EFFICACY OF BIOFUMIGATION USING AFRICAN SPIDER PLANT (*Cleome gynandra*) ON WEED CONTROL, GROWTH AND AESTHETIC QUALITY OF PASPALUM TURFGRASS (*Paspalum notatum*) DURING LAWN ESTABLISHMENT

Grace Odero Chongori

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Egerton University

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted before in any institution for any other award.

Signature …… Date...……..……..

Grace O. Chongori

KM14/3306/12

RECOMMENDATION

This thesis has been submitted with our approval as University supervisors.

Signature …… Date……

Dr. Samuel Nyalala, Ph.D.

Department of Crops, Horticulture and Soils,

Egerton University, Njoro

Signature …….. Date.……..…….

Dr. Mariam Mwangi, Ph. D.

Department of Crops, Horticulture and Soils,

Egerton University, Njoro

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DEDICATION

I dedicate this work to everyone that supported and encouraged me during this study; and to those in search of environmentally friendly options in gardening.

ACKNOWLEGEMENT

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ABSTRACT

Weeds interfere with turfgrass growth lowering functional and aesthetic quality of lawns. Conventional weed control using synthetic pesticides is hazardous to lawn users and to the environment while cultivation alone is not sufficient. A study was conducted with the aim of exploring the potential of biofumigation with African spider plant (*Cleome gynandra*) as an environmentally friendly alternative to use of synthetic herbicides for establishment of weed-free *Paspalum notatum* turfgrass. Chopped *Cleome gynandra* incorporated into the soil at 4, 6 or 8 kg m^{-2} was compared with Basamid® (97% Dazomet) at 0.029 kg m^{-2} (positive control) and untreated (negative control) in a randomized complete block design experiment with four replications. Population of various weed species in the experimental plots was recorded weekly. Total fresh and dry weight of the weeds was also determined after weeding the plots. Paspalum plug width and height were measured every 14 days and sprig internode length, leaf length, leaf width, fresh and dry weights were measured on monthly basis to determine treatment effect on the growth of the turfgrass. Treatment effect on aesthetic quality was visually determined monthly using a rating scale of 1 to 9 to evaluate uniformity, colour, density and overall quality. Rating was based on the differences observed, nine being the outstanding treatment and one the poorest. The data collected were subjected to analysis of variance. Biofumigation with *Cleome gynandra* at rates of 6 or 8 kg m^{-2} was as effective as Basamid® at 0.029 kg m^{-2} in significantly suppressing *Galinsoga parviflora*, *G. ciliata* and *Bidens pilosa* weed populations. Highest plug growth was obtained with *Cleome gynandra* at rates of 8 kg m^{-2} and Basamid® at 0.029 kg m^{-2} and untreated plots had the lowest plug growth. Biofumigation with *Cleome gynandra* at all the three rates: 4, 6 and 8 kg m^{-2} resulted in faster sprig growth than the negative control and although not significantly different from the positive control, numerically the growth rate was higher. Overall visual quality of paspalum turfgrass grown on plots treated with *Cleome gynandra* at 8 kg m^{-2} or 6 kg m^{-2} was as good as that of Basamid® 0.029 kg m^{-2}. Negative control displayed the lowest overall quality in both trials. These results suggest that biofumigation with *Cleome gynandra* is as effective as Basamid® in suppressing weeds during lawn establishment and enhancing growth and aesthetic quality of the turfgrass.

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LIST OF ACRONYMS

ANOVA- Analysis of Variance

BAC- Bukura Agricultural College

CAN- Calcium Ammonium Nitrate

DAP- Di-Ammonium Phosphate

EPA- Environmental Protection Agency

GSLs- Glucosinolates

ITCs- Isothiocyanates

LM1- Lower Mid-land one

MITC- Methyl isothiocyanate

MSM- Mustard Seed Meal

NDSU- North Dakota State University

NICHE- Netherlands Initiative for Capacity development in Higher Education

NPIC- National Pesticide Information Center

NTEP- National Turfgrass Evaluation Program

RCBD- Randomized Complete Block Design

SAS- Statistical Analysis System

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

A lawn is an area of land planted with turfgrass, a product of intensive husbandry and management resulting in a pleasant green carpet of spreading turf (Mogeni, 2012). Lawns have become integral parts of most landscapes that are professionally established and maintained to provide functional, recreational, aesthetic and therapeutic benefits to users. Their roles include: provision of play areas and outdoor recreation for golfers; protection of soil from erosion and water resources from pollution; replenishing oxygen supply in the air; cooling of the environment; reduction of noise pollution; increasing value of homes or business premises; provision of economic opportunities for seed and sod producers, lawn care operators and landscapers. These factors contribute to improved quality of urban and suburban life (Stier, 2000; Ontario Ministry of Agriculture, Food and Rural Affairs, 2008; Xu *et al*., 2011).

Lawns are major players in most eco-systems, and were estimated to cover 20 million hectares in America in 2003 (American-lawns.com, 2013). Though not documented, there are reasonable hectares already under lawn in Kenya and more are being established around homesteads, institutional grounds and recreational sites. Studies have shown that aesthetically pleasing landscapes including turfgrass contribute up to 15% of a home property value (Brown University, 2010). Landscapers and property owners therefore endeavor to construct lawns of high aesthetic quality. However, the quality of a new lawn is directly related to the success of establishment as a well-established lawn is easier to maintain (Landschoot, 2013). *Paspalum notatum* is a warm climate turfgrass desirable for sod production and makes good low-maintenance lawns (Newman *et al*., 2011; Trenholm *et al*., 2011) resistant to disease and insect pest infestations, with low to moderate fertility requirement, and tolerant to drought and close grazing by animals (Hancock *et al*., 2013). *Paspalum notatum* can also be used for phytoremediation of phosphorus-impacted soils and integrated pest management of nematodes and fungal diseases when used in rotation with annual crops (Newman *et al*., 2011). *P. notatum* is an effective aluminium hyper accumulator hence a potential aluminium hyper remover that has been widely utilized for ecological restoration of degraded land in the tropics and subtropics

where soil active aluminium is usually high as a result of acidification (Huang *et al*., 2009). However in managed turfgrass of different species, *P. notatum* can be a troublesome weed species that may affect appearance, texture and playability in home lawns, golf courses and athletic fields (Henry *et al*., 2009)

Weeds are a common problem in lawns, as the unwelcomed plants interfere with turfgrass establishment and uniformity. Initial removal from the site before establishing lawn is necessary in order to avoid persistent weed problems later (Turf and landscape digest, 2004; Landschoot, 2013). Weed management strategies for landscape and turf settings include: chemical control; cultural practices (cultivar choice, mowing of turfgrass, cultivation, mulching and solarization); biological control; and use of organic products and weed suppressive plant materials (Bertin and Weston, 2004). Some of these methods are applicable to an already established lawn only.

During site preparation, weeds are mainly controlled by cultivation and use of pesticides. Though chemical control of weeds has become an important aspect of managing golf courses, home lawns and sod production; pesticides contribute to environmental contamination and are hazardous to human health (Cole *et. al*., 2011; Grey and McCullough, 2012). Alternatives to chemical control include biofumigation and biosolarization (Bello *et. al*., 2007). Soil solarization is time and temperature dependent (Robins and Blackbum, 1997) and its effect is greatest close to the soil surface and decrease at deeper soil depth (Stapleton *et al*., 2000). Addition of organic matter like animal manures and crop residues increases efficacy of solarization in controlling weeds and soil-borne pathogens (Pokharel, 2011).

Biofumigation involves incorporation of fresh plant mass into the soil to release substances that are able to suppress soil-borne pests (Food and Agriculture Organization, 2013), among them are isothiocyanates (ITCs) (Kirkegaard and Sarwar, 1998). Brassicas produce glucosinolates (GSLs) which break down to form isothiocyanates (ITCs) in soil, hence are considered good materials for biofumigation (Roddy and Appleby, 2012). According to University of Idaho (2013), at low concentrations ITCs are beneficial to human health and at high concentrations they are general biocides that act like some commercial pesticides such as Vapam (metham sodium) and Basamid (dazomet). Incorporation of ITCs into the soil has been found to be effective in suppressing some weeds (Norsworthy and Meehan, 2005). Glucosinolate

containing plant tissues may therefore contribute to reduction in use of synthetic pesticide if weed seeds are targeted (Brown and Morra, 1996). The incorporation of glucosinolate-containing plant materials into the soil results in degradation products highly toxic to soil borne pests, pathogens and weeds; this biofumigation practice may be considered as an ecological alternative to the soil toxic fumigants (D'Addabbo *et al*., 2014)

Spider plant (*Cleome gynandra*) is a common indigenous vegetable and medicinal plant belonging to the order brassicales as brassicas (Apardh *et al*., 2012). Homogenized leaves of spider plant have also been found to emit significant quantities of biologically active ITCs (Nyalala *et al*., 2013). However, the biofumigation potential of this plant has not been studied. This study therefore evaluated the biofumigation potential of this plant on control of weeds in lawn establishment and its influence on turfgrass growth and lawn quality.

1.2 Statement of the Problem

Weeds are a menace in most lawns especially where property owners cannot afford high-cost maintenance programs. Weed seeds lie dormant but viable for long periods in the soil hence germinate and grow during favorable weather conditions posing a real challenge to lawn growers. Weeds compete with turfgrass for moisture, nutrients and light affecting the crop growth and development hence lowering the functionality and aesthetic quality of lawn. Weeds may outdo the turfgrass killing it if not controlled. Cultivation and pesticides are the commonly used weed control methods during lawn establishment as cultivation alone is insufficient. Use of synthetic pesticides, however, contributes to environmental contamination and poses a risk to humans, animals and even the lawn itself due to chemical toxicities. This scenario leaves lawn growers with limited options for safe control hence need for development of alternative strategies for weed management in lawns that are safe and effective.

