBIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY-CROPS

THE UNIVERSITY OF ZAMBIA
LUSAKA

2019

DECLARATION

I declare that this dissertation is my original work and has not been submitted for any Degree of Master of Science in Agronomy-crops program previously and all sources of information have been acknowledged by means of references.

Signature: ……

Muchimba Linda Chikeyi Date: …….

APPROVAL

This dissertation of Muchimba Linda Chikeyi was approved by the University of Zambia as partial fulfillment of the requirements of the award of the degree of Master of Science in Agronomy-Crops.

Examiner's signature: Date:

……..…… ……...……

……..…… .……..…

……..…….. ……...……

DEDICATION

This dissertation is dedicated to my family especially Bruce, Benham and Lita (twins) being the youngest brothers and the only young sister respectively.

ABSTRACT

In many agricultural systems around the world, competition from weeds is one of the major factors reducing crop yield and farmers' income. To this effect many strategies have been developed to manage weeds. One such strategy is cultural weed control. However, cultural weed control is tedious and is associated with high weed re-infestation, especially during the peak growing period. Another method is biological weed control using allelopathic plants such as *Lantana camara* L. The current study was done to determine the effect of *L. camara* on weed control in cowpea as a test crop. Specific objectives were: (i) to compare the effects of genotype of *Lantana camara* on weed control (ii) to identify the effective rate of application of *Lantana camara* on weed control and (iii) to identify the effective type of application of *Lantana camara* on weed control. Two genotypes of *L. camara* were harvested, dried under room temperature, pulverized using mortar and pestle, weighed at different rates (R0: Rate zero without cowpea, R0C: Rate zero with cowpea, R1: Rate one (100 kg ha^{-1} of *Lantana camara*), R2: Rate two (200 kg ha^{-1} of *Lantana camara*), R3: Rate three (400 kg ha^{-1} of *Lantana camara*) and applied using five different types; T0: Type zero of application without cowpea, T0C: Type of application zero with cowpea, T1: Type of application 1 (Broadcasting), T2: Type of application 2 (incorporation with the soil), T3: Type of application 3 (spraying of soaked ground *Lantana camara*). The research was conducted at the University Of Zambia School Of Agricultural Sciences Field Station arranged in a Split-Split-Plot Design with three replications. Parameters measured were weed population density and weed weight, with crop yield as derived parameter. Data analysis was conducted with Analysis of Variance and treatment means were separated using the Least Significant Difference calculated at $P \leq 0.05$ using GenStat 14^{th} Edition. Results showed significant ($P < 0.05$) differences among all factors and their interactions. The weed population density was higher ($P < 0.05$) in fields treated with genotype2 (mean = 58.07) than for genotype1 (mean = 51.46). Weed population density and weed weight were reduced the most at the highest rate of application (400 kg ha^{-1}) of ground *L. camara* and was found to be the most effective while type 3 (40.15) was also effective. However, different genotypes exhibited different effects in that G1 had better control resulting in significantly higher yield (876.9 kg ha^{-1}) than both G2 (672.1 kg ha^{-1}) and the control (533.9 kg ha^{-1}) which were in turn significantly different from each other. The study shows that there is immerse potential to use *Lantana camara* with pink flowers for biological control of weeds in cowpea.

ACKNOWLEDGEMENT

I wish to give special thanks to my supervisors Dr. Kambikambi, T. T., Dr. Munyinda, K. and Dr. Kachapulula, P. W. for their great tireless efforts, encouragements and most importantly positive technical contribution towards this work. I wish to offer many thanks to the School of Agricultural Sciences Staff especially for those who in a way assisted me throughout my research to make it a success.

I wish to thank the Ministry of General Education for giving me study leave and also the Agricultural Productivity Program for Southern Africa (APPSA) for the sponsorship rendered to support the work of my Master of Science Program.

I also thank the Technicians School of Agricultural Sciences for their support during conduct of the Research Program. Many thanks to my family for the support offered and also I wish to thank my fellow Masters students and all those who spared their time to see this work become a reality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 General

Cowpea is a key crop in the dry and arid regions of Central, Southern and Western Africa. It does well in the tropics and subtropics and is part of the diet of millions of African people. Further, it is an excellent feed for animals. The species is rich in useful genetic diversity and it produces several tasty foods. Although cowpea is ranked close to the common beans (*Phaseolus vulgaris*) as a food legume in Africa, *on marginal and in hotter and drier parts of Zambia, it replaces common bean as a food crop for grain and leaf in* Africa (*Sheahan, 2012).* As a dietary component, it complements the otherwise unbalanced diets for resource poorest people. *It is more useful for its leaves as relish.*

The seeds are exceptionally nutritious; cowpea provides food nutrients such as protein, carbohydrate, vitamins and minerals. The grain contains 22-23% protein (as opposed to 2% in cassava and 10% in maize) and good quantity of thiamine (vitamin B_1), riboflavin (vitamin B_2) and niacin (vitamin B_3), it is richer than cereals in iron and calcium content (Ngalamu *et al,* 2014).

The plant is deep rooted, vigorous in growth and reliable in production. It is both drought-tolerant and adapted to poor soils (Langyintuo *et al*., 2003). Perhaps because of its African origin, it out performs other legumes on soils with poor fertility and adverse weather conditions found across Africa (Khalid *et al*., 2012). Cowpea improves soil fertility by fixing atmospheric nitrogen in the soil. *Late maturing varieties are traditionally grown as an inter-crop with cereals such as maize or sorghum and it is one of the highest grain yielding tropical legume crops (*Osipitan *et al*., 2017*).*

However, weeds are a serious problem in cowpea production. If not periodically removed they may reduce both yield and quality of the grain through competition for resources with cultivated plants. Weeds may also act as hosts for pests and diseases, further reducing crop production (Ngalamu *et al*., 2014).

In developing countries, herbicides have limited accessibility due to high cost; hence farmers often rely on alternative methods for weed management (Zimdahl, 2006). Weeds are more competitive than other plants by being able to withstand various environmental conditions especially the adverse ones (PennState Extension, 2017). Weeds affect crop production negatively in the following ways: (i) weeds reduce yield of field crops or plants; (ii) weeds compete with the crop for growth factors; (iii) weeds harbor pests which can attack the crop; (iv) weeds reduce the quality and quantity of the crop; and (v) weed infestation increase cost of production due to application of weed management (Oerke, 2006).

Biological control is the action of parasites, predators, or pathogens to maintain another organism's population at a lower average density than would occur in their absence (Huffaker and Messenger, 2012; Van Driesche *et al*, 2008). The use of this form of weed control can be implemented through an initial introduction of natural enemy that becomes a self-sustaining population or through repeated application of a pathogen as a bio-herbicide (Appleby, 2005).

The natural enemies of weeds mostly are insects, plant diseases and certain other plants that have allelopathic effects. Allelopathy has also been used to control weeds (Jabran *et al.*, 2015). Many plants such as *Asters, Sorghum bicolor*, *Triticum aestivum* and *Lantana camara* are known to have allelopathic effects (Jabran, 2017). *L. camara* is regarded as both a notorious weed and a popular ornamental garden plant.

However, smallholder farmers rarely use one method alone rather than a combination of two or more control methods, hence moving in the realm of integrated weed management. Integrated weed management involves using a combination of weed control practices to manage weeds with the overall goal of improving or maintaining crop production, farm revenue and environmental quality (Ngalamu *et al*., 2014).

Allelopathy is the influence of one plant upon another plant growing in its vicinity by the release of certain metabolic toxic products in the environment (Mishra, 2012). Allelopathy can achieve the use of biological weed control. Allelopathic weed control may be applied as a single strategy in certain cropping systems or can be combined

with other methods to achieve integrated weed management. Under allelopathic weed control, the allelopathic potential is manipulated in such a way that the allelochemicals from these plants reduce weed competition (Jabran *et al.*, 2015). Allelopathic weed control can be implemented by growing allelopathic plants in close proximity to weeds which promote production of these chemicals (Tesio and Ferrero, 2010); or by placing the allelopathic materials obtained from dead plants in close proximity to weeds. The latter involves the use of plant residues for weed control (Tabaglio *et al*., 2008). Allelopathic weed control can also be implemented through exudes by allelochemicals which will control weeds in the subsequent season (Farooq *et al*., 2011). Lastly, allelopathy can be used to control weeds by using liquid solutions obtained by soaking the allelopathic plants.

1.2 Rationale:

Smallholder farmers have challenges of weed control; mostly they use cultural control methods because chemical control with herbicides is costly. However, these cultural methods are both tedious and re-infestation of weeds is rapid especially during the peak growing period. *L. camara* is regarded as both a notorious weed and a popular ornamental garden plant. Therefore, determining allelopathic effect of *L. camara* on weed control can offer an alternative. *L. camara* has allelopathic properties which have been studied widely to determine their use and been found to inhibit the germination, growth and metabolism of susceptible plants (Mishra, 2015, Wafaa *et al*., 2016, EL-Kenany and El-Darier, 2013 and Qasem, 2006). Despite these efforts, the use of *L. camara* as a herbicide has been disappointing because of the use of wrong genotype, improper application rate and poor type of application. However, this study will bring out the information on use of Lantana (*Lantana camara*) on weed control which will add to the body of knowledge.

1.3 Statement of the Problem

Lantana camara L. was the first weed which was targeted for classical biological control (GISD, 2019). It is used as mulch and it is planted as a hedge to keep livestock away. Weeds are reducing productivity in cowpea and that lack of information on Lantana genotype, rates of application and type of application is preventing the use of Lantana to reduce losses associated with weeds. *Lantana camara* L. is known to be allelopathic to other plants hence a worthy candidate of biological control in crops such as cowpea in Zambia.

1.4 Objectives

1.4.1. General Objective

To determine the effect of *Lantana camara* on weed control in cowpea as a test crop

1.4.2. Specific Objectives

i. To compare the effects of genotype of *Lantana camara* on weed control
ii. To identify the effective rate of application of *Lantana camara* on weed control
iii. To identify the effective type of application of *Lantana camara* on weed control

1.5 Hypotheses

H_A: Genotypes of *Lantana camara* has an effect on weed control

H_A: Rate of application of *Lantana camara* has an effect on weed control

H_A: Type of application of *Lantana camara* has an effect on weed control

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Cowpea (*Vigna unguiculata* L. Walp) attributes as a test crop

Cowpea is widely distributed throughout the world, but Central and West Africa amounts to 64 percent of the area with about 8 million hectares followed by about 2.4 million hectares in Central and South America, 1.3 million hectares in Asia and about 0.8 million hectares in East and Southern Africa (Ngalamu *et al,* 2014). Some of the leading cowpea producing countries according to Ngalamu *et al,* 2014 are: Nigeria, and Chad in Central and West Africa; Sudan, Zambia, Zimbabwe, Botswana and Mozambique in East and Southern Africa; India, China and Philippines in Asia; Cuba, Haiti, and West Indies in Central America; Brazil in South America and USA in North America. Production level in countries like Brazil, Zambia and Zimbabwe is increasing due to availability of improved cowpea varieties. However, the world estimated annual cowpea production is put at 4.5 million tonnes from an estimated land area of 12.6 million hectares (Food and Agriculture Organization [FAO], 2014). West Africa accounts for about 80% of the estimated total land area under cowpea cultivation. Nigeria is the largest producer and consumer of cowpea with about 5 million hectares' area and 2.4 million tonnes production annually.

According to Langyintuo *et al*. (2003); Asiwe and Kutu, (2007), Cowpea (*Vigna unguiculata* L. Walp) is one of the most important grain legume in many countries of the tropics particularly Asia and Africa and it is cultivated for food, feed and as a cash crop. It was estimated that cowpea supplies about 40% of the daily protein requirements to most of the people in West Africa.

Cowpea (*Vigna unguiculata* L. Walp) is an annual crop that is more tolerant to high temperatures and extended drought periods than most other legumes such as soybean, groundnuts or beans (Langyintuo *et al*., 2003). Low average grain yield of cowpea is caused by insect pests or diseases, prolonged drought and poor grain management (*Matsunaga et al, 2006).* Reliable data on cowpea production is difficult to obtain because mostly it is intercropped with other crops. The estimated total area under

production amounts to about 12.5 million hectares with an annual production of over 3 million tonnes worldwide (Ngalamu *et al*, 2014).

The magnitude of yield depends on crop variety, weed density, type of weeds, weed persistence, duration of weed interference and crop management practices (Li *et al*., 2004; Milberg and Hallgren, 2004; Osipitan and Dille, 2017). Yield reductions due to weeds were 25% for VITA 1, 33% for VITA 5, 46% for ER-1 and 54% for TVX33-IG (Li *et al*., 2004) and Tripathy and Singh (2006) also reported 12.7% to 60% yield loss in cowpea was due to weeds. Freitas *et al*., (2009) also found that weed interference in cowpea not only reduce the final stand but also the number of pods per plant, and grain yield up to 90%. Sunday and Udensi, (2013) reported that control of weed growth and/or inadequate weed control in the crop have been reported to account for 40-80% reduction in grain yield in cowpea.

The major hindrance to the cultivation of cowpea is lack of market information and access by small-scale farmers, as the majority of these farmers are rural-based, with little or no education. To address this, the World Food Programme (WFP) is currently promoting the cultivation of cowpeas in the Mazabuka, Monze and Choma districts of Southern Province of Zambia. WFP offers to buy the crop upon harvesting to assure a ready market for the farmer (Zambia daily mail, 2018).