1.3 Objectives of the Study

1.3.1 General Objective

The broad objective of the study was to contribute to establishment of weed-free lawns with enhanced turfgrass growth and aesthetic quality through development of environmentally friendly alternative to synthetic pesticides.

1.3.2 Specific Objectives

Specific objectives were to determine:-

1. The efficacy of biofumigation using spider plant (*Cleome gynandra*) on weed control in lawn establishment.
2. The effect of biofumigation using *C. gynandra* on growth of turfgrass.
3. The effect of biofumigation using *C. gynandra* on aesthetic quality of lawn grass.

1.4 Hypotheses

1. Biofumigation using *C. gynandra* has no effect on weed control in lawn establishment.
2. Biofumigation using *C. gynandra* has no effect on growth of turfgrass.
3. Biofumigation using *C. gynandra* has no effect on aesthetic quality of lawn grass.

1.5 Justification of the Study

Lawns are important facilities in human habitats offering utility for various functions in homes and public areas. Weeds interfere with turfgrass establishment and uniformity lowering functional and aesthetic quality of lawn. Killing weed seeds or suppressing their germination is necessary before establishing new lawn to prevent weeds from gaining a foothold. This gives turfgrass a competitive advantage hence smothering the weeds and making long term weed management easier and cheaper. There is need to explore weed control methods that are environmentally friendly and safe for lawn users and animals. Glucosinolates in plant tissues break down into isothiocyanates in the soil in a similar manner as commercial fumigants like Vapam (metham sodium) and Basamid (dazomet), which act by liberating methyl isothiocyanate (MITC), the primary biologically active ingredient in the soil. Plant tissues containing glucosinolates may therefore contribute to reduction in synthetic herbicide use in lawns. Unlike glucosinolate-containing brassicas which are mainly cool climate crops, spider plant is an indigenous species adapted to a wider altitude range and ecological zones. In addition, successful biofumigation with spider plant may be adopted for management of soil borne insect pests, nematodes and pathogens. Use of spider plant as a biofumigant will also increase the plant's economic value; provide a sustainable, affordable and environmentally friendly option of establishing weed free lawns with improved aesthetic appearance hence high property value.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Lawn Establishment

Lawns are typically viewed as a cultural product created by choice (Robins, 2007); important parts of landscapes that provide a sense of open space (Stack, 2011) and facilitate the needs of home owners. According to the Pennsylvania turfgrass survey, 0.8 million hectares of turfgrass are maintained in the commonwealth and approximately 1.4 billion dollars spent annually on turfgrass establishment and maintenance (Penn State University College, 2013).

Lawns are mainly established from seed or vegetative propagation. Vegetative propagation includes sodding, plugging and sprigging or stolonizing (University of Carolina, 2009; Mississippi State University, 2011; Trenholm, 2012). Material used for propagation depends on the grass species desired, site to be planted, time constraints and financial considerations (Mugaas and Pedersen, 2009; Relf, 2009). Establishment method and species planted to a great extent determine the lawn quality and ease of maintenance (Powell, 2000). Sprigging is the cheapest vegetative planting method and sodding the easiest but the most expensive because it requires more turfgrass per planting area (Cook, 2002; Mississippi State University, 2011; Trenholm, 2012). Plugs are small, circular or block shaped pieces of sod planted in holes at regular intervals and are less susceptible to desiccation than sprigs (Cameroon, 2006; Trenholm, 2012). Plugs are planted at 15-30cm apart depending on the grass species and how soon a 100% ground cover is desired (Maryland Cooperative Extension, 2005).

Paspalum (*Paspalum notatum*) is a warm climate turfgrass that can be established from seed or vegetative propagation. Though less expensive, establishment from seed takes longer to form a uniform lawn (Trenholm *et al*., 2011). *Paspalum notatum* is desirable for sod production and can make good low-maintenance lawns (Newman *et al*., 2011). Other advantages of *P. notatum* include drought tolerance, low to moderate fertility requirement, resistance to disease and insect pest infestations, tolerance to close grazing by animals (Hancock *et al*., 2013), phytoremediation of phosphorus-impacted soils and integrated pest management of nematodes and fungal diseases when used in rotation with annual crops (Newman *et al*., 2011).

2.2 Weed Problem in Lawns

Weeds have been found to be the most common pest in turfgrass areas (Martin, 2012). They are opportunistic plants in lawns that are quick to germinate and grow in the absence of turfgrass competition. Weeds mar the lawn appearance if left uncontrolled (Chalmers and McAfee, 2009). They compete with the desired turfgrass for water, nutrients, light and space resulting in lawn deterioration. If allowed to dominate, weeds outdo turfgrass necessitating total renovation of the lawn (Dernoeden, 2005). Weed invasion is a problem in especially the bare spaces between newly planted grasses (Cameroon, 2006).

Weed seed exist in almost all lawns and gardens and most of them may remain dormant for years, since they must reach the soil surface and receive sufficient light and moisture before they germinate (Lowe, 2013). Weeds interfere with the activities or welfare of man; they increase lawn protection cost and some affect human health by causing allergy reactions (Zimdahl, 2007). Turfgrass weeds can be grouped into one of three life cycles; annuals, biennials and perennials (Menalled, 2011; Landschoot, 2013) and their control is one of the biggest frustrations of keeping lawns (Burke, 2013).

2.3 Weed Control in Lawns

Weeds are detrimental and therefore must be controlled (Zimdahl, 2007). Weed control can be approached in two phases: prior to planting and as a component of post establishment program. Key to dealing with the weed problem is initial removal from the site before establishing the lawn, in order to avoid persistent weed problems later (Thurn *et al*., 1994; Turf and landscape digest, 2004; Landschoot, 2013). Prevention is the best weed control strategy when establishing new lawn; weeds should be prevented from getting a foothold (Thurn *et al*., 1994). It is important to use weed free soil during lawn construction or renovation to minimize weed invasion during establishment (Unruh *et al*., 2010) and to plant grass species tolerant to the region's growing conditions. Most weeds have little chance to establish if thick grass blocks sunlight, captures moisture and takes advantage of available nutrients. Good fertilization program can help grow a dense, vigorous and competitive lawn (Menalled, 2011). Plants compete for space and the first plant that occupies an area tends to exclude all the others and have a competitive advantage (Zimdahl, 2007). A healthy dense lawn will therefore help reduce

weed invasion (Hulett, 2004). Sufficient time for removing weeds prior to lawn establishment is necessary (Smith and Dale, 2009).

Methods used to control weeds in lawn include; chemical control, cultural practices (cultivar choice, mowing of turfgrass, cultivation, hand-pulling, fertilizer application, mulching, fire or flame and solarization), biological control (by natural enemies of the weeds) and other alternative strategies such as use of organic products and weed suppressive plant materials (Bertin and Weston, 2004). The best time to attack weeds is before they mature and form seeds. Effective control method should kill the weed seeds before they germinate or the plants when they are still young, tender and actively growing (Lowe, 2013).

During site preparation, weeds are mainly controlled by cultivation and use of chemicals (herbicides or fumigants). Three commonly used fumigants are Vapam (metham sodium), Basamid (dazomet) and Methyl bromide. In soil, the active ingredients in Vapam and Basamid are converted to Methyl isothiocyanate (MITC), which is biologically active and highly toxic (Neal and Waren, 2013). Methyl bromide was deregistered in developed countries due to environmental concerns (Earlywine *et al*., 2010) and was set for complete phase-out in developing countries by the year 2015. On the other hand, sulfonylurea herbicides used in turfgrass (Chlorosulfuron, flazasulfuron, formsulfuron, halosulfuron, metasulfuron, sulfometuron, sulfosulfuron and trifloxysulfuron) are weak acids with residual activity and variable persistence; some tend to persist for longer periods with half-lives extending into years rather than days (Grey and MacCullough, 2012). Though with no soil residual effect (Chalmers and McAfee, 2009; Smith, 2012), glyphosate classified as a group E chemical by the Environmental Protection Agency (EPA) and being the most widely used herbicide around the world has been found to contain an "inert" ingredient that can suffocate human cells even at concentrations much more diluted than those used on farms and lawns (Gammon, 2009; National Pesticide Information Center, 2013). Use of synthetic herbicides is proving more dangerous than previously understood, although it is still popular (Burke, 2013). Weeds have also been known to develop resistance to herbicides even to glyphosate (Heap, 2014) especially with the advent of transgene technology which has been reported to generate herbicide-resistant weeds (Duke *et al*., 2015). Therefore there is need for safe and effective weed control alternatives applicable in integrated weed management approaches.

2.4 Biofumigation for Control of Weeds

Soil solarization and biofumigation are among the most useful of the non-chemical disinfestation methods (Stapleton *et al*., 2000). Unlike other nonchemical controls such as cultivation and mowing, soil solarization and biofumigation can kill weeds with underground vegetative structures (Elmore *et al*., 1993). Soil solarization is time and temperature dependent (Robins and Blackbum, 1997) and its effect is greatest close to the soil surface and decreases at deeper soil depth (Stapleton *et al*., 2000). Addition of organic matter like animal manures and crop residues increases efficacy of solarization in controlling weeds and soil-borne pathogens (Pokharel, 2011). Using solarization and chicken manure for control of *Orobanche crenata* and other weeds, Haidar and Sidahmed (2000) found solarization treatments alone to kill Orobanche seeds at depth 0 cm but with no significant effect on seeds below, while solarization with chicken manure killed Orobanche seeds at up to 10 cm depth.

Biofumigation is the practice of using chemicals released from decomposing plant material to suppress soil pathogens, insects and germinating weed seeds (Karavina and Mandumbu, 2012). Biofumigant effects are largely related to the high concentration of glucosinolates (GSLs) precursors to isothiocyanates (ITCs) which have broad biocidal activity (Johnstone *et al*., 2013). Isothiocyanates are sulfur containing compounds generated by the glucosinolate-myrosinase system in plants (Hara *et al*., 2009). Significant amounts of unhydrolysed GSLs and ITCs can be detected in soil for several days following incorporation of biofumigants such as *Brassica napus* and *B. juncea*. Their concentration in the soil is highest 30 minutes after incorporation of pulverized biofumigation crops and can still be detected for up to 8 and 12 days respectively (Gimsing and Kirkegaard, 2006). Soil biofumigation is effective for weed control (Bello *et al*., 2007). Biofumigation has to be tested and appropriate rates of application determined as at high rates it may result in phytotoxicity which may hamper crop growth rate (Baldi *et al*., 2015)

Evaluating herbicidal potential of ITCs released by turnip-rape mulch (*Brassica rapa-B. napus* L.), Petersen *et al*. (2001) identified six ITCs from the chopped turnip-rape which interact with weed seeds in soil solution and as vapour in soil pores. Susceptibility of different weed species to the ITCs mainly depended on the seed size, smaller seeds being more sensitive. The ITCs were strong suppressants of germination on the species tested (spiny sow thistle, scentless

mayweed, smooth pigweed, barnyard grass, black grass and wheat). Earlywine *et al*. (2010) found oriental mustard seed meal (MSM), a byproduct generated by pressing the seed for oil, to exhibit herbicidal properties; it suppresses emergence and growth of a number of weeds common in turfgrass.

Norsworthy and Meehan (2005) in a greenhouse experiment to evaluate the herbicidal activity of ITCs on *Panicum texanum*, *Digitaria sanguinalis* and *Senna obtusifolia*; found that soil applied and incorporated ITCs were effective in suppressing growth of these weeds. Application techniques that minimized loss of volatile ITCs enhanced their potential as effective means of control. They found that at low concentrations, ITCs stimulated weed emergence but at high concentrations, they suppressed germination resulting in weed density reduction ranging from 37% to 100%. This explains results obtained by Oloo *et al*. (2009) where emergence of some weeds was enhanced in plots treated with chopped *Brassica napus* and *B. juncea* each applied at 2, 3 and 4 kg m^{-2} respectively; which also showed potential of suppressing emergence of some weeds. In season one of these experiments, *B. juncea* treatment applied at 4 kg m^{-2} had significantly similar effect on emergence of grass weeds but more effective than both metham and dazomet treatments on malva weeds.

2.5 Potential of Spider Plant as a Biofumigant

Although brassicas are known to produce glucosinolates (GSLs) which break down to form isothiocyanates (ITCs) in the soil, GSLs are not confined to brassicas alone. Plant families with the most GSL- containing genera include brassicaceae, capparaceae and caricaceae although GSL concentration in cells of specific plants differ substantially (Kruger *et al*., 2013). Spider plant, *Cleome gynandra* belongs to the family cleomaceae in the order brassicales (Apardh *et al*., 2012). Cleomaceae family is sister to families brassicaceae and capparaceae based on recent phylogenetic studies (Volznesenskaya *et al*., 2007) and major cleomaceae members are closer to brassicaceae more than capparaceae. Cleome is the largest genus in the cleomaceae family with about 200 species of medicinal, ethno botanical and ecological importance (Apardh *et al*., 2012).

Cleome gynandra is indigenous to tropical and pan tropical regions with main secondary metabolites in it being alkaloids, cyanogenetic glycosides, steroidal nucleus and anthraquinones (Ajaiyeoba, 2000). Glucosinolates in spider plant include methylglucosinolate, cleomin and

glucocapparin which give rise to methyl isothiocyanates when hydrolyzed (Silué, 2009). Using gas chromatography-mass spectrometry to investigate volatile compounds emitted from homogenized leaves, Nyalala *et al*. (2013) found spider plant to contain significant levels of isothiocyanates (ITCs) that included methyl-isothiocyanates, proply-isothiocyanates, butly-isothiocyanates, and isobutyl-isothiocyanates. They also found it to contain a number of aldehydes, terpenes, alcohols, acetates and ketones. Spider plant, an indigenous species, is widely distributed all over Kenya from altitude of 0 m to 2,400 m above sea level and in ecological zones one to six (Maundu, 1999). Plant species used is one of the factors that affect efficacy of biofumigation because glucosinolates concentration in cells of different species differ substantially therefore the need to establish the efficacy of a glucosinolates rich species in suppressing soil-borne pests like weed seeds. (Ngouajio *et al*., 2014)

The biofumigation potential of *Cleome gynandra* had not been studied therefore this study evaluated its potential on control of weeds in lawn establishment and its influence on turfgrass growth and lawn quality.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The study was conducted at Bukura Agricultural College (BAC) in western Kenya which lies at longitude 0° 13' 15" North, latitude 34° 36' 44" East and altitude of 1389 m above sea level (GeoNames, 2015). The area has a daily mean temperature of about 22^{o}C and annual rainfall range of about 1700 to 1800mm distributed over two main cropping seasons; the long rainy season from March to July, and the short rainy season from September to December. The region is in the Lower Mid-land one agro-ecological zone (LM1), normally described as the sugar cane zone with soil classified as Orthic Ferralsol (Opala, *et al*., 2009; Suge, *et al*., 2011). The study comprised of field experiments carried out in two consecutive trials. The first from August 2013 to March 2014 during the short rainy season and the second March to October 2014 during the long rainy season.

3.2 Plant Material and Preparation

Planting materials used in the study were plugs of *Paspalum notatum* turfgrass which were obtained at Bukura Agricultural College (BAC) and spider plant seeds purchased from Kenya Seed Company, Kakamega. Spider plant was planted prior to the time of establishing the turfgrass. Planting of spider plant (*C. gynandra*) was done by direct seeding in rows spaced 30cm apart. At planting, P was applied at the rate of 40 kg ha^{-1} plus N at the rate of 18 kg ha^{-1}. Plants were thinned to intra row spacing of 20 cm three weeks after planting then topdressed with N at the rate of 52 kg ha^{-1}. At flowering stage, the plants for biofumigation were uprooted, chopped into small pieces (Plate. 1) of equal or less than three centimeters (≤ 3cm) and applied immediately to the specific plots.

Plate 1: Preparation of *Cleome gynandra* for biofumigation

3.3 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications and plot size of 4 m^2. Blocks were separated by 1 m wide buffer space and plots by 0.5 m (Figure 1). Five treatments were applied as follows: - Untreated (negative control); cultivation and incorporation of chopped spider plant (*C. gynandra*) at 4, 6 and 8 kg m^{-2} respectively; and cultivation plus application of Basamid® at 0.029 kg m^{-2} (positive control). Range of spider plant treatments was based on the study by Oloo *et al*. (2009) in which biofumigation with *Brassica napus* and *Brassica juncea* at rate of 4 kg m^{-2} suppressed germination of grass and malva weeds while rates of 2 kg $m^{-2}$and 3 kg m^{-2} enhanced their germination.

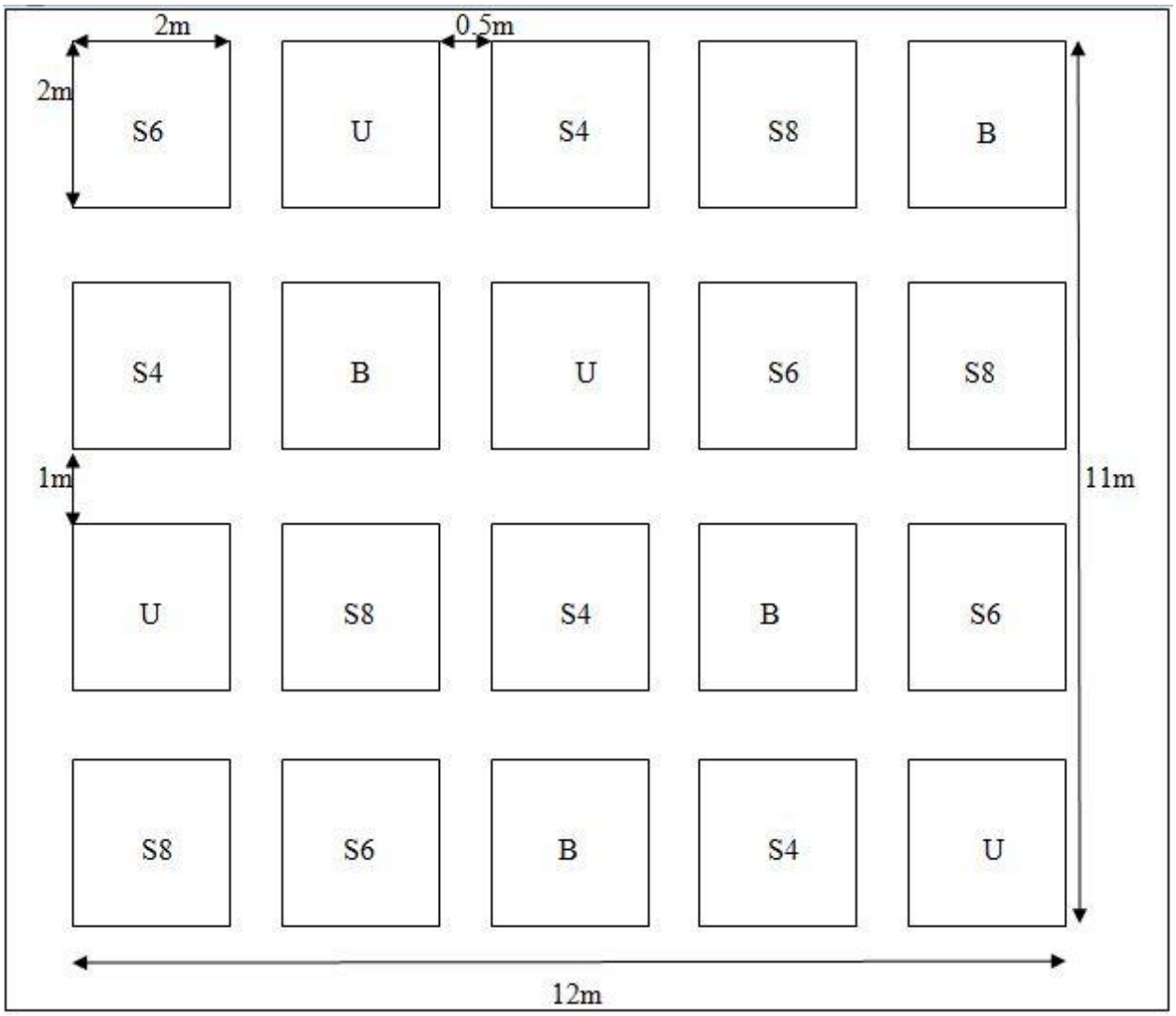


Figure 1: Experimental layout

Key

U- Untreated (negative control)