Cowpea is a major or importance crop to livelihoods of relatively poor people in less developed countries of the tropics including Zambia, especially where animal protein is not easily available for the family. In Zambia, where maize-based farming is predominant, cowpea as a grain legume is an important crop because:

i. Cowpeas are widely grown as intercrops or in rotations on maize-based farming systems. They fix substantial amounts of atmospheric nitrogen through biological nitrogen fixation in the soil, help improve soil fertility and also contribute to improved crop productivity (Africa rising, 2016).
ii. Many cowpea varieties can maintain some growth or at least survive and yield under dry conditions where other crop plants cannot grow. Some varieties of cowpea with deep rooting habit can grow under semi-arid conditions.

iii. Petty trading in fresh cowpea leaves, fresh produce and processed food provides both rural and urban communities opportunities for earning some money, particularly by women. Trading in cowpea haulms as food for large and small ruminants can be remunerative.
iv. It takes short period to mature,
v. Its faster cooking and
vi. Its duo use of both its leaves and seeds

With all these positive aspects, weed control is necessary to study in crop production.

2.2 Weed

A weed is a plant that grows where it is not needed. A weed can be classified as an annual, biennial or perennial depending on life-cycle, growth habit, morphology or physiology. The definition of a weed is completely context-dependent. To one person, one plant may be a weed and to another person it may be a desirable plant. In one place, a plant may be a weed whereas in another place, the same plant may be desirable. However, a plant is often termed a "weed" when it has one or more of the following characteristics; (i) little or no recognized value; (ii) rapid growth and (iii) ease of germination and competitive with crops for growth factors (Oerke, 2006). Weeds have negative impact on the plant growth because they are very competitive to crops. Weeds are able to withstand various environmental conditions and are capable of adapting to a wide range of environments (PennState Extension, 2017).

2.2.1 Definitions

Weeds have been variously defined by several workers. Some of the definitions commonly used are outlined below:

i. A weed is a plant that originated in a natural environment and, in response to imposed or natural environments, evolved, and continues to do so, as an interfering associate with our crops and activities (Zimdahl, 2006). A weed is a plant considered undesirable in a particular area. A weed is a plant that grows where it is not needed and has negative impact on the growth of the desired plants because of the interference they cause. In other words, it is also considered as a plant in the wrong place (Ward *et al*., 2008).

ii. A weed is also defined as a herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation (Ward *et al*., 2008). When introduced into new environments some plants become dominant simply because the animal in their original environment, that compete with them or feed on them are absent and sometimes is called the natural enemies hypothesis.

iii. Keton and Price, (2016) define a weed as any plant growing where it is not wanted. This definition can apply to crops, native plants as well as non-native species. If it is considered to be a nuisance where it is growing, it can be termed a weed. However, weeds are not just unwanted species, they can have substantial negative impacts where they are present. Manning (2004), describes weeds as plants that thrive in disturbed habitats and produce an abundance of seed that is not useful to humans.

2.2.2 Effects of weeds in agriculture and cowpea production

In many agricultural systems around the world, competition from weeds is one of the major factors reducing crop yield and farmers' income (Ward *et al*., 2008). In developed countries, despite the availability of high-tech solutions such as selective herbicides and genetically-modified herbicide-resistant crops, the share of crop yield loss to weeds does not seem to reduce significantly over time (Sutherland, 2004). In developing countries, herbicides are rarely accessible at a reasonable cost; hence farmers often need to rely on alternative methods for weed management (Zimdahl, 2006).

Weeds constitute a major constraint to crop production globally. Yield losses caused by weeds alone in cowpea production can range from 25% to 76% (Adigun *et al*., 2014; Gupta *et al*., 2016; Osipitan and Dille, 2017; Ugbe *et al*., 2016). Problems caused by weed in cowpea production include reduction in crop yield, less efficient land use, higher cost of production due to insects and plant disease control, reduction in crop quality, water management problems, and less efficient utilization of labour (Patil *et al*., 2014; Getachew *et al*., 2015; Prabhu *et al*., 2015; Singh *et al*., 2016).

Primarily, weed reduced crop yield through competition for crop water, soil nutrient, light, and carbon dioxide. Weeds may also reduce crop yield by releasing allelopathic compounds into the environment (Marinov-Serafimov, 2015). In addition, Madukwe *et*

al., (2012) reported that in Nigeria, the presence of weeds caused 53-60% yield loss in legumes including cowpea. Competitiveness of weeds is determined by several plant characteristics. One of the most common traits of a weed species is its tendency to be an annual or biennial rather than a perennial as this allows the species a faster reproduction rate leading to a higher fecundity (Sutherland, 2004).

There are other characteristics that determine the "weediness" of a species such as the ability to colonize under high sunlight and low soil moisture conditions. Plants that have capabilities of dealing with herbivory as well as plants that have allelopathic traits also tend to be better at out-competing surrounding plant species (Keton and Price, 2016). Ward *et al*., (2008) suggests that some non-native plants can grow faster and bigger to increase reproduction rates, and can have increased survival rates when outside of their native habitat. This may be due, in part, to the loss of environmental checks that keep these plants in balance within their natural habitat.

Further, weeds have other adverse effects. For instances, weeds increase protection costs because they harbor other pests. Weeds harbor a wide range of organisms thereby increasing opportunities for those organisms to persist in the environment and re-infest crops in succeeding years. Weeds that exist on the edges of crop fields also serve as hosts when crops are not present and as sources of re-infestation (Anderson, 1999). Besides, weeds can reduce land value and sale price because they restrict crop choice and increase the costs of crop production (Ward *et al*., 2008).

Furthermore, any weed-control operation, from hand hoeing to herbicide application, costs money. These costs are often necessary to prevent greater crop loss or even crop failure and are regarded as necessary to gain a profit. However, if the weeds were not there, there would be no control cost (Haidar *et al.*, 2005).

Another important aspect of weeds is that they reduce the quality of seed crops. Purchasers of certified seed expect to receive a high-quality product that will give high yields and not be infested with weed seed. This necessitates weed control in seed crops, and failures lead to high cleaning costs before sale (Haidar *et al.*, 2005).

2.2.3 Weed Control

Weed control is defined as the attempt to stop the growth and propagation of unwanted, fast growing, or invasive plants so as to limit competition for space, nutrients, water and light with agricultural forage crops or more desirable species (Harris, 2009). Weed control can also be defined as a botanical component of pest control which stops weeds from reaching a mature stage of growth when they could be harmful to domesticated plants, by using manual techniques including soil cultivation, mulching and herbicides (Harris, 2009).

Some of the control measures that can be used to control weeds are as follows:

i. Preventive weed control: This is a control measure that aims to thwart weeds from being established in a cultivated crop, a pasture, or a greenhouse. Examples of preventative weed control would be using certified weed free seed, only transporting hay that is weed free, making sure farm equipment is cleaned before moving from one location to another, and screening irrigation water to avoid weed seeds from traveling along irrigation ditches (Walters, 1999).

ii. Cultural /physical weed control: refers to any control measure that involves maintaining field conditions such that weeds are less likely to become established and increase in number. Examples of cultural weed control include crop rotation, avoiding overgrazing of pastures or rangeland, using well-adapted competitive crop species, and maintaining good soil fertility (Jabran and Chauhan, 2018; Singh *et al*., 2006, Naylor, 2002*)*. **Mechanical** weed control is usually considered part of cultural weed control and involves the use of farm equipment to control weeds. The two mechanical control techniques most often used are tillage and mowing (Forage Information Systems, 2017).

iii. Chemical weed control is any measure that involves the application of a chemical (herbicide) to adversely affect or kill weeds or to control the germination or growth of the weed seeds. In economic terms, chemical control of weeds is a very large industry and there are many examples of chemical weed control products (Zimdahl, 1993).

iv. Biological weed control is the utilization of insects or other plant parasites to reduce the density of a weed to an acceptable level (Taylor and Francis, 2018). It can also be defined as the deliberate use of natural enemies to reduce the density of a particular weed to a tolerated level.

Preventing the spread of weeds is difficult, as many weeds have different characteristics that allow their seeds and reproductive parts to be easily transported over long distances (Sutherland, 2004). Too much emphasis has been given to the development of weed control tactics (especially synthetic herbicides) as the solution for any weed problems, while the importance of integrating different tactics such as preventive, cultural, mechanical, and chemical methods in a cropping system-based weed management strategy has mostly been neglected (Appleby, 2005).

While biological control can never eradicate a pest organism completely, because if the control agent reduces the pest population too far, it destroys its own food source, it however has the following advantages; i) cheap and environmentally friendly, ii) reasonably permanent, iii) self-perpetuating, iv) has no additional inputs required once agent is established successfully, v) has no harmful side effects, vi) attack is limited to target weed and vii) a few close relatives and risks are known and evaluated before release and it works best in stable environments (Taramani *et al.*, 2017).

Biological control of weeds is not all rosy and has some of the following disadvantages; i) control is slow, ii) suitable agents may not even exist, iii) potential agents are also expensive to test for specificity, iv) host specificity testing may take several years to complete because of the need for thoroughness (however, herbicides often take as long and cost even more to develop) (Agriculture and Food, 2017). The advantages of biological weed control outweigh the disadvantages and recently this biological weed control received renewed interest because of being an environmentally compatible method of weed control without residue and pollution problems (Harris, 2009). The objective of biological weed control is not eradication but simply the reduction of the weed population to an economically low level in fact for biological control to be continuously successful, small numbers of the weed host must always be present to assured the survival of the natural enemy. *L. camara* is also an option for weed control.

2.3 Botany and taxonomy of *Lantana camara*

The word *Lantana camara* derives from Latin 'lento' which means to bend (Ghisalberti, 2000). Sanders (2012), describes *Lantana camara* as a notorious, noxious and invasive weed that belongs to the family Verbenanceae, order: Lamiales, genus: *Lantana* and species: *camara*. *Lantana camara* is a perennial shrub which can grow to around 2 m tall and form dense thickets in a variety of environments.

2.3.1 Genetic and Diversity of *Lantana camara*

Lantana camara is commonly known as Lantana and its diverse and widespread is a reflection of its wide ecological tolerance. Lantana occurs in various habitats ranging from open unshaded regions such as wastelands, rainforest edges, beachfronts, forests and it's only disturbed by activities that include fire and frost. *L. camara* also survives in disturbed areas such as canals, rail tracks and road sides (Lakshmi and Sekhar, 2018).

Lantana camara is a low, erect and vigorous shrub. The leaf for *L. camara* is ovate or ovate oblong, it is 2 - 10 cm long and 2 - 6 cm wide and it is arranged in opposite pairs. The leaves are bright green, rough, finely hairy, with serrate margins and emit a pungent odour when crushed. The stem in cultivated varieties is often non- thorny and in weedy varieties with recurved prickles (El-Kenany and El-Darier, 2013). It is woody, square in cross section, hairy when young, cylindrical and up to 15 cm thick as it grows older. *Lantana camara* is able to climb to 15 m with the support of other vegetation. Flower heads contain 20 - 40 flowers, usually 2.5 cm across; the flowers for *Lantana camara* come in many different colours which include red, yellow, white, pink and orange (Figure 1).

Figure 1: Different colors of flowers for different genotypes of *Lantana camara*.
Source: *Flora of Zambia, 2018. These are different genotyes whose attributes may equally vary.*

These are different genotypes of *Lantana camara* L. whose attributes may equally vary (Ambika *et al*., 2003).

The species was first described and given its binomial name by Linnaeus in 1753 (Munir, 1996; Kumarasamyraja *et al.*, 2012). It is in the Verbenaceae family with 600 varieties existing worldwide (Mishra, 2015). *Lantana camara*, a native species of South, Central America and the Caribbean islands (Baars, 2002), has its presence recorded even in Brazil, Florida, Jamaica and Mexico (Table 1) (Ambika *et al*., 2003).

Table 1: *Lantana* biotypes and their distribution in Australia

Flower colour	Distribution	Toxicity
I. Pale pink/Pink flower forms		
Townsville red centered pink	Ayr _ Cook Town	Very-toxic
Small-flower red centered pink	Brisbane _ northern NSW	Toxic
Mackay red centered pink	Cooktown _ St. Lawrence	Toxic
Rockhampton red centered pink	Rockhampton	Toxic
Pink Minnie Basil	Brisbane _ Gatton Beenleigh	Toxic
Helidon white	Burnett _ Moreton District	Toxic
Coolum pink	Coolum	Toxic
Bundaberg small flower pink	Bundaberg	Non - Toxic
Bundaberg large flower pink	Bundaberg	Highly Toxic
Common Pink	Cook town _ northern NSW	Non - Toxic
II. Red flower forms		
Proserpine pink edged red	Gordonvale _ Brisbane	Toxic
Balnagowan pink edged red	Mackay	Toxic
Common pink edged red	Atherton tableland northern NSW	Very - Toxic
Stafford red	Brisbane _ northern NSW	Toxic
Round red	Brisbane _ northern NSW	Toxic
III. Orange flower forms		
Large flowered orange	Portcurtis _ Moreton Districts	Toxic
True orange	Bundaberge _ northern NSW	Toxic
Townsville prickly orange	Mission Beach _ Agr	Non - Toxic

Source: *Mount Morgon's Environment. NSW: New South Wales (Ambika, 2003).*

Lantana camara is a common weed that is easy to access with berries which turns from green to dark purple when mature. *Lantana camara* is known to be as a weed that is very invasive and dominant to other crops because of its allelopathic effects on other plants. This means it is able to release a chemical which inhibit growth on other crops (El-Kenany and El-Darier, 2013). *Lantana camara*'s allelopathic nature allows it to spread rapidly (Brogger, 2012). Many of the allelochemical compounds found in *Lantana camara* are phytotoxic and have potential as herbicides or as templates for new herbicides classes (El-Kenany and El-Darier, 2013).

2.3.2 Uses of *Lantana camara* L.

2.3.2.1 Domestic utilization of *Lantana camara*

Lantana camara stems are used for making furniture which is not easily eaten by termites. It is equally sturdy and cheaper than cane. The tribal artisans of South India are ingeniously utilizing *L. camara* in many ways that include toys, articles of household utility, fuel for cooking, herbal medicine, adulticidal activity against mosquitoes, incense cakes as mosquito repellants, and serves as nectar source for butterflies and moths (Kannan *et al*., 2008). Lantana leaves and fruits are edible. The young leaves mixed with salt are eaten to stimulate digestion and ripe fruits are eaten in many remote and under developed areas.

2.3.2.2 Uses of *Lantana camara* in weed control

EL-Kenany and El-Darier, (2013) reviewed that, many of the allelochemical compounds found in *Lantana camara* are phytotoxic and have potential as herbicides for new herbicides classes. Mishra (2015) found that seeds that imbibed in aqueous extracts of leaf, stem and root of *Lantana camara* showed inhibition in seed germination. It is evident from the data that allelochemicals present in *L. camara* might inhibit the process of seed and spore germination. The leaf extracts of *Lantana camara* are having inhibitory effect on aquatic weeds like *Microcystis aeruginosa* and *Eichhorniacrassipes* (Chaudhary, 2011). Its extract has potential as biocide (aqueous leachate), at 1-3 % can kill water hyacinth, a troublesome weed in many tropical countries. Its application as weedicide depends on size of the water body being treated and the cost of extraction of the leachate (GISD, 2019). Mishra (2015) hence postulated that the generative and aggressive capacity of a species determines the percentage values of its survival in the natural environment.

Physiological processes inhibited and delayed the germination as well as growth of mung bean under the influence of allelochemicals present in leaf extracts and leaf leachates. These chemicals interfered with various physiobiochemical processes of seed germination, root elongation, plant growth as well as various metabolic activities of many species (Mishra, 2015). The aqueous extracts from fresh and dry leaves of *Lantana camara* inhibited the growth of water hyacinth and killed the plant within six

days because of salicylic acid which is major allelochemicals in *Lantana* (Zhung *et al*., 2005).

2.3.3 Risks associated with *Lantana camara*

Zambia's National Biodiversity Strategy and Action Plan of 1998 identified *L. camara* as one of the invasive plants that negatively impacts ecosystems and indigenous plant diversity (Rusell, 2005). *Lantana camara* is a serious threat to biodiversity because numerous plant and animal species of conservation significant are threatened. It imposes negative impact on plant diversity and abundance by suppressing native vegetation through allelopathy and competition for resources. Allelopathy effects result in either no growth or reduced growth in other plants close to *L. camara* and it was demonstrated in crops such as *Triticum aestivum* (wheat), *Zea mays* (Maize) and *Glycine max* (soyabean) (Lakshmi and Sekhar, 2018). In disturbed native forests it becomes the understorey species thus dominating the flora, causing disruption in succession and loss in biodiversity. Volatile oils and water leachates of *Lantana camara* significantly inhibits the seedling growth of cucumber, radish and tomato. For this reason, it is a problem in gardens because it can cross pollinate with weed varieties to form new, more resilient forms (Lakshmi and Sekhar, 2018).

2.3.4 Allelopathic effect of *Lantana camara* L.

Weed Management Guide (2013) explains *Lantana camara* as an allelopathic plant that can release chemicals into the surrounding soil which prevent germination and competition from some other plant species. Allelopathy is the influence of one plant upon another plant growing in its vicinity by the release of certain metabolic toxic products in the environment. It covers biochemicals interactions, both beneficial and harmful, between plant species including fungi and bacteria (Mishra, 2012).

Allelopathy refers to the direct or indirect chemical effects of one plant on the germination, growth, or development of neighboring plant. Allelopathy can be regarded as a component of biological control in which plants are used to reduce the vigour and development of other plants (Mishra, 2012). Qasem (2006) showed that allelopathic plant *Lantana camara* inhibited or suppress germination, growth, development or

metabolism of crops due to secretion of allelochemicals to the rhizosphere of neighboring crop plants. According to Galindo *et al*. (1999) many phytotoxic allelochemicals have been isolated, identified, and found to influence a number of physiological reactions. These allelochemicals affected many cellular processes in target plant species, including disruption of membrane permeability, ion uptake (Lehman and Blum, 1999), inhibition of electron transport in both photosynthesis and the respiratory chain (Abarahim *et al*., 2000).

Ambika *et al.,* (2013) reported that aqueous extracts of *L. camara* leaves inhibited the germination and seedling growth of weeds. Phytotoxic compounds were fractionated from crude aqueous extracts and fractions were evaluated for their phytotoxicity. High concentrations of *Lantana camara* leaf extracts caused significant inhibitory effect on germination and growth of weeds (Hossain and Alam, 2010).

Reduction in weeds was due to the chemicals Lantadene A and Lantadene B from *Lantana camara* (Kong *et al*., 2006). In addition, Zhung *et al*., (2005) reported that the aqueous extracts from fresh and dry leaves of *Lantana camara* inhibited the growth of water hyacinth and killed the plant within six days because of salicylic acid which is major allelochemical in *Lantana camara*.

According to Gantayet *et al*. (2014), the release of these phenolic compounds of *Lantana camara* might have adversely affected the growth and yield of test cultivars through their interference in energy metabolism, cell division, biosynthetic processes and many more.

2.3.5 Allelochemicals found in *Lantana camara*

Allelochemicals are present in leaves, stem, roots, fruits and flowers of *Lantana camara.* The chemical compounds present in *Lantana camara* extracts include mono and sesquiterpenes, flavinoids, iridoid glycoside, furanonaphoquinones, sthsteroids triterpenes and diterpenes (Gopie-shkhanna and Kannabiran, 2007 and Wahab, 2004). The *Lantana camara* produce volatile allelochemicals from its leaves. The allelochemicals have been identified as phenolics, with umbelliferone, methylcoumarin, and salicylic acid being the most phytotoxic. In addition to phenolics, a recent report indicates lantadene A and B as more potent allelochemicals (Sharma, 2007). Yi *et al.,*

(2005) also reported the presence of several phenolic compounds in lantana leaf extract identified by HPLC as salicylic, gentisic, β-resorcylic acid, vanillic, caffeic, ferulic, phydroxybenzoic acids, coumarin and 6-methylcoumarin, lantadene A and lantadene B as more potent allelochemicals (Table 2).

Table 2: Chemical constituents of *Lantana camara* for all parts (Mishra, 2015)

S.No	Compound	Biological Activity
1	β-pinene	inhibiting the seed germination, growth and antibacterial activity.
2	β-sitosterol	Not determined
3	Betulonic acid	Not determined
4	Betulinic acid	Not determined
5	Caffeic acid	Suppress root-infecting fungi and root-knot nematode.
6	Calceolarioside	Not determined
7	Camaraside	Not determined
8	Camarinic acid	Antimutagenic , antimicrobial and nematicidal activity.
9	Camaric acid	Nematicidal activity
10	Campesterol	Not determined
11	1, 8-Cineole	Inhibiting the growth of plant.
12	Cinnamic acid	Inhibited the activity of plasma H+-ATPase, PPase and Inhibit the process of seed germination.
13	Dipentene	Inhibiting the growth of plant.
14	8-epiloganin	Not determined
15	Ferulic acid	Reduced chlorophyll contents in soybean leaf and inhibit the process of seed germination.
16	Geniposide	Inhibited hepatoxicity and the DNA repair synthesis induced by aflatoxin B1 in rat primary hepatocytes.
17	Hispidulin	Not determined
18	Icterogenic acid	Toxic to sheep, cattle, goats.
19	Isonuomioside A	Not determined
20	Isoverbascoside	Not determined
21	Lamiridoside	Not determined
22	Lantadene A, B,C	Death of horses, cattle, sheep, goats and rabbits by failure of liver and other organs.
23	Lantanilic acid	Nematicidal activity.
24	Lantanolic acid	Not determined
25	Linaroside	Antimicrobial and Nematicidal activity.
26	Lantanoside	Antimicrobial and Nematicidal activity.
27	Lantic acid	Not determined
28	Linaroside	Antibacterial activity
29	Myristic acid	Inhibiting the growth of plants

Table 2 continued.

30	Oleanolic acid	hepatoprotective, Anti-flammatory, antimicrobial, antiulcer, anti fertility antimicrobial and Nematicidal activity.
31	Oleanonic acid	Inhibit the growth of mouse melanoma cell sin cultures and Herpes simplex virus type Iand II in vitro.
32	Palmitic acid	Inhibiting the growth of vegetables.
33	ρ-Coumaric acid	suppress root-infecting fungi, root-knot nematode, inhibit the process of seed germination and inhibit the growth of morning glory.
34	Pectolinarigenin	Not determined
35	Pectolinarin	Not determined
36	ρ-hydroxybenzoic acid	Inhibit the enzymatic activity, Nematicidal activity.
37	Theveside	Not determined
38	Ursonic acid	Inhibit the growth of mouse melanoma cell sin cultures and Herpes simplex virus type I and II in vitro.

Table 2 continued.

39	Ursolic acid	Inhibitors of human leucocyte elastase.
40	Verbascoside	Inhibitor of protein kinase and possesses antitumor activity.
41	Vanillic acid	Inhibit the enzymatic activity.

2.3.6 Methods of application of solutions from allelopathic plants in weed control

Allelopathy will play an important role in future weed control and crop production. The allelopathic compounds can be used as natural herbicides and other pesticides. They are less disruptive of the global ecosystem than synthetic agrochemicals (Khalid et al., 2002).

Work done by Hossain and Alam, (2010) showed that different concentrations of *Lantana camara* leaf extracts caused significant inhibitory effect on germination of agricultural crops. The highest inhibitory effect was found in *Cucurbita pepo*

and *A. tricolor* at 100% treatment. The maximum relative germination ratio was found in *A. esculentus* at 25% treatment while the minimum was occurred in *Cucurbita pepo* at 25% treatment.

The strategy for using allelopathy for weed management could be either through directly exploiting natural allelopathic interactions, especially of crop plants, or applying allelochemicals as a source of natural herbicides. Derivatives of allelochemicals from plants used as herbicides with environmental properties include mesotrione and citronella and bilanaphos oil. Several microbial allelochemicals products are marketed worldwide, such as glufosinate and bialaphos (Duke *et al*., 2000).

According to Bhadoria, (2010) tens of thousands of secondary substances out of several hundreds of low molecular weight compounds of primary metabolism are known today, but only a limited number has been recognized as allelochemicals. Rainfall causes the leaching of allelopathic substances from leaves which fall to the ground during period of stress; leading to inhibition of growth and germination of crop plants (Bhadoria, 2010).

Biodegradable natural plant products rarely contain halogenated atoms and possess structural diversity and complexity, constituting one such class of chemicals and these can act directly as herbicides or may provide lead structures for herbicidal discovery (Duke *et al*., 2000). Selection of allelopathic plants is a good and commonly used approach for identification of plants with biologically active natural products (Duke *et al*., 2000). According to Gantayet *et al*. (2014), concentrations of leaf-litter dust considerably reduced the seed weight as compared with respective control plants and the same concentrations of leaf-litter dust of *Lantana camara* considerably reduced the number of pods per plant.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location (Site)

The research was conducted at the University of Zambia, School of Agricultural Sciences Field Station area. The location is on latitude 15^0 23' 24" S and longitude 28^0 19' 48" E at an altitude of 1,260m above the sea level. The nearest meteorological station with records of weather data is at the same station – the University of Zambia (School of Agricultural Sciences Weather Station – Department of Soil Science, 2017/2018). The climatic condition for the Field Station is tropical and falls under Agroecological Region IIa of Zambia which covers much of the country's middle plateau areas. This region has unimodal rainfall from November to April. May – July is the period with low and minimum temperatures with no rainfall while August to October is the dry and hot period of the year which evaporation was highest (Appendix 1). This latter period is the period with the highest irrigation demands for crops. Region IIa is characterized by total annual rainfall of between 800 -1,000 mm. Under rain-fed conditions the length of the growing period ranges from 120 to 130 days starting in the first week of December (University of Zambia, School of Agricultural Sciences Weather Station, 2017/2018).

Soil colours range from dark brown in the top soil to dark yellowish brown in the sub soil. Soil texture also grades from sandy loam in the top soil to clay loam in the subsoil. The soil depth exceeds 20 cm in the surface horizon and the textural class of the soil is sandy loam. The soil had the moderate pH which ranges from pH 6.81 to pH 7.3 (University of Zambia, School of Agricultural Sciences, Soil Science Department). Macro and micro nutrients are shown in appendix 3.

3.2 Collection of the two genotypes of *L. camara*

The leaves close to the flowers of two genotypes of *Lantana camara* L. were harvested. It was done during senescence from two different places on 24th November, 2017. The

genotype with pink flowers (Figure2) was collected within the locality (University of Zambia, School of Agricultural Sciences Field Station area), while the genotype with orange flowers (Figure 3) was collected from Pemba District, which is 228 km away from Lusaka, Zambia with latitude 16°31'35.69" S and Longitude 27°21'51.41" E, Southern Province of Zambia (Article by country, 2018) (Figure 3).