B- Cultivation plus application of Basamid® at 0.029 kg m^{-2} (positive control)

S4- Cultivation and incorporation of chopped spider plant (*C. gynandra*) at 4 kg m^{-2}

S6- Cultivation and incorporation of chopped spider plant (*C. gynandra*) at 6 kg m^{-2}

S8- Cultivation and incorporation of chopped spider plant (*C. gynandra*) at 8 kg m^{-2}

3.4 Treatments application

The chopped plant materials were incorporated into the soil up to 0.3 m depth and plots covered with 0.14 mm thick clear polyethylene sheet. At the same time, plots for treatment with Basamid® were also re-dug and fumigated at the rate of 0.029 kg m^{-2} and covered (Plate: 2). The edges of the polyethylene sheet were buried 0.15 m into the soil to ensure air tight conditions for four weeks. The untreated plots (negative control) were re-dug and left without incorporating *Cleome gynandra* or Basamid® application. After four weeks; the treated plots were uncovered and left to aerate for 14 days to clear effects of the isothiocyanates, as recommended for Basamid®, before the turfgrass was planted. Crops with compounds inhibitory to weed seeds may also be phytotoxic to crop seeds (Ngouajio *et al*., 2014). Isothiocyanates from biofumigants have been detected in the soil for up to 12 days. Therefore 14 days aeration period was applied for all the treatments after which all the plots were raked and leveled for establishment of *Paspalum notatum* turfgrass.

Plate 2: Application of treatments to the experimental plots

3.5 Establishment of turfgrass

Paspalum turfgrass was dug up, cut into circular plugs of 0.15 m diameter using a prefabricated cutter (Plate: 3) and planted in holes spaced at 0.3 m by 0.3 m ensuring the plugs were at ground level (Plate: 4) and watered immediately after planting. During planting, P was applied at the rate of 40 kg ha^{-1} plus N at the rate of 18 kg ha^{-1} and one month later topdressing was done with N at the rate of 52 kg ha^{-1}. The plots were maintained moderately moist until the turfgrass got well established. Four weeks after establishment of the turfgrass, all plots were weeded after collecting the samples that were used to obtain total fresh and dry weed weight.

Plate 3: Prefabricated plug cutter

Plate 4: Planting of the paspalum plugs in the experimental plots

3.6 Data Collection

Data collection was done on weed prevalence, turfgrass growth and aesthetic quality. A distance of 0.3 m from the plot margins served as guard row and data was collected from the remaining area at the centre of the plots. Days to first emergence of weeds were recorded and a 0.3 m x 0.3 m quadrate (Plate: 5) was used to randomly select areas to sample for weeds. The quadrate was randomly thrown onto plots and weeds within the quadrate counted; the weed number per species were recorded every 7 days and the total fresh and dry weight for all species present weighed together after four weeks to determine effectiveness of the treatments applied on weed suppression.

Plate 5: A 0.3 m x 0.3 m quadrate

To determine the effect of treatments applied on growth of the turfgrass, five paspalum plugs were randomly tagged in each plot and their width and height measured every 14 days. Ten sprigs were also randomly sampled from each plot on monthly basis and individually measured for internode length, leaf length and leaf width by use of a ruler. The fresh and dry weights of the ten sprigs were also measured. Fresh weight was measured when the sprigs were still fresh after being obtained and dry weight taken after sun drying them for four days six hours per day. Measurements for leaf length were taken in centimeters (cm) while internode length and leaf width in millimeters (mm). Internode length was taken on the first internode starting from the stem base. The leaf width was measured breadth wise in the middle widest portion of a healthy full leaf from the base of the sprig and the length was the distance between the leaf apex and the lamina base.

Visual appearance was rated on monthly basis using the National Turfgrass Evaluation Program (NTEP) of USA to assess the treatment effects on aesthetic quality of the lawn. Rating was carried out as per Morris and Shearman (2013) guidelines, on a 1 to 9 scale based on overall differences that were observed. Nine was the outstanding treatment and one the poorest. A rating of ≥ 6 was considered acceptable. Rating was by a panel of ten individuals, to ensure consistency

the panel constituted of the same persons throughout the study who were given written guidelines and score forms to fill in. Treatments applied to the various plots were not disclosed to them to avoid biasness. Factors rated were: uniformity, colour and density and overall quality determined by considering the ratings for the three; uniformity, color and density. Each of the ten panel individuals rated all the three attributes respectively from which they obtained respective individual overall rating which were averaged to rate the treatments.

Uniformity was the estimate of even appearance of the turf obtained by visually looking at the plots for bare areas, weeds and damaged or diseased turf. Rating of 9 was uniformly growing plants and absence of weeds and damaged or diseased turf; a rating of 1 was presence of weeds, damaged or diseased turf and bare patches. Colour was the visual observed colour with 9 being dark green and 1-light green. Density of plots was visually decided by observing the extent of compactness excluding dead patches with 9 being maximum density and 1 lowest. High shoot density was considered as a positive attribute for good growth as it lessens weed encroachment (Komma, 2003; Pease and Stier, 2010).

3.7 Data Analysis

The data collected was subjected to Analysis of Variance (ANOVA) at $P \leq 0.05$ and significantly different means separated using Tukey's honestly significant difference (Tukey's HSD) test at $P \leq 0.05$. SAS statistical package was used to analyze the data (SAS Institute, 2005). The RCBD experimental model below was used:

$Y_{ijk} = \mu + \beta_i + \alpha_j + \tau_k + \alpha\tau_{kj} + \varepsilon_{ijk}$

$i = 1, 2, 3, 4 \quad j = 1, 2, 3, 4, 5 \quad k = 1, 2$

Where: - Y_{ijk} = effectiveness of controlling weeds or turfgrass response

μ = overall mean

β_i = i^{th} blocking effect

α_j = effect of the j^{th} treatment

τ_k = effect of the k^{th} season

$\alpha\tau_{kj}$ = interaction effect of the j^{th} treatment and the k^{th} season

ε_{ijk} = random error component (assumed to be independently and normally distributed with mean 0 and common variance σ^2)

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of biofumigation with African spider plant (*Cleome gynandra*) on Weed Emergence

Different weed species emerged after turfgrass establishment; emergence took 14 days in all treatments during trial one and varying days during trial two. The untreated (negative control) took the least number of days (6.0) and was significantly different from all the treatments while biofumigation with *Cleome gynandra* at 8 kg m^{-2}, which was at par with Basamid® 0.029 kg m^{-2} (positive control) took the highest number of days (12.75) to weed emergence during trial two (Table 1). *Oxalis latifolia* species was the first weed species to emerge across the treatments during trial one.

Table 1: Effect of biofumigation with African spider plant (Cleome gynandra) on days to weed emergence after paspalum turfgrass establishment

Treatment	Time to weed emergence (Days)	
	Trial 1	Trial 2
Untreated	14	6.00c
Basamid® (0.029 kg m^{-2})	14	12.75a
Cleome gynandra (4 kg m^{-2})	14	8.00b
Cleome gynandra (6 kg m^{-2})	14	11.50a
Cleome gynandra (8 kg m^{-2})	14	12.75a

Means followed by the same letter in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD

4.2 Effects of biofumigation with African spider plant (*Cleome gynandra*) on Weed Populations

There were significant differences in prevalence of *Galinsoga parviflora*; *G. ciliata* and *Bidens pilosa* weed species among the treatments and no significant differences in prevalence of *Oxalis latifolia* during both trials. *Galinsoga parviflora* and *G. ciliata* grew on untreated plots (negative control) in higher numbers as compared to the treated plots. Biofumigation with *Cleome gynandra* at rates of 6 and 8 kg m^{-2} were respectively as effective as the Basamid® at 0.029 kg m^{-2} (positive control) in significantly suppressing *Galinsoga parviflora* and *G. ciliata* weed populations (Plate 6) during both trial one and two. Application of *Cleome gynandra* 4 kg m^{-2} had no significant effect on the same weed species but was significantly effective than the untreated (negative control) in suppressing *Bidens pilosa* (Plate 7).

Plate 6: Plots with low weed population

Plate 7: Plots with high weed population

4.2.1 Effect of biofumigation with African spider plant (*Cleome gynandra*) on gallant soldier (*Galinsoga parviflora*)

Mean number of *Galinsoga parviflora* weed species (Table 2) taken per 0.09 m^2 at 14, 21, 28 and 35 days after establishment of paspalum turfgrass was highest under the negative control on all the days and lowest under Basamid® 0.029 kg m^{-2} (positive control) which was not significantly different with *Cleome gynandra* 8 kg m^{-2} treatment on all the days during both trial one and two. In season one; there were no significant differences in the prevalence of *G. parviflora* between the negative control and *Cleome gynandra* 4 kg m^{-2} treatments at 14, 21 and 28 days after establishment of the paspalum turf grass but at 35 days the number was significantly higher under the negative control than under *C. gynandra* 4 kg m^{-2} although the mean number of the weed at 28 days under *C. gynandra* 4 kg m^{-2} was also not significantly different with that under *C. gynandra* 6 kg m^{-2} treatment. There was no significant difference in prevalence of *G. parviflora* under positive control, *C. gynandra* 6 kg m^{-2} and *C. gynandra* 8kg m^{-2} at 14, 21, 28 and 35 days, respectively, after paspalum turfgrass establishment. In trial two; mean numbers of *G. parviflora* were significantly high under negative control followed by *C. gynandra* 4kg m^{-2} at all 14, 21, 28 and 35 days respectively and lowest under *C. gynandra* 6 kg m^{-2}, *C. gynandra* 8 kg m^{-2} and Basamid® 0.029 kg m^{-2} (positive control) which had no significant

differences in the weed numbers at 14, 28 and 35 days respectively after establishment of paspalum turfgrass. At 21 days the weed numbers under *C. gynandra* 6 kg m^{-2} was significantly higher than under *C. gynandra* 8 kg m^{-2} and Basamid® 0.029 kg m^{-2} (positive control) which were not significantly different.