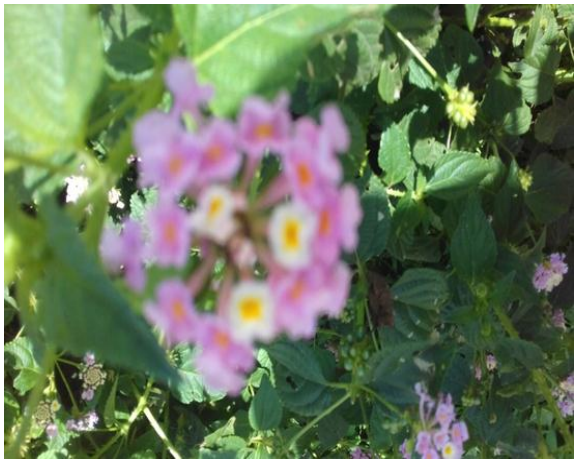

Figure 2: *Lantana camara* with pink flowers (Genotype 1 (G1))

Figure 3: Orange flowered *Lantana camara* (Genotype 2 (G2))

Source: *Distancesto, 2019*

The genotype with orange flowers was packed in bags which allowed air circulation as it was transported from Pemba to the University of Zambia, School of Agricultural Sciences Botany laboratory. The genotype with pink flowers was also carried to the Botany laboratory.

3.2.1 Preparation of the powder and extract solutions from the two genotypes of *Lantana camara*

Both genotypes of *Lantana camara* L. were offloaded and spread separately on the tables in the Botany laboratory. They were labeled for easy identification as G1 (Genotypes 1) for pink-flowered and G2 (Genotypes 2) for orange-flowered *L. camara*. Both genotypes were room dried under ambient temperatures within the laboratory using the methods described by Wafaa *et al*, (2016) for seven (7) days (from 24th November, 2017 to 30th November, 2017).

Dried leaves were milled using a mortar and pestle and sieved through a 0.1 mm sieve – (Figure 4) (Wafaa *et al*, 2016). Just before planting of the experiment, the powder of *L. camara* for both genotypes (G1 and G2) was weighed out and either broadcasted (application method T1=broadcasting) onto the soil surface or incorporated into the soil directly (application method T2=incoporation) 10 days before planting (16th February, 2018) but after ploughing the land, or soaked in 2,777.78 L of water for 4 days and then sprayed onto the soil surface (application method T3=spraying) on the same day of planting (26th February, 2018). A negative control (field without cowpea planting and no Lantana added, T0) and a positive control (field with cowpea planted, but no Lantana added, T0C) were also included. The weights of Lantana powder, corresponding to the five different rates, were rate 0/R0 (negative control applied to fields without cowpea), rate zero/R0C (positive applied added to fields with cowpea, Rate one/R1:100 kg ha^{-1}, Rate two/R2: 200 kg ha^{-1} and Rate three/R3: 400 kg ha^{-1}, equivalent, respectively.

3.2.2 Experimental Design and Field Layout

The experiment ran from November, 2017 to April, 2018. The experiment was arranged in a split-split plot design with three replications. The choice of what to consider main-plot, sub-plot and sub-subplot factors was based on ease of application to experimental units and desired level of precision for a given factor. Genotypes (G1 and G2) being the easiest to apply to experimental units were placed in the main plots, rate of application (R0, R0C, R1, R2 and R3) in the sub-plots and type of application (T0, T0C, T1, T2 and T3) sub-subplots.

The main plots were 14.0 m x 10.0 m each, subplots were 14.0 m x 3 m and sub-subplots were 2.4 m x 3 m with four rows in each. The spacing between subplot and sub-subplots was 0.5 m while between the main plots; it was 1 m apart as well as between replications. The layout for the field is shown in appendix 3. The treatments were randomly allocated to the plots (26th February, 2018). Each of the treatment combination was applied in three replications as in the systematic diagram (Figure 4).

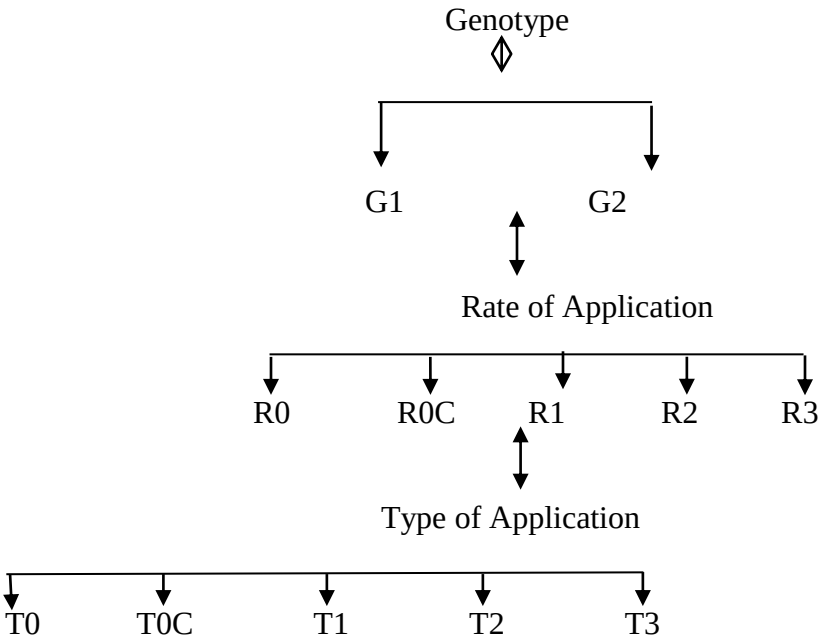

Figure 4: Main factors, Subplot factors and Sub-subplot factors (Split-split plot arrangement).

G1: Genotype 1 (Lantana camara with pink flowers), G2: Genotype 2 (Lantana camara with orange flowers), R0: Rate zero with no cowpea, R0C: Rate zero with cowpea, R1: Rate one (100 kg ha^{-1} of Lantana camara), R2: Rate two (200 kg ha^{-1} of Lantana camara), R3: Rate three (400 kg ha^{-1} of Lantana camara), T0: Type of application zero with no cowpea, T0C: Type of application zero with cowpea, T1: Type of application 1 (Broadcasting), T2: Type of application 2 (incorporation with the soil), T3: Type of application 3 (soaked ground Lantana camara)

3.3 Cultural / Agronomic Practices

Land preparation was done manually in February, 2018. Land preparation comprised of hand hoeing, after which raking was done to smoothen the tilth and flatten the land in readiness for planting. However, raking helped to loosen the soil to avoid compaction.

Cowpea (*Vigna unguiculata* L.) seed, bubebe variety was planted on 26th February, 2018 at the rate of 25 kg ha^{-1}. Spacing was 60 cm inter-row (with 30 cm on each side) x

15 cm x 2 cm intra row and depth, respectively. One seed was planted on each station. 300 Kg ha^{-1} of basal dressing fertilizer (Compound – D with a percentage of Nitrogen (N) 10: Phosphorus (P) 20: and Potassium (K) 10) was applied at planting on the 26th February, 2018. Supplementary irrigation was given when there was no rainfall in week five and week six after planting using overhead irrigation.

Plant protection was done using insecticides which included: i) Phorate with active ingredient phorate applied at 2 g per plant. Phorate was broadcasted in the second week after planting (7th of March, 2018) to ensure the plants were safe from pests just after germination. It controls insects as well as birds that feed on cowpea seedlings, ii) Thunder with imidacloprid and beta-cyfluthrin as active ingredients applied at 400 ml ha^{-1} and iii) Ninja plus 5EC an emulsifiable concentrate containing five percent of Lamda-cyhalothrin applied at 400 ml ha^{-1}. The last two insecticides were applied using a sprayer in week 6 and 8 after planting, respectively to prevent sucking (aphids) and chewing (hoppers) pests.

Cowpea pods where harvested at physiological maturity, signified by pods turning yellow during the final stage of growth, and becoming brown and brittle when they reached maturity at a moisture content of 12%. Cowpea yield was done by removing mature pods by hand and they were packed in harvesting bags from the field to the Botany laboratory where they were allowed to dry completely. Cowpea was then threshed and the cowpea grain yield was weighed in plastic papers per plot to determine the effect of *L. camara* on weed control in cowpea.

3.4 Data Collection and analysis

3.4.1 Data Collection

Parameters measured were weed population density (WPD) and weed weight (WW) for both grasses and broad leaved weeds which were present in the field. Crop stand (CS) and Cowpea grain yield (CGY) were determined as significant values. Cowpea grain yield was measured following the determination of weed population density and weed weight. To determine weed density, a 1 m^2 quadrant was used for sampling weeds around the research area as a baseline. A quadrant was thrown at random in 15 different areas, three days before planting. The collected weeds per 1 m^2 quadrant were counted

physically to obtain the weed population density and weed identification was done in order to determine the types of weeds present per quadrant around the research area using the field guide (Vernon, 1987). Weed samples were put in labeled envelopes and then oven-dried at 70^{o}C for two days and weighed using an electronic balance in order to obtain weed weight (WW). Emergence count was done by counting the number of cowpea seedlings in each row per plot in the second week after planting. All the cowpea seeds that were planted germinated. Crop stand was also determined in the second week after planting.

Data on weed population density and weed weight from the research area was collected in the third week after planting using the same 1 m^2 quadrant and an electronic balance respectively. Data collection was then done after two weeks (week 5, 7, 9, 11 and week 13) to determine weed population density and weed weight. A 1 m^2 quadrant was thrown at random between the two middle rows of each and every plot. All the weeds in the quadrant were collected per plot, counted physically to determine the weed population density (WPD) and identified the types of weeds. Thereafter, weed samples were put in envelopes and then oven-dried at 70^{o}C for two days and weighed in order to obtain weed weight (WW) using an electronic balance. Cowpea yield was collected per plot using paper bags. Cowpea was harvested and grain from each plot weighed separately using an electronic balance and then converted to kilogram per hectare.

3.4.2 Statistical analysis

Data collected during the experiment was statistically analyzed as a split-split plot design, with genotype as the main plot, rate of application as the subplot and type of application of *Lantana camara* as the sub-subplot. The interactions among these three factors were all included in the model. Data analysis was conducted with Analysis of variance (ANOVA) and treatment means were separated using the Least Significant Difference (LSD) calculated at $P \leq 0.05$ using GenStat 14th Edition.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of genotype of *Lantana camara* on weed control in cowpea

The summary of analysis of variance showed significant differences between weed population density and weed weight in fields treated with different genotypes (main plots) of *L. camara* ($P < 0.05$), in plots treated with rate of application (subplots) ($P < 0.05$) and in an interaction ($P < 0.05$) between the main plot and the subplot factors (rate of application) for both weed population density and weed weight (Table 3). There was significant variation in plots treated with type of application (sub-subplots, $P < 0.05$), interaction between genotype and type of application ($P < 0.05$), rate of application by type of application ($P < 0.05$) and finally in a combination between genotype by rate of application by type of application ($P < 0.05$, Table 3).

Table 3: Analysis of Variance (ANOVA) for weed population density and weed weight in cowpea

Source of variation	df	MS (WPD)	MS (WW g m^{-2})
Replication	2	21.54	629.50
Genotype (G)	1	1638.75***	5617.70**
Error	2	1.53	9.60
Rate (R)	4	9761.09***	16264.90***
Genotype (G) x Rate (R)	4	360.87***	2844.90***
Error	16	14.31	301.10
Type (T)	4	5094.04***	49301.60***
Genotype (G) x Type (T)	4	114.37***	1421.70***
Rate (R) x Type (T)	16	184.6***	2575.50***
G x R x T	16	250.34***	1643.90***
Error	80	7.64	230.10
Total	149		

*P was calculated at P< 0.05. ** means very significant at P = 0.01, while *** means highly significant at P< 0.001. G x R x T means: Genotype by Rate by Type of application of Lantana camara, Genotype: main plot factor, Rate of application of Lantana camara as a subplot factor and Type of application as the sub-subplot factors*

The weed population density was more reduced ($P < 0.05$) in fields treated with genotype 1 (mean = 51.46) than those which were treated with genotype 2 (mean = 58.07) (Table 4). Weed weight was lower ($P < 0.05$) in fields where genotype1 was applied (118.90 g m^{-2}) than in fields where genotype 2 was applied (130.40 g m^{-2}, Table 4).

Table 4: Single and interactive effects of genotypes, rate of application and type of application of weed control of *Lantana camara* applied on cowpea

Genotype	Means of Weed population density	Mean of Weed weight (g m^{-2})
Genotype 1	51.46	118.90
Genotype 2	58.07	130.40
Lsd (G)	0.869	2.180
Rate of application (R)		
Rate zero with no cowpea	73.51	156.2
Rate zero with cowpea	70.74	140.8
Rate one	54.83	104.4
Rate two	44.05	115.2
Rate three	30.68	101.7
Lsd (R)	2.070	9.500
Type of application (T)		
Type zero with no cowpea	74.02	161.00
Type zero with cowpea	60.39	142.10
Type one	47.36	82.60
Type two	51.89	125.60
Type three	40.15	78.00
Lsd (R)	1.420	7.790
Genotype x Rate G1 R0	72.90	156.60
G2 R0	74.12	155.80
G1 R0C	70.03	144.10
G2 R0C	71.46	137.50
G1 R1	46.71	101.70

Table 4 continued.

G2 R1	62.95	113.00
G1 R2	38.18	108.40
G2 R2	49.92	122.00
G1 R3	29.47	79.90
G2 R3	31.90	123.60
Lsd (G R)	2.644	12.050
Rate x Type R0 T0	86.43	184.10
R0C T0	95.83	179.20
R1 T0	84.86	126.50
R2 T0	56.11	155.40
R3 T0	46.89	159.90
R0 T0C	82.06	177.40
R0C T0C	72.77	180.20
R1 T0C	58.00	140.40
R2 T0C	49.38	158.60
R3 T0C	39.74	113.90
R0 T1	68.82	160.80
R0C T1	66.17	58.10
R1 T1	43.61	69.00
R2 T1	34.62	58.90
R3 T1	23.58	66.20
R0 T2	71.03	169.30

Table 4 continued.

R0C T2	59.67	169.60
R1 T2	52.89	137.10
R2 T2	48.58	138.80
R3 T2	27.27	113.00
R0 T3	59.21	89.40
R0C T3	59.28	116.70
R1 T3	34.77	63.80
R2 T3	31.56	64.30
R3 T3	15.95	55.60
Lsd (R T)	3.440	17.920
Genotype x Type G1 T0	77.89	167.80
G2 T0	78.16	174.30
G1 T0C	63.78	158.90
G2 T0C	65.00	165.30
G1 T1	42.47	85.40
G2 T1	52.25	79.80
G1 T2	51.75	137.40
G2 T2	52.02	153.70
G1 T3	37.39	77.20
G2 T3	42.91	78.70
Lsd (G T)	1.841	9.910

Table 4 continued.

Genotype x Rate x Type G1 R0 T0	81.75	184.20
G1 R0C T0	84.72	179.90
G1 R1 T0	75.67	96.00
G1 R2 T0	56.16	143.40
G1 R3 T0	51.17	135.30
G2 R0 T0	91.11	184.10
G2 R0C T0	106.94	178.50
G2 R1 T0	94.06	157.00
G2 R2 T0	56.06	167.30
G2 R3 T0	42.61	184.60
G1 R0 T0C	73.23	181.80
G1 R0C T0C	63.19	164.10
G1 R1 T0C	56.17	121.00
G1 R2 T0C	43.33	164.90
G1 R3 T0C	42.97	82.60
G2 R0 T0C	90.89	173.10
G2 R0C T0C	82.34	196.40
G2 R1 T0C	59.83	159.80
G2 R2 T0C	55.42	152.30
G2 R3 T0C	36.50	145.10

Table 4 continued.

G1 R0 T1	70.36d	175.30
G1 R0C T1	66.06	48.70
G1 R1 T1	32.31	83.40
G1 R2 T1	25.07	61.70
G1 R3 T1	18.56	58.00
G2 R0 T1	67.28	146.40
G2 R0C T1	66.28	67.50
G2 R1 T1	54.92	54.60
G2 R2 T1	44.18	56.10
G2 R3 T1	28.61	74.50
G1 R0 T2	73.33	164.90
G1 R0C T2	71.96	172.80
G1 R1 T2	46.17	156.60
G1 R2 T2	43.33	118.00
G1 R3 T2	23.97	74.80
G2 R0 T2	68.73	173.60
G2 R0C T2	47.38	166.50
G2 R1 T2	59.61	117.60
G2 R2 T2	53.82	159.60
G2 R3 T2	30.56	151.20
G1 R0 T3	65.83	76.80
G1 R0C T3	64.23	155.00
G1 R1 T3	23.22	51.70

Table 4 continued.

G1 R2 T3	23.00	54.00
G1 R3 T3	10.67	48.70
G2 R0 T3	52.58	102.10
G2 R0C T3	54.33	78.40
G2 R1 T3	46.32	75.90
G2 R2 T3	40.11	74.70
G2 R3 T3	21.22	62.50
Lsd (G R T)	4.718	24.720
Factor significance (p values)		
Genotype	< .001	0.002
Rate	< .001	< .001
Type of application	< .001	< .001
Genotype x Rate	< .001	< .001
Rate x Type	< .001	< .001
Genotype x Type	< .001	< .001
Genotype x Rate x Type	< .001	< .001

G1: Genotype 1 (Lantana camara with pink flowers), G2: Genotype 2 (Lantana camara with orange flowers), R0: Rate zero with no cowpea, R0C: Rate zero with cowpea, R1: Rate one (100 kg ha^{-1} of Lantana camara per hectare), R2: Rate two (200 kg ha^{-1} of Lantana camara per hectare), R3: Rate three (400 kg ha^{-1} of Lantana camara per hectare), T0: Type of application zero with no cowpea, T0C: Type of application zero with cowpea, T1: Type of application 1 (Broadcasting), T2: Type of application 2 (incorporation with the soil), T3: Type of application 3 (soaked ground Lantana camara), The least significant differences (LSD) were calculated at P < 0.05.

4.2 Effect of Rate of application of *L. camara* on weed control in cowpea

Weed population density in fields treated with rate of application showed significant differences ($P < 0.05$) in the control of weeds in cowpea (Table 4). There was a decrease in weed population density in fields treated with rate of application with increase in rates. Rate 3 (400 kg ha^{-1}) had the lowest number of weeds (mean = 30.68) while rate zero with no cowpea (R0) had the highest (73.51) number of weeds. Rate 2 (200 kg ha^{-1}) controlled more weeds (mean = 44.05) than rate 1 (100 kg ha^{-1}) which controlled a mean of 54.83 weeds, but reduced more weeds in cowpea as compared to rate zero with cowpea (70.74) (Table 4).

Similarly, fields treated with rate of application of *L. camara* in the subplots showed significant differences ($P < 0.05$) in weed weight. Fields treated with the highest rate of application had the least weed weight (mean = 101.70 g m^{-2}) which was not significantly different from rate 1 (104.40 g m^{-2}) in weed control (Table 4). Rate 2 of application (115.2 g m^{-2}) was higher than both controls of rate of application (R0C and R0) in cowpea, (140.8 g m^{-2} and 156.2 g m^{-2}, respectively, Table 4).

The interaction between genotype and rate of application of *L. camara* was significantly affected (Table 4) in weed population density. The combination between genotype 2 with rate zero without cowpea (74.12) was the highest in terms of weed population density. It was not significant different from genotype 1 by rate zero with no cowpea (72.90) and genotype 2 by rate zero with cowpea (71.46). However, the latter combinations were not significantly different from each other as well as from genotype 1 by rate zero with cowpea (70.03). These were compared to other combinations. The next one was a combination of genotype 2 by rate of application 1 (62.95). An interaction between genotype 1 by rate 3 (29.47) was not significantly different from genotype 2 by rate of application 3 (31.90), these had the least number of weed population density among all combinations (Table 4).

Weed weight in an interaction between genotype and rate of application showed significant differences ($P < 0.05$). A combination between genotype 1 by rate zero with no cowpea (156.60 g m^{-2}), genotype 2 by rate zero with no cowpea (155.80 g m^{-2}) and between genotype 1 by rate zero with cowpea (144.10 g m^{-2}) had the highest weights as

compared to combinations such as genotype 1 by rate 3 (79.90 g m^{-2}) and genotype 1 by rate 2 (108.40 g m^{-2}) which was in turn not significant different from genotype 2 by rate 1 (113.00 gm^{-2}) (Table 4).

4.3 Effect of Type of application (sub-subplot factor) of *L. camara* on weed control in cowpea.

There were significant differences ($P < 0.05$) in weed population densities from sub-subplots treated using different types of application methods. The highest weed population density (mean=74.02) was observed in type zero with no cowpea (T0) and the lowest (mean=40.15) in type 3 (socked ground *L. camara,* Table 4). There were significant differences ($P < 0.05$) in weed weights from sub-subplots treated using different types of application methods (Table 3). The highest weed population density (mean=161.00 g m^{-2}) was observed in type zero with no cowpea (T0) and the lowest (mean=78.00 g m^{-2}) in type 3 (socked ground *L. camara*) which was not significant different from type 1 (broadcasting, mean=82.60 g m^{-2}, Table 4).

The highest reduction of weed population density was observed between rate 3 and type 3 (15.95). It was also observed that a combination between rate 3 and type 2 (27.27) was also effective on weed control in cowpea (Table 4). An interaction between rate and type on weed weight was higher with rate 3 and type 3 (55.60 g m^{-2}) which was not significantly different from rate 1 by type 1 (69.00 g m^{-2}), rate 3 by type 1 (66.20 g m^{-2}), rate 2 by type 1 (58.90 g m^{-2}) and rate 2 by type 3 (64.30 g m^{-2}). Weed weight had no distinct pattern (Table 4).

A combination of genotype 1 by type 3 (37.39) was the most effective in that it had less number of weeds as it was compared to the control. The next ones in terms of effectiveness were interactions between genotype 1 by type 1 (42.47) and genotype 2 by type 3 (42.91) which were not significant different from each other. However, the least effective was genotype 2 by type zero with no cowpea (78.16) which was not significantly different from genotype 1 by type zero with no cowpea (77.89) (Table 4).

The effect of genotype and type of application on weed weight was highly significant at $P < 0.05$. The interactions between genotype 1 by type 1 (85.4 g m^{-2}), genotype 1 by type 3 (77.2 g m^{-2}), genotype 2 by type 1 (79.8 g m^{-2}) and genotype 2 by type 3 (78.7 g

m^{-2}) were lower and not significantly different from each other. Genotype 1 by type 2 (137.4 g m^{-2}) and genotype 2 by type 2 (153.7 g m^{-2}) were lower than the control but higher than these other combinations (Table 4).

The lowest weed population density was obtained from the interaction of Genotype 1, rate 3 and type 3 (10.67). It was followed by genotype 2 by rate 3 by type 3 (21.22), genotype 1 by rate 2 by type 3 (23.00), genotype 1 by rate 1 by type 3 (23.22) which were not significant different from each other (Table 4). The most effective weed weight was obtained from a combination of genotype 1 by rate 3 by type 3 (48.7 g m^{-2}). The least effective combinations were from the two controls from both genotypes (Table 4).

4.4 Effect of genotype of *L. camara* on cowpea grain yield

The summary of Analysis of Variance showed significant differences between cowpea grain yield from fields treated with genotype ($P < 0.05$), rate of application ($P < 0.05$) and interaction between genotype and rate of application ($P < 0.05$). There was also significant variation in fields treated with type of application ($P < 0.05$), interaction between genotype and type of application ($P < 0.05$), rate of application by type of application ($P < 0.05$) and finally a combination between genotype by rate by type of application ($P < 0.05$) (Table 5).

Table 5: Analysis of Variance (ANOVA) for cowpea grain yield (kg ha^{-1})

Source of variation	df	MS
Replication	2	539
Genotype (G)	1	1007334.00**
Error	2	1583.00
Rate (R)	3	946548.00***
G x Rate (R)	3	151852.00***
Error	12	802.00
Type (T)	3	619394.00***
G x RT	3	107095.00***
Rate x Type	9	41383.00***
G x R x T	9	25715.00***
Error	48	1282.00
Total	95	

*G: Genotype, R: Rate of application, T: Type of application, P was calculated at P < 0.05. ** means very significant at P = 0.01, while *** means highly significant at P < 0.001.*

The cowpea grain yield was higher from plots treated with genotype 1 (876.90 kg ha^{-1}) than in those treated with genotype 2 (672.10 kg ha^{-1}). The difference in cowpea grain yield from fields treated with genotype 1 over genotype 2 was 30.47% (Table 6).

Table 6: Single and interactive effects of genotypes, rate of application and type of application of weed control of *Lantana camara* applied on cowpea grain yield

Genotype	Mean yield (kg ha^{-1})
Genotype 1	876.90
Genotype 2	672.10
Lsd (G)	34.940
Rate of application (R)	
Rate zero with cowpea	533.90
Rate one	724.30
Rate two	831.60
Rate three	1008.30
Lsd (R)	17.810
Type of application (T)	
Type zero with cowpea	579.60
Type one	823.70
Type two	732.40
Type three	962.30
Lsd (R)	20.780
Genotype x Rate G1 R0C	560.80
G2 R0C	507.00
G1 R1	814.10
G2 R1	634.40
G1 R2	910.20
G2 R2	753.10
G1 R3	1222.70
G2 R3	793.80
Lsd (G R)	29.080
	473.50

Table 6 continued.

Rate x Type	R0C T0C	
	R1 T0C	562.10
	R2 T0C	556.20
	R3 T0C	726.70
	R0C T1	533.40
	R1 T1	750.80
	R2 T1	948.70
	R3 T1	1061.80
	R0C T2	502.20
	R1 T2	681.40
	R2 T2	803.90
	R3 T2	942.30
	R0C T3	626.50
	R1 T3	902.80
	R2 T3	1017.70
	R3 T3	1302.20
	Lsd (R T)	39.380
Genotype x Type	G1 T0C	582.40
	G2 T0C	576.80
	G1 T1	954.80
	G2 T1	692.60
	G1 T2	878.10
	G2 T2	586.80

Table 6 continued.

G1 T3	1092.50
G2 T3	832.10
Lsd (G T)	31.490
Genotype x Rate x Type	
G1 R0C T0C	440.40
G1 R1 T0C	657.10
G1 R2 T0C	496.40
G1 R3 T0C	735.80
G2 R0C T0C	506.70
G2 R1 T0C	467.10
G2 R2 T0C	616.00
G2 R3 T0C	717.70
G1 R0C T1	583.60
G1 R1 T1	858.60
G1 R2 T1	1026.10
G1 R3 T1	1350.08
G2 R0C T1	483.10
G2 R1 T1	643.00
G2 R2 T1	871.30
G2 R3 T1	772.80
G1 R0C T2	550.30
G1 R1 T2	760.10
G1 R2 T2	952.30

Table 6 continued.

G1 R3 T2	1249.60
G2 R0C T2	454.10
G2 R1 T2	602.70
G2 R2 T2	655.50
G2 R3 T2	635.00
G1 R0C T3	668.80
G1 R1 T3	980.70
G1 R2 T3	1165.90
G1 R3 T3	1554.70
G2 R0C T3	584.20
G2 R1 T3	824.90
G2 R2 T3	869.50
G2 R3 T3	1049.70
Lsd (G RT)	56.910
Factor significance (p values)	
Genotype (G)	0.002
Rate	< .001
Type of application	< .001
	< .001

Table 6 continued.