Table 2: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Galinsoga parviflora* weed species 0.09 m^{-2} 0n different days after Paspalum establishment

		Weed population 0.09 m^{-2}							
		Trial1				Trial 2			
Treatment	Day	14	21	28	35	14	21	28	35
Untreated		2.0a	6.8a	8.8a	18.3a	9.5a	18.3a	19.5a	19.5a
Basamid® (0.029 kg m^{-2})		0.0b	0.0b	0.3c	0.5c	0.0c	0.0d	0.0c	0.3c
C. *gynandra* (4 kg m^{-2})		0.8ab	5.8a	6.0ab	11.8b	5.8b	9.5b	12.8b	13.3b
C. *gynandra* (6 kg m^{-2})		0.0b	1.3b	3.5bc	5.3c	0.8c	2.3c	2.0c	2.3c
C. gynandra (8 kg m^{-2})		0.0b	1.8b	1.8c	3.8c	0.0c	0.5d	0.5c	0.5c

Means followed by the same letter in a column (day) within a trial are not significantly different at P≤ 0.05 according to Tukey's HSD

4.2.2 Effect of biofumigation with African spider plant (*Cleome gynandra*) on *Galinsoga ciliata*

Effect of biofumigation with *Cleome gynandra* on mean number of *Galinsoga ciliata* weed species (Table 3) had a similar trend as its effect on *G. parviflora*. Untreated (negative control) recorded the highest mean numbers of *G. ciliata* 0.09 m^{-2} at 14, 21, 28 and 35 days respectively after establishment of paspalum turfgrass, followed by *C. gynandra* 4 kg m^{-2} and lowest numbers under Basamid® 0.029 kg m^{-2} (positive control) which was not significantly

different from *C. gynandra* 8 kg m^{-2} and *C. gynandra* 6 kg m^{-2} treatments on all the days during both trial one and two.

Table 3: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Galinsoga ciliata* weed species 0.09 m^{-2} on different days after Paspalum establishment

		Weed population 0.09 m^{-2}							
		Trial 1				Trial 2			
Treatment	Day	14	21	28	35	14	21	28	35
Untreated		1.00a	5.50a	8.25a	17.00a	9.00a	18.50a	19.50a	19.00a
Basamid® (0.029 kg m^{-2})		0.00a	0.00b	0.00b	0.50c	0.00c	0.00d	0.00d	0.50c
C. *gynandra* (4 kg m^{-2})		0.25a	4.25a	7.25a	15.00a	5.50a	10.00b	12.00b	12.00b
C. *gynandra* (6 kg m^{-2})		0.00a	0.75b	1.50b	6.25b	1.00c	3.50c	2.75c	2.50c
C. gynandra (8 kg m^{-2})		0.00a	0.25b	1.75b	6.75b	0.00c	0.75d	0.50d	1.25c

Means followed by the same letter, in a column (day) within a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD

4.2.3 Effect of biofumigation with African spider plant (*Cleome gynandra*) on blackjack (*Bidens pilosa*)

Mean number of *Bidens pilosa* weed species taken per 0.09 m^2 at 14, 21, 28 and 35 days after establishment of paspalum turfgrass was highest under the untreated (negative control) throughout the season and lowest under Basamid® 0.029 kg m^{-2} (positive control) which was not significantly different from all the *Cleome gynandra* treatments 8, 6 and 4 kg m^{-2} during trial one. Similarly negative control in trial two had highest number of *Bidens pilosa* on all days and lowest under Basamid® 0.029 kg m^{-2} which was not significantly different with *C. gynandra*

treatment of 8 and 6 kg m^{-2} respectively on all days but *C. gynandra* 4 kg m^{-2} was significantly different from all the other treatments at 35 days after Paspalum establishment (Table 4).

Table 4: Effect of biofumigation with African spider plant (*Cleome gynandra*) on number of *Bidens pilosa* weed species 0.09 m^{-2} on different days after Paspalum establishment

		Weed population 0.09 m^{-2}							
		Trial 1				Trial 2			
Treatment	Day	14	21	28	35	14	21	28	35
Untreated		0.0	2.0a	2.0a	3.0a	0.0	2.5a	1.8a	3.0a
Basamid® (0.029 kg m^{-2})		0.0	0.0b	0.0b	0.0b	0.0	0.0b	0.0b	0.0c
C. *gynandra* (4 kg m^{-2})		0.0	0.5b	0.3b	0.3b	0.3	0.0b	0.0b	1.0b
C. *gynandra* (6 kg m^{-2})		0.0	0.0b	0.3b	0.0b	0.0	0.0b	0.00b	0.0c
C. gynandra (8 kg m^{-2})		0.0	0.0b	0.0b	0.0b	0.0	0.0b	0.0b	0.0c

Means followed by the same letter, in a column (day) within a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD

4.2.4 Effect of biofumigation with African spider plant (*Cleome gynandra*) on Oxalis (*Oxalis latifolia*)

There were no significant differences on prevalence of *Oxalis latifolia* weed species across the treatments during trial one. In trial two, there was no significant difference after 14 and 35 days respectively across all the treatments. But after 21 and 28 days respectively; the untreated (negative control) had significantly highest number of *Oxalis latifolia* weed species which was not significantly different from the number under *Cleome gynandra* 4 kg m^{-2} treatment. Basamid® 0.029 kg m^{-2} (positive control) had the lowest number though not significantly different from the number under *C. gynandra* treatment of 8 and 6 kg m^{-2} respectively (Table 5).

Table 5: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Oxalis latifolia* weed species 0.09 m^{-2} on different days after Paspalum establishment

		Weed population 0.09 m^{-2}							
		Trial 1				Trial 2			
Treatment	Day	14	21	28	35	14	21	28	35
Untreated		1.50	2.50	4.25	2.75	2.50	5.00a	5.00a	5.00
Basamid® (0.029 kg m^{-2})		1.50	2.25	2.00	4.00	0.75	2.50c	2.50b	3.25
C. *gynandra* (4 kg m^{-2})		2.25	3.50	5.00	2.75	2.75	4.25ab	4.50a	4.50
C. *gynandra* (6 kg m^{-2})		1.25	2.50	3.75	3.50	2.50	4.00abc	3.00b	3.75
C. gynandra (8 kg m^{-2})		1.50	1.75	2.75	2.75	1.50	3.25bc	2.50b	3.75

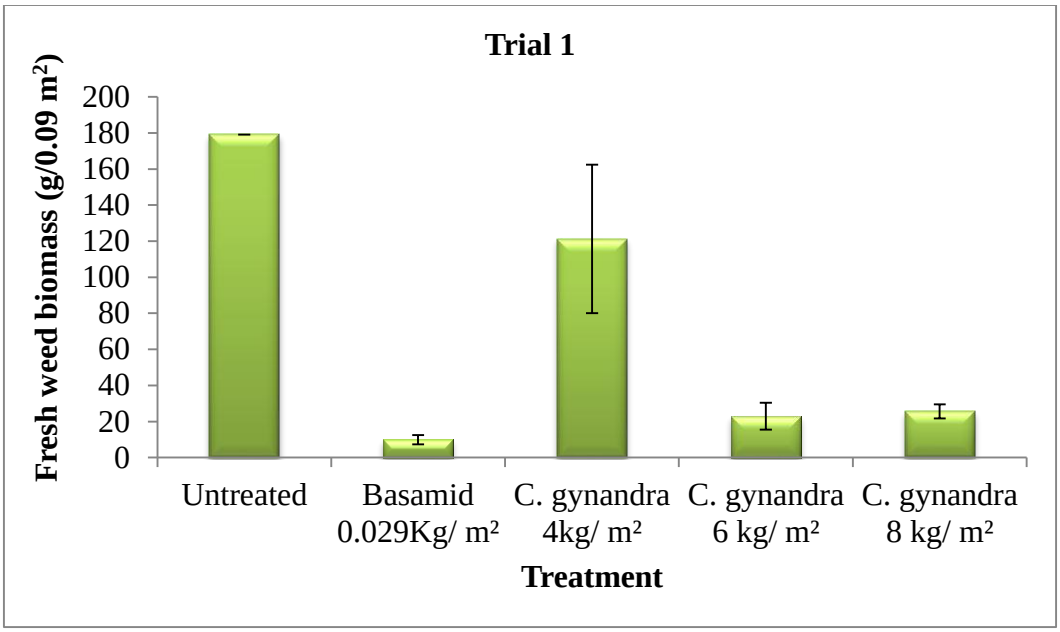
Means followed by the same letter, in a column (day) within a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD

Other weed species i.e. *Amaranthus sp., Euphorbia hirta, Cynodon dactylon, Cyperus rotundas, Phylanthus urinaria* and *Xanthium occidentale* occurred in the experimental plots but in insignificant populations.

4.3 Effects of biofumigation with African spider plant (*Cleome gynandra*) on Weed Biomass

4.3.1 Fresh Weed Biomass

Treatments had an effect on fresh weed biomass with the highest biomass realized under untreated (negative control) in both trials. There was no significant difference in fresh weed biomass under *Cleome gynandra* 4 kg m^{-2} and negative control in trial one; but in trial two biomass under *C. gynandra* at 4 kg m^{-2} was significantly higher. Biofumigation with *C. gynandra* at 6 and 8 kg m^{-2} respectively reduced total fresh weed biomass to levels significantly similar to Basamid® 0.029 kg m^{-2} (positive control) during both trials (Figure 2).



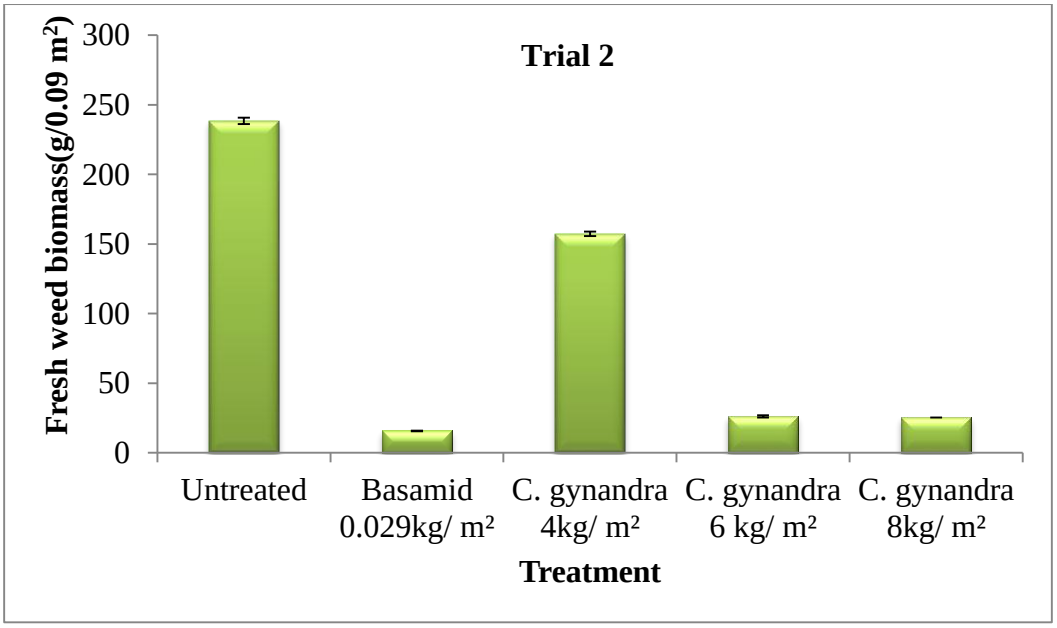


Figure 2: Treatment effects on fresh weed biomass (g 0.09 m^{-2}) for two trials of the experiment

4.3.2 Dry Weed Biomass

Treatments effect on dry weed biomass had a similar trend as that on fresh weed biomass; biofumigation with *Cleome gynandra* at 4 kg m^{-2} was not significantly different from cultivation only (negative control) which had the highest dry weed biomass. Basamid® at 0.029 kg m^{-2}

(positive control) had the lowest dry weed biomass while *C. gynandra* at 8 kg m^{-2} and 6 kg m^{-2} respectively were significantly similar to Basamid® at 0.029 kg m^{-2} in reduction of total dry weed biomass during both trials one and two (Figure 3).

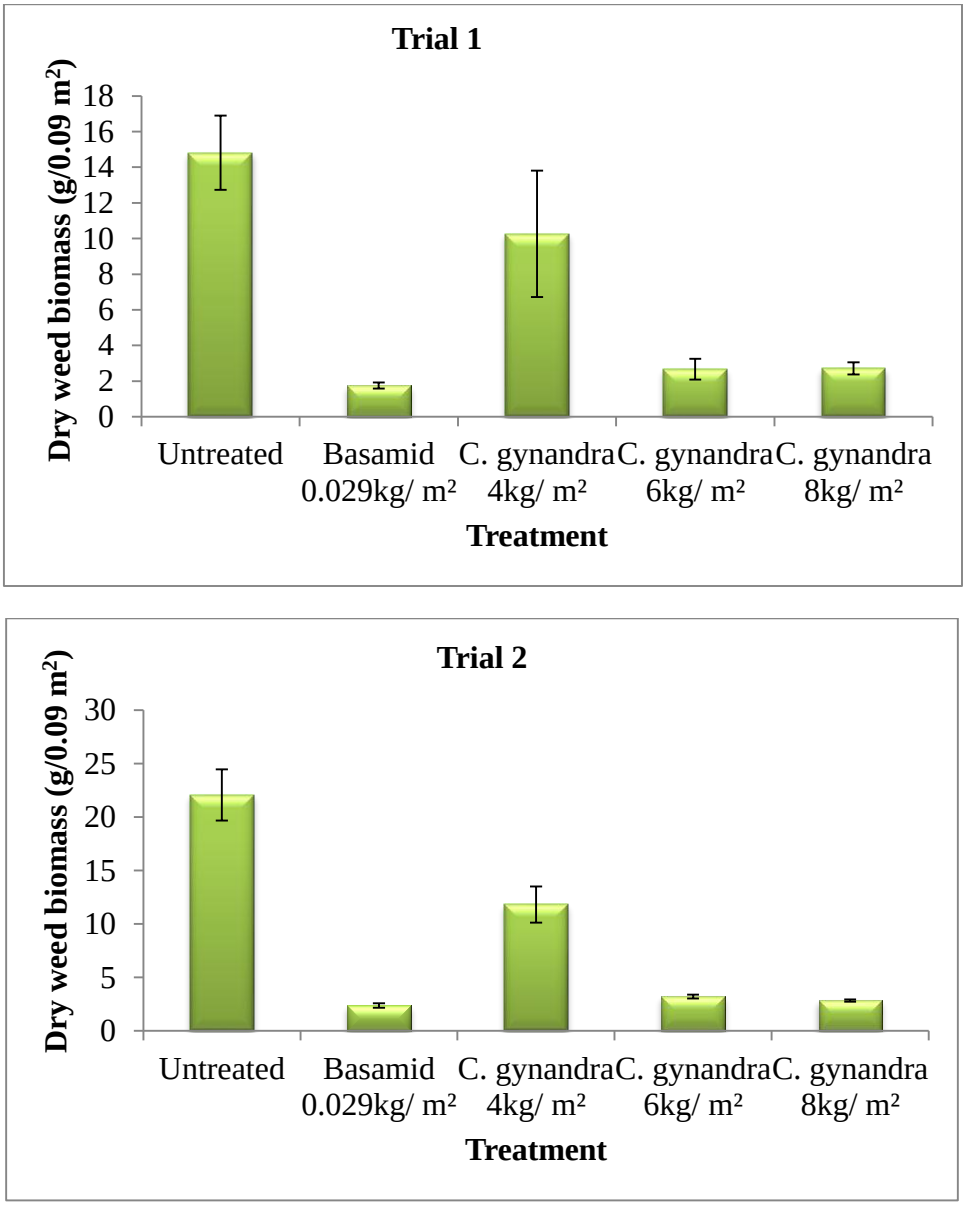


Figure 3: Effect of biofumigation with African spider plant (*Cleome gynandra*) on dry weed biomass (g 0.09 m^{-2}) for trials one and two

4.4 Effects of biofumigation with African spider plant (*Cleome gynandra*) on Turfgrass growth

The Paspalum turfgrass plugs exhibited growth in both width and height although rate of growth differed across the treatments during both trials.

4.4.1 Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug width

During trial one; highest plug width growth rate was displayed under *Cleome gynandra* 8 kg m^{-2} treatment which was not significantly different from growth under Basamid® at 0.029 kg m^{-2}, *C. gynandra* at 6 and 4 kg m^{-2} respectively. Negative control had the lowest plug width growth rate. In trial two the highest plug width growth rate was under *C. gynandra* at 8 kg m^{-2} treatment followed by *C. gynandra* at 6 kg m^{-2} which was not significantly different from Basamid® 0.029 kg m^{-2} treatment, then followed with growth under *C. gynandra* 4 kg m^{-2} and lowest plug width growth rate was under negative control (Table 6).

Table 6: Effect of biofumigation with African spider plant (*Cleome gynandra*) on width of *Paspalum notatum* plugs (cm)

		Plug width (cm)							
		Trial 1				Trial 2			
Treatment	Day	49	63	77	91	49	63	77	91
Untreated		20.80b	24.65b	27.10b	29.40c	20.25c	23.85b	27.75c	31.30c
Basamid® (0.029 kg m^{-2})		23.65a	26.75a	29.15a	31.15ab	22.35a	26.10a	30.15a	34.30b
C. gynandra (4 kg m^{-2})		23.35a	27.00a	29.10a	30.60b	21.25b	24.50a	29.10b	33.30b
C. gynandra (6 kg m^{-2})		24.15a	27.1a	29.30a	31.00ab	22.10ab	25.75a	30.30a	34.25ab
C. gynandra (8 kg m^{-2})		24.15a	27.3a	29.50a	31.30a	22.50a	26.55a	31.20a	35.25a

Means followed by the same letter, in a column (day) in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD.

4.4.2 Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug height

During trial one; growth rate of plug height was highest under Basamid® 0.029 kg m^{-2} treatment followed by *Cleome gynandra* 8 kg m^{-2} treatment which was not significantly different from spider plant 6 kg m^{-2} then *C. gynandra* 4 kg m^{-2} and lowest height growth rate was under negative control. In trial two highest plug height growth rate was under *C. gynandra* 8 kg m^{-2} treatment which was not significantly different from that under *C. gynandra* 6 kg m^{-2}, Basamid® 0.029 kg m^{-2} and *C. gynandra* 4 kg m^{-2} respectively. The lowest growth rate was under negative control (Table 7).