Genotype x Rate	
Rate x Type	< .001
Genotype x Type	< .001
Genotype x Rate x Type	< .001

G1: Genotype 1 (Lantana camara with pink flowers), G2: Genotype 2 (Lantana camara with orange flowers), R0: Rate zero with no cowpea, R0C: Rate zero with cowpea, R1: Rate one (100 kg ha^{-1} of Lantana camara), R2: Rate two (200 kg ha^{-1} of Lantana camara), R3: Rate three (400 kg ha^{-1} of Lantana camara), T0: Type of application zero with no cowpea, T0C: Type of application zero with cowpea, T1: Type of application 1 (Broadcasting), T2: Type of application 2 (incorporation with the soil), T3: Type of application 3 (soaked ground Lantana camara), LSD: Least significant difference. The least significant differences (LSD) were calculated at P < 0.05.

4.5 Effect of rate of application (subplot factor) of *L. camara* on cowpea grain yield

Rate of application of *Lantana camara* had an impact on cowpea grain yield. The results showed significant differences among plots treated with rates (R) of application ($P < 0.05$). There was an increase in cowpea grain yield obtained from plots treated with rate of application. Rate 3 (1008.30) had the highest cowpea grain yield while rate zero with cowpea (R0C) had the least cowpea grain yield (Table 6).

There was increase in cowpea yield grain obtained from fields treated with genotype 1 by rate of application 3 (1222.70 kg ha^{-2}) of *L. camara.* The highest cowpea grain yield was obtained from plots treated with the highest rate of application (400 kg ha^{-1}). Genotype 1 showed an increase in cowpea grain yield with increase in rate of application. There was no significant difference between genotype 1 by rate 1 (814.10 kg ha^{-2}) and genotype 2 by rate 3 (793.80 kg ha^{-1}) in cowpea grain yield (Table 6).

4.6 Effect of type of application of *L. camara* on cowpea grain yield

The type of application had an effect on cowpea grain yield. The results showed variations in cowpea grain yield obtained from fields treated with type of application ($P < 0.05$, Table 5). Cowpea grain yield increased by 66% in plots with type 3 (962.30 kg ha^{-1}) as it was compared to the control (Table 6). Type 3 was the most effective as

compared to other types of applications. It was higher than type 1 (823.70 kg ha^{-1}) and type 2 (732.40 kg ha^{-1}) by 16.83% and 31.39%, respectively (Table 6).

The highest cowpea grain yield was observed between type 3 with rate 3 (1302.20) and type 1 with rate 3 (1061.80) across genotype (Table 6). A combination of genotype 1 and type of application 3 (1092.5 kg ha^{-1}) was the most effective in increasing the cowpea grain yield. The results showed significant differences ($P < 0.05$) in cowpea grain yield for an interaction between genotype and type of application (Table 5). There was no significant difference between a combination of genotype 1 by type zero with cowpea (582.40 kg ha^{-1}), genotype 2 by type zero with cowpea (576.80 kg ha^{-1}) and genotype 2 by type 2 (586.80 kg ha^{-1}). While at genotype 1 by type 1 (954.80 kg ha^{-1}) cowpea grain yield was higher than genotype 1 at type 2 and type zero with cowpea, genotype 2 at type zero with cowpea, type 1 and type 3 (Table 6).

The highest cowpea grain yield was obtained from the interaction of genotype 1, rate 3 and type 3 (1554.70). In addition, the cowpea grain yield was significant different when genotype 1, rate 3 and type 1 (1350.80) was applied. In the case of genotype 2, the highest yield was obtained when it was combined with rate 3 and type 3 (1049.70) which was not significant different from genotype 1 by rate 2 by type 1 (1026.10). Although it was higher it was still lower than what was obtained in genotype 1 by 48.11% (Table 6).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of genotype (Main plot factor) of *Lantana* camara on weed control in cowpea

The study showed that *Lantana camara* had an effect on weed control in cowpea by reducing weed population density and weed weight; it could be that *L. camara* released allelochemicals which inhibited germination of weeds and reduced the weight for the weeds. It was also observed by Kenany and Darier (2013) who reviewed that, many of the allelochemical compounds found in *L. camara* are phytotoxic and have potential as herbicides for new herbicides classes. Similarly, Qasem (2006) reported that, allelopathic plant of *L. camara* inhibited or suppressed germination, growth, development or metabolism of crops due to secretion of allelochemicals to the rhizosphere of neighboring crop plants.

The reduction of weed population density and weed weight by *L. camara* could be due to its allelopathic effect which inhibited weed germination and suppression of weed growth. Genotype1 was more effective because it reduced weed population density by 64% and weed weight than genotype 2, it maybe because genotype1 is highly concentrated with allelochemicals and highly toxic as described by Ambika (2003). It is less costly and environmental friendly to use the leaves of *L. camara* for weed control in cowpea. Similarly, Agriculture and Food (2017), reported that recently biological weed control received renewed interest because it is an environmentally compatible method of weed control without residue and pollution problems.

5.2 Effect of rate of application (subplot factor) of *L. camara* on weed control in cowpea.

Weed population density and weed weight responded differently to the applied *Lantana camara* in plots treated with rate of application of *L. camara*. At higher rate of application of *L. camara* more weeds were controlled especially the grasses. It could be higher rate of application released more allelochemicals which controlled weed population density. This was in agreement with the findings of Hossain and Alam (2010) who observed that the inhibitory effects of *L. camara* on weed germination and

growth increased with dose. Allelochemicals of *L. camara* interfered with various physiobiochemical processes of weed germination, root elongation, plant growth as well as various metabolic activities of many species and it was clearly seen in rate of application (Mishra, 2015). Mishra (2015) also reported that, the harmful effect of higher extract concentration on weed population density might be due to excess of allelochemicals which inhibit gibberellin and IAA (Indole-acetic acid) induced growth.

The weed population density decreased with increase in rates. It was maybe as a result of allelopathic effect of *L. camara* at higher concentration (Weed Management Guide, 2013). It was also confirmed by the findings of (Mishra, 2015), who reported that the suppressed seed germination and seedling growth in all associated weeds and the suppressive effect increased with an increase in percent content of *L. camara* extracts. Kong *et al*. (2007) also reported that the reduction was due to the chemicals Lantadene A and Lantadene B from *L. camara*. The number of weeds reduced linearly per rate of application as a result of the *L. camara* which was applied (Table 4). Allelopathy played an important role in weed control and crop productivity. The allelopathic compounds can be used as natural herbicides and other pesticides, they are less disruptive of the global ecosystem than the synthetic agrochemicals (Khalid *et al,* 2002).

Weed weight was reduced in plots treated with rate of application because rates 3 and 1 showed no significant differences, it maybe because the two rates of application of *L. camara* released more allelochemicals which reduced the weed weight. Similar observation was done by Wafaa *et al* (2016), who found that significant reduction in dry weights of *C. olitorius* and *E. colonum* was by using leaf residues of *L. camara*. Mishra (2012), suggested that allelopathy in *L. camara* has a component of biological control in which plants are used to reduce the vigour and development of other plants.

It was found that the variation of genotype with rate of application on weed population density and weed weight was significant, it reduced weed population density as well as weed weight and it was in agreement with the hypothesis that *L. camara* has an effect on weed control in cowpea. The reduction in weed

population density with genotype was attributed to higher rates of application of *L. camara* and this was supported by Mishra, 2012 who stated that allelopathic plants are used to reduce the vigor and development of other plants.

The linear decline in weed population density which was observed between genotype and rate of application was attributed to the high rates as it was also ascribed by Bhadoria (2010) who reviewed that allelopathic substances from leaves of *L. camara* lead to inhibition of growth and germination of plants. Weed weight had no discernable pattern (Table 4) which was contrary to Wafaa *et al* (2016) who indicated significant reduction in dry weights of *C. olitorius* and *E. colonum* by using leaf residues of *L. camara*. Galindo *et al*. (1999) postulated that many phytotoxic allelochemicals have been isolated, identified, and found to influence a number of physiological reactions.

5.3 Effect of Type of application (sub-subplot factor) of *L. camara* on weed control in Cowpea.

Weed population density and weed weight decreased most in plots treated with sprayed socked ground *L. camara*, it could be because socked ground *L. camara* releases more allelochemicals as compared to ground (powdered) *L. camara*. It was similar with the work done by Hossain and Alam, (2010) which showed that higher concentrations of *L. camara* leaf extracts caused significant inhibitory effect on germination of weeds in agricultural crops. In addition, Zhung *et al*. (2005) reported that the aqueous extracts from fresh and dry leaves of *L. camara* inhibited the growth of water hyacinth and killed the plant within six days because of salicylic acid which is major allelochemical in *L. camara*. Allelopathic weed control can be implemented by growing allelopathic plants in close proximity to weeds which promote production of these chemicals (Tesio and Ferrero, 2010) or by placing the allelopathic materials obtained from dead plants in close proximity to weeds. The latter involves the use of plant residues for weed control (Tabaglio *et al*., 2008). In addition, the study was also similar to the findings of Wafaa *et al*., (2016) who suggested that reduction in dry weight of weeds was due to treatments with leaf residues of *L. camara*.

Type 3 was the most effective for both genotypes it maybe because the combination of genotype by type of application released more allelopathic chemicals which eventually

controlled the weeds. The strategy for using allelopathy for weed management could be either through directly exploiting natural allelopathic interactions (Hossain and Alam, 2010). Weed weight was not very sensitive measure for weed control in cowpea; however, weed weight showed significant difference between genotype and type of application, it could be allelochemicals in *L. camara* in the combination did not affect weed weight. Contrary, Kenany and Darier, (2013) reported that emergence and dry weight of selected plant species were affected when *L. camara* was present on the soil surface or incorporated into the soil.

Genotype 1 was more effective at lower rates but at higher rates with type of application 3 they had similar effect in weed population density which was similar with Galindo *et al*. (1999) who postulated that many phytotoxic allelochemicals have been isolated, identified, and found to influence a number of physiological reactions. On the contrary, weed weight had no discernable pattern (Table 4) it maybe because the interaction had weak allelochemicals which failed to manage the weeds.

5.4 Effect of genotype (Main plot factor) of *Lantana camara* on cowpea grain yield

The results of genotype on cowpea grain yield showed significance which could be attributed to the allelopathic effect of *L. camara* as ascribed by Li *et al*., (2004); Milberg and Hallgren, (2004); Osipitan and Dille, (2017), the magnitude of yield increase depended on characteristics such as, weed density, type of weeds, crop management practices and many more. In addition, Qasem (2006) found that allelopathic plants release chemicals into the surrounding soil which prevent germination and competition from some other plant species.

The higher level of genotype (1) application in main plots was able to increase cowpea grain yield by 64% more than the control, it maybe as a result of the *L. camara* which was applied and released allelochemicals which reduced weed population density. From this study, it was found that genotype of *L. camara* with pink flowers decreased weed population density more than genotype 2 and the control which eventually increased cowpea grain yield; it could be because *L. camara* with pink flowers is more toxic and release a lot of allelochemicals than *L. camara* with orange flowers (Ambika *et al*.,

2003). Genotype 1 was able to reduce competition from weeds being one of the major factors that reduce crop yield and farmers' income (Ward *et al*., (2008).

5.5 Effect of rate of application (subplot factor) of *L. camara* on cowpea grain yield

The results of the study showed significant differences ($P < 0.05$) among rates of application which were contrary to the findings of Gantayet (2014), who reported that plants of control set, yielded the maximum quantity of seeds (28.71 ± 0.06) and minimum (2.64 ± 0.05) per plant grown in 16% concentration of leaf-litter dust of *L. camara*. All the concentrations of leaf-litter dust of *L. camara* considerably reduced the number of pods per plant as compared to the mean maximum and minimum number of pods recorded in plants grown in control (Gantayet, 2014). It maybe because the rate of application of *L. camara* released allelochemicals that reduced the weed population density and weed weight which eventually lead to high cowpea grain yield.

A linear increase in cowpea grain yield was as a result of an increase in rate of application of *L. camara*, which was in agreement with Mishra (2015), who postulated that, the high concentration of *L. camara* caused marked inhibition of germination and growth of weeds and eventually lead to increase in yield. Failure to control the weeds in cowpea results in lower yields. Similar studies were done which reviewed that yield reductions due to weeds were 25% for VITA 1, 33% for VITA 5, 46% for ER-1 and 54% for TVX33-IG (Li et al., 2004) and Tripathy and Singh (2001) also reported 12.7% to 60% yield loss in cowpea was due to weeds.

There was an increase in cowpea grain yield for genotype 1 with rate of application of *L. camara.* The highest cowpea grain yield was obtained from highest rate of application (400 kg ha^{-1}) it could be as a result of controlled weed population density as it was against Gantayet (2014), who ascribed that all concentrations of leaf-litter dust considerably reduced the seed weight compared with respective control plants.

5.6 Effect of type of application (sub-subplot factor) of *L. camara* on cowpea grain yield

The type of application had an effect on cowpea grain yield. It could be the soaked ground *L. camara* which controlled more weed population density by releasing allelochemicals which resulted to high yield. Similarly, other authors ascribed that yield

losses caused by weeds alone in cowpea production can range from 25% to 76% (Adigun *et al*., 2014; Gupta *et al*., 2016; Osipitan *et al*., 2016; Ugbe *et al*., 2016).