Table 7: Effect of biofumigation with African spider plant (*cleome gynandra*) on height of *Paspalum notatum* plugs (cm)

	Plug height (cm)								
		Trial 1				Trial 2			
Treatment	Day	49	63	77	91	49	63	77	91
Untreated		6.15b	7.20b	8.90b	10.45b	6.45b	7.15b	8.60c	10.80b
Basamid® (0.029 kg m^{-2})		7.10a	8.15a	10.00a	11.95a	6.90ab	8.10a	9.55ab	12.60a
C. gynandra (4 kg m^{-2})		6.40b	7.50ab	9.00ab	11.35ab	6.70ab	7.75ab	9.20bc	12.85a
C. gynandra (6 kg m^{-2})		6.75ab	7.85ab	9.25a	11.60a	7.20a	8.25a	9.95ab	12.85a
C. gynandra (8 kg m^{-2})		6.50ab	7.60ab	9.35a	11.25ab	7.20a	8.25a	10.25a	13.20a

Means followed by the same letter, in a column (day) in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD.

4.5 Effect of biofumigation with African spider plant (*Cleome gynandra*) on Sprig Growth

Although there were significant differences in the treatment effects on sprig internode length (Table 8), leaf length (Table 9) and leaf width (Table 10) there was no consistent trend for both trials one and two.

4.5.1 Effect of biofumigation with African spider plant (*Cleome gynandra*) on internode length of *Paspalum notatum* sprigs

Highest internode length of *Paspalum notatum* sprigs during trial one was recorded with *Cleome gynandra* 6 kg m^{-2} treatment followed by *C. gynandra* 4 kg m^{-2} treatment. However, *C. gynandra* 4 kg m^{-2} was statistically similar to; *C. gynandra* 8 kg m^{-2} and Basamid® 0.029 kg m^{-2} on day 68; *C. gynandra* 8 kg m^{-2} and negative control on day 96. At 124 days after establishment of the turf grass there was no significant difference between internode length under *C. gynandra* 6 and 4 kg m^{-2} treatments which was significantly higher than *C. gynandra* 8 kg m^{-2}, Basamid® 0.029 kg m^{-2} and negative control that were statistically similar. Although *C. gynandra* 6 kg m^{-2} treatment also had highest internode length throughout in trial two, it was not significantly different from *C. gynandra* 8 kg m^{-2} and 4 kg m^{-2} treatments respectively. The internode length under *C. gynandra* 8 kg m^{-2} and 4 kg m^{-2} were also not significantly different from internode length under Basamid® 0.029 kg m^{-2}; however internode length of *C. gynandra* 6 kg m^{-2} was significantly higher than that of Basamid 0.029 kg m^{-2} treatment. Negative control recorded the least sprig internode length in both the trials (Table 8).

Table 8: Effect of biofumigation using African spider plant (*Cleome gynandra*) on internode length of *Paspalum notatum* sprigs (mm)

	Internode length (mm)						
		Trial 1			Trial 2		
Treatment	Day	68	96	124	68	96	124
Untreated		3.58c	4.70bc	4.40b	3.93c	4.85b	6.08c
Basamid® (0.029 kg m^{-2})		4.33b	4.23c	4.78b	4.43b	5.18b	6.68b
C. *gynandra* (4 kg m^{-2})		4.53b	4.83bc	5.73a	4.63ab	5.60a	6.98ab
C. *gynandra* (6 kg m^{-2})		5.10a	5.85a	5.63a	4.95a	5.90a	7.33a
C. gynandra (8 kg m^{-2})		4.30b	5.25b	4.85b	4.68ab	5.58a	6.93ab

Means followed by the same letter, in a column in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD.

4.5.2 Effect of biofumigation with African spider plant (*Cleome gynandra*) on leaf length of *Paspalum notatum* sprigs

There was no significant difference in the leaf length of *Paspalum notatum* sprigs during trial one but in trial two *Cleome gynandra* 6 kg m^{-2} treatment had the highest leaf length although it was not significantly different from *C. gynandra* 8 kg m^{-2} and 4 kg m^{-2} respectively. The sprig leaf length under *C. gynandra* 8 and 4 kg m^{-2} were also not significantly different from Basamid® 0.029 kg m^{-2} on the 96 and 124 day after establishment of the turf grass; but that under *C. gynandra* 6 kg m^{-2} was significantly higher than Basamid® 0.029 kg m^{-2} throughout. Untreated plots (negative control) had the least sprig leaf length although it had no significant difference with Basamid® 0.029 kg m^{-2} on the 68 and 124 day after the establishment of Paspalum turf grass (Table 9).

Table 9: Effect of biofumigation using African spider plant (*Cleome gynandra*) on leaf length of *Paspalum notatum* sprigs (cm)

	Leaf length (cm)						
		Trial 1			Trial 2		
Treatment	Day	68	96	124	68	96	124
Untreated		11.04	10.51	11.74	10.79b	10.63c	13.27c
Basamid® (0.029 kg m^{-2})		10.88	10.85	11.85	10.95b	11.44b	13.86bc
C. *gynandra* (4 kg m^{-2})		10.85	11.70	11.35	11.66a	11.87ab	14.34ab
C. *gynandra* (6 kg m^{-2})		11.22	11.46	11.65	12.16a	12.14a	15.07a
C. gynandra (8 kg m^{-2})		10.59	13.47	12.15	11.58a	11.83ab	14.33ab

Means followed by the same letter, in a column in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD.

4.5.3 Effect of biofumigation with African spider plant (*Cleome gynandra*) on leaf width of *Paspalum notatum* sprigs

Highest leaf width of *Paspalum notatum* sprigs during trial one was recorded with *Cleome gynandra* 6 kg m^{-2} treatment which was not significantly different from *C. gynandra* 4 kg m^{-2} treatment on the 68, 96 and 124 days respectively after the establishment of Paspalum turfgrass. The leaf width of *C. gynandra* 6 kg m^{-2} treatment was also significantly similar to *C. gynandra* 8 kg m^{-2} treatment on the 68, 96 and 124 days respectively but *C. gynandra* 4 kg m^{-2} treatment had significantly higher width than *C. gynandra* 8 kg m^{-2} treatment on day 96 after turfgrass establishment. Although the lowest leaf width was under Basamid® 0.029 kg m^{-2} (positive control) it was not significantly different from *C. gynandra* 8 kg $m^{-2}$and the untreated (negative control) on day 68, 96 and 124 respectively after turfgrass establishment and from *C. gynandra* 4 kg m^{-2} treatment on day 68 and 124 respectively. *C. gynandra* 4 kg m^{-2} treatment had significantly higher sprig width than Basamid® 0.029 kg m^{-2} at 96 days. Width for negative control was not significantly different form Basamid® 0.029 kg m^{-2} and *C. gynandra* 4 kg m^{-2} treatments respectively but was significantly less than *C. gynandra* 6 kg m^{-2} and *C. gynandra* 8 kg m^{-2} treatments on day 96 after turfgrass establishment. During trial two *C. gynandra* 6 kg m^{-2} treatment still had the highest leaf width although not significantly different from *C. gynandra* 8 kg m^{-2} and *C. gynandra* 4 kg m^{-2} respectively and also Basamid® 0.029 kg m^{-2} at 96 and 124 days respectively. Untreated (negative control) had the lowest leaf width which was not significantly different from Basamid® 0.029 kg m^{-2} at 68 and 124 days after turfgrass establishment (Table 10).

Table 10: Effect of biofumigation using African spider plant (*Cleome gynandra*) on leaf width of *Paspalum notatum* sprigs (mm)

		Leaf width (mm)					
		Trial 1			Trial 2		
Treatment	Day	68	96	124	68	96	124
Untreated		8. 95c	9.43ab	9.65ab	9.53c	9.58b	10.92b
Basamid® (0.029 kg m^{-2})		9.23bc	9.33b	9.50b	9.78bc	10.38a	11.25ab
C. *gynandra* (4 kg m^{-2})		9.35abc	9.70a	9.83ab	10.18a	10.58a	11.40a
C. *gynandra* (6 kg m^{-2})		9.65a	9.58ab	9.95a	10.22a	10.80a	11.62a
C. gynandra (8 kg m^{-2})		9.45ab	9.55b	9.65ab	10.00ab	10.62a	11.42a

Means followed by the same letter, in a column in a trial are not significantly different at $P \leq 0.05$ according to Tukey's HSD.

4.5.4 Effect of biofumigation with African spider plant (*Cleome gynandra*) on fresh weight of *Paspalum notatum* sprigs

Treatments had effect on sprig fresh weight during both trials with *Cleome gynandra* 6 kg m^{-2} generally recording highest weight during trial one although it was not significantly different from *C. gynandra* 8 kg m^{-2}, *C. gynandra* 4 kg m^{-2} and Basamid® 0.029 kg m^{-2} (positive control) treatments respectively. The untreated (negative control) had the least sprig fresh weight however it was statistically similar to Basamid® 0.029 kg m^{-2} treatment and also to *C. gynandra* 8 and 4 kg m^{-2} treatments at 124 days after turfgrass establishment. Similarly *Cleome gynandra* 6 kg m^{-2} recorded highest weight in trial two and was also not significantly different from *C. gynandra* 8 kg m^{-2} and *C. gynandra* 4 kg m^{-2} treatments. Untreated (negative control) recorded the least sprig fresh weight although not significantly different from Basamid® 0.029 kg m^{-2}, *C. gynandra* 8 kg m^{-2} and *C. gynandra* 4 kg m^{-2} treatments respectively at 68 days and Basamid® 0.029 kg m^{-2} at 96 days after turfgrass establishment. Basamid® 0.029 kg m^{-2} (positive control) treatment had the second least sprig fresh weight in trial two (Table 11).