Contrary to the findings of Gantayet (2014), who reported that the release of these phenolic compounds of *L. camara* might have adversely affected the growth and yield of test cultivars through their interference in energy metabolism, cell division, biosynthetic processes and many others interferences. In addition, Marinov-Serafimov (2015), suggested that weeds such as *L. camara* may also reduce crop yield by releasing allelopathic compounds into the environment.

The results showed significance in cowpea grain yield for genotype and type of application (Table 5). It was against Gantayet (2014) who found that all concentrations of leaf-litter dust of *L. camara* considerably reduced the seed weight compared with respective control plants. The highest cowpea grain yield was obtained from interaction of genotype 1, rate 3 and type 3. It was found that the cowpea grain yield was significant different when genotype 1, rate 3 and type 1 was applied. It could be because the combination released more allelochemicals which controlled more weeds and increased cowpea grain yield. A combination of genotype 1, rate 2 and T3 was also effective though it was lower than genotype 1, rate 3 and type 2 and genotype 1, rate 3 and type 1. There was less *L. camara* in an interaction of genotype 1, rate 2 and type 3 (200 kg ha^{-1} in 2,777.78 litres of water) which was used as compared to genotype 1, rate 3 and type 3 (400 kg ha^{-1} in 2,777.78 litres of water). More area can be covered using the same combination (genotype 1, rate 2 and type 3) as compared to genotype 1, rate 3 and type 3. It was against what was noticed by Gantayet (2014) that all the concentrations of leaf-litter dust of *Lantana camara* considerably reduced the yield efficiency of the test crops compared with their respective control plants. It could be that the genotype by rate by type of application did not affect the cowpea negatively.

The weed population density contributed more to cowpea grain yield because plots with reduced or controlled weeds had increased yield and this was confirmed by Adigun *et al*., (2014); Gupta *et al*., (2016); Osipitan*et al*., (2016); Ugbe *et al*., (2016) who reported that yield losses caused by weeds alone in cowpea production can range from

25% to 76%. Therefore, it is evident that controlling weed population density better optimizes cowpea grain yield as ascribed by Stepwise Regression Analysis.

However, Tripathi and Singh (2001) also reported that presence of weeds in cowpea reduced yield by 82% and significant increase in pod yield was recorded by controlling weeds up to 45 days of sowing. Other authors such as, Li *et al*., (2004) reported that yield loss due to weeds was 12.7-60.0%. Likewise, Madukwe *et al*., (2012) reported that in Nigeria, the presence of weeds caused 53-60% yield loss in legumes including cowpea. Similarly, Freitas *et al*., (2009) also reported that weed interference in cowpea not only reduced the final stand but also the number of pods per plant, and grain yield up to 90%. Sunday and Udensi, (2013) reported that control of weed growth and/or inadequate weed control in the crop have been reported to account for 40-80% reduction in grain yield in cowpea.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The objective of this study was to determine the effect of *L. camara* on weed control in cowpea and the findings indicate that *L. camara* had an effect on weed control in cowpea. The genotype of *L. camara* with pink flowers (G1) was most effective in that it increased cowpea grain yield by 30.47% than the genotype of *L. camara* with orange flowers and the control (64%). However, different genotypes exhibited different effects in that genotype 1 had better control resulting in significantly higher yield (876.90 kg ha^{-1}) than both genotype 2 (672.10 kg ha^{-1}) and the control (533.90 kg ha^{-1}) which were in turn significantly different from each other. *L. camara* can be used to formulate herbicides which can control weeds in cowpea. Mostly it controlled the grasses such as *Eleusin indica* and *Cynodon dactylon* than the broad leaved weeds. Weed population density and weed weight were reduced the most at the highest rate of application (400 kg ha^{-1}) or 14% aqueous extract of ground *L. camara* was found to be most effective. The effect of application of *L. camara* at type 3 (spraying of socked ground *L. camara*) and at type 1 (broadcasting) were more effective than at type 2 (incorporation in the soil).

6.2 Recommendations

Small scale farmers can use *L. camara* with pink flowers to control weeds in cowpea.

The highest rate (400 kg ha^{-1}) of application can be applied in cowpea to control weeds because it was the most effective in weed control.

Smallholder farmers can spray socked ground *L. camara* (T3) to control weeds in cowpea.

The future study should be on the effect of *L. camara* on specific types of weeds in weed control.

REFERENCES:

1. Abarahim, D, W.L. Braguini, A.M. Kelmer-Bracht, E.L. Ishii-Iwamoto, 2000. Effect of four monoterpenes on germination, primary root growth, and mitochondrial respiration of maize. J. Chemical Ecology. 26: 611-624.
2. Adigun, J., A.O. Osipitan, S.T. Lagoke, R.O. Adeyemi, and S.O. Afolami, 2014. Growth and yield performance of cowpea (*Vigna unguiculata* L. Walp) as influenced by row-spacing and period of weed interference in South-West, Nigeria.
3. Africa-rising, 2016. https://africa-rising.net/2016/01/11/quality-cowpea-seeds/ Downloaded on 3rd January, 2019.
4. Agriculture and Food, 2017. Department Of Primary Industries and Regional Development. Government of Western Australia.
5. Ambika, S.R., S. Poornima, R. Palaniraj, S.C. Sati, S.S. Narwal, 2003. Allelopathic plants. JnanaBharathi Campus, Bangalore University, India.
6. Anderson, W.P., 1999. Perennial weeds: Characteristics and identification of selected herbaceous species. Iowa State University Press, Ames, IA. 228 pp.
7. Appleby, A.P., 2005. A History of Weed Control in the United States and Canada - A Sequel. Weed Science, 53: 762-768.
8. Article by country, 2018. https://latitude.to/articles-by-country/zm/zambia/289872/pemba-zambia. Downloaded on 29th December, 2018.
9. Asiwe, J. A. N. and R. F. Kutu, 2007. Effect of plant spacing on yield, weeds, insect infestation and leaf blight of bambara groundnut. Proceedings of African Crop Science Society, 4: 1947-1950.
10. Baars, J., 2003. Geographic range, impact, and parasitism of lepidopteran species associated with the invasive weed *Lantana camara* in South Africa. Biological Control. 28: 293-301.
11. Bhadoria, B.P.S., 2010. Allelopathy: A Natural Way towards Weed Management, Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur, 302 - 721.
12. Brogger, W., 2012. The efficacy of lantana (*Lantana camara*) flowers and leaves extract on cockroach. Ischoollgrominez.
13. Chaudhary, N., 2011. Lantana – A Menace or Friend? Science Reporter. 54-57.
14. Cowpeas facts and health benefits, 2018. https://www.healthbenefitstimes.com/cowpeas/. Downloaded on 23rd May, 2018.
15. Distancesto.com., 2019. https://www.distancesto.com.history. Downloaded on 2nd February, 2019.
16. Duke, S.O., F.E. Dayan, J.G. Romagni, A.M. Rimando, 2000. Natural products as sources of herbicides: current status and future trends. Weed Research, 40: 099-111.

17. El- Kenany, E.T. and S. M. El- Darier, 2013. Suppresion effects of *Lantana camara* L. Aqueous extracts on germination efficiency of Phalaris minor Retz. and Sorghum bicolor L. (Moench).Alexandria University, Egypt.
18. Food and Agriculture Organization (FAO), 2014. http://www.fao.org. Downloaded on 3rd May, 2018.
19. Flora of Zambia, 2018. https://www.zambiaflora.com. Downloaded on 17th May 2018.
20. Forage Information Systems, 2017. National Forage and Glasslands Curriculum, Department of Crop and Soil Science. Oregon State University.
21. Farooq, M., K. Jabran, H. Rehman and M. Hussain, 2008. Allelopathic effects of rice on seedling development in wheat, oat, barley, and berseem. Allelopathy Journal, 22: 385-390.
22. Freitas, F.C.L., V.F.L.P. Medeiros, L.C. Grangeiro, M.G.O. Silva, P.G.M.L. Nascimento, G. H. Nunes, 2009. Wed interference in cowpea .Indian Journal of weed science, 27(2): 241-247.
23. Galindo, J.C., C,A. Hernandez, F.E. Dayan, M.R. Tellez, F.A. Macias, R.N. Paul, 1999. Dehydrozaluzanin C, a natural sesquiterpenolide, causes rapid plasma membrane leakage. Phytochemistry, 52: 805-813.
24. Gantayet, P.K., S.P. Adhikary, K.C. Lenka and B. Padhy, 2014. Allelopathic Impact of *Lantana Camara* on Vegetative Growth and Yield Components of Green Gram (*Phaseolus radiatus*), Odisha, India.
25. Getachew, M., J.J. Sharma, N. Lisane work, and T. Tamado, 2015. Effect of integrated weed management practices on weeds infestation, yield components and yield of cowpea [*Vigna unguiculata* L. Walp.] in eastern Wollo, northern Ethiopia.
26. Ghisalberti E.L. 2000. Lantana camara Linn. (Review). Fitoterapia, 71: 467-485.
27. Global Invasive Species Database, 2019. Species profile: *Lantana camara*. http://www.iucngisd.org/gisd/species.php? sc. Downloaded on 16th May, 2019.
28. Gopie-shkhanna, V. and K. Kannabiran, 2007. Larvicidal effect of Hemidesmusindicus, Gymnemasylvestre, and Eclipta prostrate against Culexquinquifaciatus mosquito larva. Biotechnol, 6: 307-311.
29. Gupta, K.C., A.K. Gupta, and S. Rani, 2016. Weed management in cowpea [*Vigna unguiculata* L. Wasp] under rainfed conditions. International Journal of Agricultural Sciences, 12(2): 238-240.
30. Haidar, M.A., M.M. Sidahmed, R. Darwish, and A. Lafta, 2005. Selective control of Orobancheramosa in potato with rimsulfuron and sub-lethal doses of glyphosate. Crop Protection, 24: 747 743.
31. Harris, P., 2009. Biological Control of Weeds, https://www.tandfonline.com/author/Harris%2C+P Downloaded on 3rd January, 2019.
32. Hossain, M.K. and N.M.D. Alam, 2010. Allelopathic effects of *Lantana camara* leaf extract on germination and growth behavior of some agricultural and forest crops in Bangladesh. Pakistan Journal of Weed Science, 16(2): 217-226.

33. Huffaker, C.B. and P.S. Messenger, 2012. Theory and practice of biological control. Academic Press.
34. Jabran, K. 2017. Manipulation of Allelopathic Crops for Weed Control. Springer Briefs in Plant Science, Springer International Publishing AG, Switzerland.
35. Jabran, K. and B. Chauhan (Ed.), 2018. Non chemical weed control. Academic Press.
36. Jabran, K., G. Mahajan, V. Sardana, and B.S. Chauhan, 2015. Allelopathy for weed control in agricultural systems. Crop Protection, 72: 57-65.
37. Kannan, R., N.A. Aravind, G. Joseph, K.N. Ganeshaiah and R.U. Shanker, 2008. Lantana Craft: A Weed for a Need. Biotech News. 3(2): 9-11.
38. Keton, J. A. and A. J. Price, 2016. Weed Science and Management, Auburn University, USA.
39. Khalid, I. I., S. B. Elhardallov, and E. A. Elkhalifa, 2012. Composition and functional properties of cowpea (*Vigna unguiculata* L. Walp) flour and protein isolates. American Journal of Food Technology 7: 113-122.
40. Khalid, S., T. Ahmad, A. R. Shad, 2002. Use of Allelopathy in Agriculture. Asia.
41. Kong, C.H., P. Wang, C.X. Zhang, M.X. Zhang and HUF 2006. Herbicidal potential of allelochemicals from *Lantana camara* against *Eichhornia crassipes* and the alga *Microcystis aeruginosa*. Weed Research, 46(4): 290-295.
42. Kumarasamyraja D, N.S. Jeganathan, R. Manavalan 2012. Pharmacological Review of Lantana camaraL. International Journal of Pharmacy and Industrial Research, 2 (1): 1-5.
43. Langyintuo, A. S., J. Lowenberg-DeBoer, M. Faye, D. Lambert, G. Ibro, B. Moussa, and G. Ntoukam, 2003. Cowpea supply and demand in West and Central Africa. Field Crops Research, 82(2): 215-231.
44. Lakshmi, C. S. and C. C. Sekhar, 2018. Impact, Management and Uses of *Lantana camara* – A Noxious Weed. India.
45. Lehman, M.E., U. Blum, 1999. Evaluation of ferulic acid uptake as a measurement of allelochemical dose: Effective concentration Journal of Chemical Ecology, 25: 2585-2600.
46. Li, R., Z. Guidong, Z. Yumei and X. Zhanzhi, 2004. Damage loss and control technology of weeds in cowpea field. Weed Science, 2: 6-25.
47. Madukwe, D.K., H.C. Ogbuehi, and M.O. Onuh, 2012. Effect of weed control method on the growth and yield of cowpea (*Vigna unguiculata* L) Walp) under Rain- fed condition Owerri. American-Eurasian Journal of Agriculture and Environment Science, 12(11): 1426-1430.
48. Manning, R. 2004: Against the grain: How agriculture has hijacked civilization. North Point Press, New York. 232 pp.

49. Marinov-Serafimov, P. 2015. Determination of allelopathic effect of some invasive weed species on germination and initial development of grain legume crops. Pesticidi I Fitomedicina, 25(3): 251-259.
50. *Matsunaga, R., B.B. Singh, M. Adamou, S. Tobita, K. Hayashi, A. Kamidohzono, 2006.* Cowpea [*Vigna unguiculata*] cultivation on the Sahelian region of West Africa: Farmers' preferences and production constraints. *Japanese Journal of Tropical Agriculture*, ISSN 0021-5260.
51. Milberg, P. and E. Hallgren, 2004. Yield loss due to weeds in cereals and its large-scale variability in Sweden. Field Crops Research, 86(2): 199-209.
52. Mishra, A. 2012. Phytotoxic effect of L. *camara* leaf, stem and root aqueous extract on chlorophyll contents of Physterophorus in seedling stage. Flora and Fauna, 18(2): 138-143.
53. Mishra, A. 2015: Allelopathic properties of *Lantana camara*, International Research Journal of Basic and Clinical Studies, 3(1): 13-28.
54. Munir, A. 1996. A taxonomic review of *Lantana camara* L. and L. montevidensis (Spreng.) Briq. (Verbenaceae) in Australia. Journal of the Adelaide Botanic Gardens, 17: 1-27.
55. National Research Council, 2006. Lost crops of Africa. Volume II: Vegetables. Washington DC. The National Academic Press.
56. Naylor. R.E.L. (ed.), 2002. Weed management handbook. Blackwell Publishing.
57. Ngalamu, T., J. Odra, and N. Tongun, 2014. Cowpea production handbook. College of Natural Resources and Environmental Studies, University of Juba, Southern Sudan.
58. Oerke, E.C. 2006. Crop losses to pests. Journal of Agricultural Science, 144: 31–43.
59. Osipitan, O.A., and J.A. Dille, 2017. Fitness Outcomes Related to Glyphosate Resistance in Kochia (Kochia scoparia): What Life History Stage to Examine? Frontiers in Plant Science, 8: 10-90.
60. Osipitan, O.A., J. A. Adigun, and R. O. Kolawole, 2016. Row spacing determines critical period of weed control in crop: Cowpea (*Vigna unguiculata* L) as a case study. Azarian Journal of Agriculture, 3(5): 90-96.
61. Patil, B.C., L.A. Padanad, K. H. Yashvantkumar, S. Soumya, and L. Ravi, 2014. Efficacy and economics of integrated weed management in vegetable cowpea [*Vigna unguiculata* L. Walp]. Agriculture Update, 9(1): 124-127.
62. PennState Extension, 2017. College of Agricultural Sciences, Pennsylvania State University.
63. Prabhu, G., R. Srinivasan, S.R. Kantwa, D.R. Palsaniya, and M. Chaudhary, 2015. Weed seed bank studies in the field of Fodder Cowpea [*Vigna unguiculata* L.]. International Journal of Applied and Pure Science and Agriculture, 1: 83-87.
64. Qasem, J.R., 2006. Response of onion (*Allium cepa* L.) plants to fertilizers, weed competition duration and planting times in the central Jordan Valley. Weed Biology and Management 6: 212-220.

65. Russell, E. 2005. **Effect of *Lantana camara* on Plant Diversity in Zambia.** Train Fellow, Zambia.
66. Researchgate., 2018. Allelopathy for weed management in sustainable agriculture. https://www.researchgate.net/publication/270394246. Downloaded on 3rd January, 2019.
67. Sanders, R.W. 2012. Preliminary key to species of *Lantana* Sect. *camara*. Ecological Restoration, 1: 45–59
68. Sharma, G.P. 2007. Habitat fragmentation induced plant species invasion in Vindhyan highlands. Ph.D. Dissertation. Banaras Hindu University, Varanasi, India.
69. *Sheahan, C.M. 2012.* Plant guide for cowpea (*Vigna unguiculata* L.).*USDA-Natural Resources Conservation Service, Cape May Plant Materials Center, Cape May.*
70. Singh, H.P., D.R. Batishand and R. K. Kohli (Ed.), 2006. Handbook of sustainable weed management. Food Products Press. Haworth Press.
71. Singh, M.C. and C.V. Sairam, 2016. Effect of spacing and intercropping with cowpea on weed growth in banana. International Journal of Science, Environment and Technology, 5(2): 558-563.
72. Sunday, O. Udensi, U.E. 2013. Evaluation of pre-emergence herbicides for weed control in cowpea (*Vigna unguiculata* L.) American Journal of Experimental Agriculture, 3(4): 767-779.
73. Sutherland, S. 2004. What Makes a Weed a Weed: Life History Traits of Native and Exotic Plants in the USA. Oecologia, 141: 24-39.
74. Tabaglio, V., C. Gavazzi, M. Shultz, and A. Maracco, 2008. Alternative weed control using the allelopathic effect of natural benzoxazinoids from rye mulch. Agronomy of sustainable and development, 28: 397-401.
75. Taramani, Y., K. Nisha, N.K. Chopra, M.R. Chopra, R. Yadav, D.K. Kumar, P.G. Rathore, G. Soni, A. Makarana, M. Tamta, H. Kushwah, R.K. Ram, Meena and M. Singh, 2017. Weed Management in Cowpea-A Review,1ICAR- National Dairy Research Institute, India, 2: 001-132
76. Taylor and Francis group. https://www.tandfonline.com/author/Harris%2C+P. Downloaded on 3rd Jan. 2019.
77. Tesio, F. and A. Ferrero, 2010. Allelopathy, a chance for sustainable weed management. International Journal of sustainable development. World ecology, 17: 377-389.
78. Tripathi, S.S. and G. Singh, 2001. Critical period of weed competition in summer cowpea (*Vigna unguiculata* L.) Indian Journal of weed science, 33: 8-67.
79. Ugbe, L.A., N.U. Ndaeyo and J. F. Enyong, 2016. Efficacy of Selected Herbicides on Weed Control, Cowpea (*Vigna unguiculata* L. Walp) Performance and Economic Returns in Akamkpa, South-eastern Nigeria. International Journal, 19: 19-27.
80. University of Zambia, 2017/2018. School of Agricultural Sciences weather Station, Soil Science Department, Lusaka, Zambia.
81. Van Driesche, R.L., M. Hoodle and T. Centre, 2008. Control of pests and weeds by natural enemies; An introduction to biological control. Blackwell Publishing.

82. Vernon, R. 1987. Field to Important Arable Weeds of Zambia. Mount makulu central Research Station. Department of Agriculture, Chilanga, Zambia.
83. Wafaa, M.A.E., M.M.A. Youssef1 and G.E. Kowthar, 2016. Department of Plant Pathology, Nematology Lab., National Research Centre, Dokki, Cairo, Egypt.
84. Wahab, A. 2004. Studies on the chemical constituents of *Lantana camara* L. Thesis University of Karachi, Pakistan.
85. Walters, C. 1999. Weed control without poisons. Acres USA.
86. Ward, S.M., J.F. Gaskin, and L.M. Wilson 2008. Ecological Genetics of Plant Invasion: What do We Know? Invasive Plant Science and Management, 1: 98-109.
87. Weed Management Guide, 2013. Weeds of National Significance, Weed Management and the Commonwealth Department of the Environment and Heritage, CRC for Australian.
88. Yi, Z., M. Zhang, B. Ling, D. Xu and J. Ye, 2005. Inhibitory effects of *Lantana camara* and its contained phenolic compounds in Eichhorniacrassipes growth. Journal of applied ecology, 17: 1637-1640.
89. Zambia daily mail, 2018. http://www.daily-mail.co.zm/farmers-should-consider-crop-diversification/ Downloaded on 3rd January, 2019.
90. Zhung, M, B. Ling, C. Kong, G. Liang, Y. Dong, 2005. Allelopathic effect of Lantana (*Lantana camera* L) on Water hyacinth (Eichorneacrasspes. solum). Allelopathy Journal, 15: 125-130.
91. Zimdahl, R. L. 1993. Fundamentals of weed science. Academic Press.
92. Zimdahl, R. L. 2006. Fundamentals of Weed Science.Department of Bioagricultural Sciences and Pest Management. Colorado State University, Colorado, USA. 19pp.

APPENDICES

Appendix 1: weather condition for the UNZA Field Station (2017-2018)

Month	Air temp. (avg)	Precip. (total)	Humidity (avg)	Barom. Press. (avg)	Solar Irradiance (avg)
	[°C]	[mm]	[%]	[hPa]	[W/m^2]
November, 2017	22.62	25.93	2.23	69.98	281.10
December, 2017	22.4	25.91	4.64	79.67	230.20
January, 2018	22.88	26.28	0.88	69.87	268.40
February, 2018	21.33	25.02	12.88	89.85	189.10
March, 2018	21.59	25	4.63	86.42	218.10
April, 2018	20.49	23.4	0.27	78.3	221.70
May, 2018	19.52	21.71	1.04	73.24	210.80

Source: *University of Zambia, School of Agriculture Field Station, 2017-2018 Growing Season.*

Appendix 2: Soil Analysis

Horizon	**Composite**	**Ap**	**Bt1**	**Bt2**	**Bt3**
Depth (cm)		0 – 20	20 – 45	45 -80	80 -120+
Clay (%)		26.4	42.4	40.4	44.4
Silt(%)		31.6	33.6	31.6	33.6
Total sand (%)		42.0	24	28.0	22.0
Texture class		L	C	C	C
pH $CaCl_2$		7.29	6.81	7.14	7.31
O.M. (%)		1.24	0.64	0.48	0.44
P (ppm)		15.09	2.38	2.52	1.68
K (me%)		0.14	0.17	0.18	0.16
Na (me %)		0.03	0.04	0.03	0.04
Ca (me %)		5.21	4.51	3.79	4.45
Mg (me %)		0.77	0.91	0.90	1.22
Cu (ppm)		1.01	0.12	1.22	1.23
Zn (ppm)		0.57	0.54	0.34	0.15
Fe (ppm)		3.38	2.38	2.05	1.56
Mn (ppm)		4.64	5.59	3.5	2.70
CEC (me/100g)		6.00	7.73	7.47	8.80

Source: *University of Zambia Agricultural Sciences Field Station, 2018.*

Appendix 3: A Layout for A Split-split plot Design

G – Genotype of *Lantana camara* (G_1, G_2)

R – Rate of Application of *Lantana camara* in Kilograms (R0, R0C, R_1, R_2, R_3)

T – Type of application of *Lantana camara* (T0, T0C, T_1, T_2, T_3)

50 cm

G1 R1 T2		G1 R1 T1		R0T		G1 R1 T3		R0 TC	**1m**	G2 R1 T2		G2 R1 T1		R0 TC		R0T		G2 R1 T3

50cm

G1 R2 T1		R0 TC		R0T		G1 R2 T2		G1 R2 T3	**1m**	G2 R2 T2		R0T		G2 R2 T1		R0 TC		G2 R2 T3

G1 R3 T2		G1 R3 T3		G1 R3 T1		R0 TC		R0T	**1m**	G2 R3 T2		G2 R3 T1		G2 R3 T3		R0 TC		ROT

Rep 1

G1: Lantana camara with pink flowers, G2: Lantana camara with orange flowers, R1: Rate 1 (100 Kgha^{-1}), R2: Rate 2 (200 Kgha^{-1}), R3: Rate 3 (400Kgha^{-1}), R0TC: 0 rate of application with cowpea and R0T: 0 rate of application without cowpea. T1: Type of application 1 (Broadcasting), T2: Type of application 2 (Incorporation with the soil), T3: Type of application 3 (Spraying of soaked ground Lantana camara) and T0: Type of application 0 (No application in both controls).

1 m

G1 R1 T1		R0 TC		R0T		G1 R1 T3		G1 R1 T2	**1m**	G2 R1 T1		R0T		G2 R1 T3		R0 TC		G2 R1 T2

50 cm

G1 R2 T2		G1 R2 T1		R0T		G1 R2 T3		R0 TC	**1m**	R0T		G2 R2 T1		R0 TC		G2 R2 T2		G2 R2 T3

50cm

G1 R2 T1		R0 TC		G1 R3 T2		G1 R3 T3		R0T	**1m**	G2 R3 T2		ROT		G2 R3 T3		R0 TC		G2 R3 T1

Rep **2**

G1:

Lantana camara with pink flowers, G2: Lantana camara with orange flowers, R1: Rate 1 (100 Kgha^{-1}), R2: Rate 2 (200 Kgha^{-1}), R3: Rate 3 (400Kgha^{-1}), R0TC: 0 rate of application with cowpea and R0T: 0 rate of application without cowpea. T1: Type of application 1 (Broadcasting), T2: Type of application 2 (Incorporation with the soil), T3: Type of application 3 (Spraying of soaked ground Lantana camara) and T0: Type of application 0 (No application in both controls).

1m

PG R2 T1		G1 R2 T2		G1 R2 T3		R0 TC		R0T	**1m**	G2 R2 T2		G2 R2 T3		G2 R2 T1		R0 TC		R0T

50cm

G1 R1 T2		G1 R1 T1		R0 T		G1 R1 T3		R0 TC	**1m**	G2 R1 T2		G2 R1 T1		R0 TC		R0 T		G2 R1 T3

50 cm

Rep	G1		G1		G1		R0		R0T	**1m**	G2		G2		R0		G2		ROT	**3**
G1:	R3		R3		R3		TC				R3		R3		TC		R3			
	T2		T1		T3						T2		T1				T3			

Lantana camara with pink flowers, G2: Lantana camara with orange flowers, R1: Rate 1 (100 Kgha^{-1}), R2: Rate 2 (200 Kgha^{-1}), R3: Rate 3 (400Kgha^{-1}), R0TC: 0 rate of application with cowpea and R0T: 0 rate of application without cowpea. T1: Type of application 1 (Broadcasting), T2: Type of application 2 (Incorporation with the soil), T3: Type of application 3 (Spraying of soaked ground Lantana camara) and T0: Type of application 0 (No application in both controls).