Table 11: Effect of biofumigation using African spider plant (*Cleome gynandra*) on sprig fresh weight of *Paspalum notatum* turfgrass seasons one and two

	Sprig fresh weight (g)					
	Trial 1			Trial 2		
Treatment	Day 68	96	124	68	96	124
Untreated	15.80	19.06b	16.98b	14.94b	16.88c	20.54c
Basamid® (0.029 kg m^{-2})	18.77	20.99ab	17.43ab	15.32ab	18.84bc	23.92b
C. *gynandra* (4 kg m^{-2})	17.34	23.20a	19.66ab	15.93ab	20.64ab	25.56a
C. *gynandra* (6 kg m^{-2})	18.67	24.66a	20.65a	16.71a	22.55a	26.21a
C. gynandra (8 kg m^{-2})	19.09	23.40a	20.11ab	16.30ab	21.84a	25.51a

Means followed by the same letter, in a column and in a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

4.5.5 Effect of biofumigation with African spider plant (*Cleome gynandra*) on dry weight of *Paspalum notatum* sprigs

There were minimal significant differences in sprig dry weight among the treatments. Highest dry weight during trial one was under *Cleome gynandra* 8 kg m^{-2} treatment which was statistically similar to *C. gynandra* 6 kg m^{-2}, *C. gynandra* 4 kg m^{-2} and Basamid® 0.029 kg m^{-2}. Although untreated (negative control) had the lowest dry weight it had no significant difference with that of *C. gynandra* 4 kg m^{-2} and Basamid® 0.029 kg m^{-2}. In trial two, sprig dry weight was highest under the three *Cleome gynandra* treatments; 8 kg m^{-2}, 6 kg m^{-2} and 4 kg m^{-2} respectively which were significantly different from Basamid® 0.029 kg m^{-2} and untreated (negative control) after the 124 days of establishment of Paspalum lawn grass (Table 12).

Table 12: Effect of biofumigation using African spider plant (Cleome gynandra) on sprig dry weight of Paspalum notatum turfgrass seasons one and two

	Sprig dry weight (g)					
	Trial 1			Trial 2		
Treatment	Day 68	96	124	68	96	124
Untreated	5.44	6.10b	7.01b	5.70a	6.70	6.30c
Basamid® (0.029 kg m^{-2})	5.87	6.50ab	7.42ab	5.65a	6.51	9.67b
C. *gynandra* (4 kg m^{-2})	5.54	6.89ab	7.99ab	5.94a	6.86	11.32a
C. *gynandra* (6 kg m^{-2})	5.85	7.03ab	8.43a	6.59a	7.21	11.98a
C. gynandra (8 kg m^{-2})	5.73	7.13a	8.43a	6.70a	7.76	11.28a

Means followed by the same letter, in a column and in a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

4.6 Effect of biofumigation with African spider plant (*Cleome gynandra*) on Aesthetic Quality of *Paspalum notatum* turfgrass

Treatments had an impact on visual appearance (uniformity, colour, density and overall quality) of the Paspalum turfgrass (Plate 8).

Plate 8: Visual appearance of Paspalum turfgrass under the different treatments

4.6.1 Effect of biofumigation with African spider plant (*Cleome gynandra*) on lawn uniformity

During trial one, uniformity of the paspalum turfgrass lawn grown on plots treated with *Cleome gynandra* 8 kg m^{-2} and 6 kg m^{-2} respectively were not significantly different from that under Basamid® 0.029 kg m^{-2} treatment (positive control) which was the most uniform. *C. gynandra* 4 kg m^{-2} treatment and untreated (negative control) displayed the least uniform lawns respectively. Basamid® 0.029 kg m^{-2} treatment recorded the most uniform lawn in trial two and untreated the least uniform. *C. gynandra* 8 kg m^{-2} treatment was the second most uniform

statistically followed by *C. gynandra* 6 kg m^{-2} treatment which was significantly more uniform than *C. gynandra* 4 kg m^{-2} (Table 13).

Table 13: Effect of biofumigation with African spider plant (*Cleome gynandra*) on uniformity of *Paspalum notatum* turfgrass

	Uniformity					
		Trial 1			Trial 2	
Treatment	Day 76	106	140	76	106	140
Untreated	6.92b	6.42c	4.63c	5.64d	5.21e	6.07e
Basamid® (0.029 kg m^{-2})	8.08a	8.54a	8.88a	8.71a	8.93a	8.93a
C. *gynandra* (4 kg m^{-2})	7.63a	7.54b	6.96b	7.00c	6.96d	7.43d
C. *gynandra* (6 kg m^{-2})	7.58a	8.04ab	8.42a	7.93b	8.04c	8.21c
C. gynandra (8 kg m^{-2})	7.88a	8.21a	8.71a	8.14b	8.50b	8.57b

Means followed by the same letter in a column within a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

4.6.2 Effect of biofumigation with African spider plant (*Cleome gynandra*) on colour of *Paspalum notatum* turfgrass

During trial one, all the three *Cleome gynandra* treatments 8 kg m^{-2}, 6 kg m^{-2} and 4 kg m^{-2} respectively displayed deep colour intensity which was not significantly different from that of Basamid® 0.029 kg m^{-2} treatment (positive control) which had the most intense colour, while untreated (negative control) had the least intense colour. In trial two; colour intensity under *C. gynandra* treatments 8 kg m^{-2} and 6 kg m^{-2} respectively was also not significantly different from that under Basamid® 0.029 kg m^{-2} treatment which was highest followed by *C. gynandra* 4 kg m^{-2} and least under untreated (Table 14).

Table 14: Effect of biofumigation with African spider plant (*Cleome gynandra*) on colour of *Paspalum notatum* turfgrass

		Colour					
		Trial 1			Trial 2		
Treatment	Day	76	106	140	76	106	140
Untreated		7.79	7.92b	8.50b	7.89c	7.71c	8.04c
Basamid® (0.029 kg m^{-2})		8.21	8.50a	9.00a	8.61a	8.89a	9.00a
C. *gynandra* (4 kg m^{-2})		7.96	8.46a	8.67ab	8.04bc	8.39b	8.61b
C. *gynandra* (6 kg m^{-2})		7.83	8.25ab	8.88a	8.39ab	8.86a	8.89a
C. gynandra (8 kg m^{-2})		8.25	8.46a	8.83ab	8.49ab	8.79a	8.86ab

Means followed by the same letter in a column within a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

4.6.3 Effect of biofumigation with African spider plant (*Cleome gynandra*) on density of *Paspalum notatum* turfgrass

Trend of treatments effect on the paspalum lawn density was similar during both trials one and two. Highest density was realized under *Cleome gynandra* 8 kg m^{-2} treatment which was not significantly different from *C. gynandra* 6 kg m^{-2} and Basamid® 0.029 kg m^{-2} (positive control); followed by *C. gynandra* 4 kg m^{-2} and lowest density under untreated (negative control) (Table 15).

Table 15: Effect of biofumigation with African spider plant (*Cleome gynandra*) on density of *Paspalum notatum* turfgrass

	Density					
	Trial 1			Trial 2		
Treatment	Day 76	106	140	76	106	140
Untreated	7.00	7.33b	7.13c	6.71c	6.68c	7.36c
Basamid® (0.029 kg m^{-2})	8.13	8.33a	8.58ab	8.39a	8.71a	8.96a
C. *gynandra* (4 kg m^{-2})	7.88	8.21a	8.13b	7.39b	7.57b	7.96b
C. *gynandra* (6 kg m^{-2})	7.67	8.25a	8.5ab	8.11a	8.57a	8.82a
C. gynandra (8 kg m^{-2})	8.21	8.33a	8.79a	8.39a	8.86a	8.86a

Means followed by the same letter in a column within a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

4.6.4 Effect of biofumigation with African spider plant (*Cleome gynandra*) on overall quality of *Paspalum notatum* turfgrass

Overall quality of Paspalum turfgrass grown on plots treated with *Cleome gynandra* 8 kg m^{-2} and *C. gynandra* 6 kg m^{-2} was as good as that on plots treated with Basamid® 0.029 kg m^{-2} which were significantly better than spider plant 4 kg m^{-2}. Untreated (negative control) displayed the lowest overall quality during both trials (Table 16).

Table 16: Effect of biofumigation with African spider plant (*Cleome gynandra*) on overall quality of *Paspalum notatum* turfgrass

		Overall quality					
		Trial 1			Trial 2		
Treatment	Day	76	106	140	76	106	140
Untreated		6.96c	7.33b	6.42c	6.57d	6.43d	7.11c
Basamid® (0.029 kg m^{-2})		8.29a	8.50a	8.79a	8.57a	8.89a	8.96a
C. *gynandra* (4 kg m^{-2})		7.67b	8.21a	7.75b	7.5c	7.54c	7.93b
C. *gynandra* (6 kg m^{-2})		7.71ab	8.13a	8.58a	8.11b	8.46b	8.79a
C. gynandra (8 kg m^{-2})		8.08ab	8.38a	8.71a	8.57a	8.82a	8.82a

Means followed by the same letter in a column within a trial are not significantly different at P≤ 0.05 according to Tukey's HSD.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Efficacy of biofumigation with African spider plant (*Cleome gynandra*) on Weed Emergence, Prevalence and Biomass

Seed germination is regulated by an interaction of environmental conditions. Soil moisture is among the environmental factors that affect seed germination (Lu *et al*., 2006). Dry conditions that limit water availability also limit germination (Dadach *et al*., 2015) and hence emergency of the plants. The difference in days to weed emergency between the two trials can be attributed to moisture availability. Both trials were carried out under rain fed cultivation and supplemented with watering during dry weeks. In trial one, before the onset of the short rainy season, the soils were drier while in trial two during the onset of the long rainy season the soil moisture was comparatively higher hence the shorter period taken for weed emergence for the weed species that were not affected by the applied treatments. Water stress affects most of the functions of plant growth resulting in growth reduction (Boutraa *et al*., 2010). During trial one, germination was affected by treatments plus limited soil moisture, while in trial two only the treatments affected germination because the soil had sufficient moisture for germination hence emergence of the weed seeds.

Soil incorporation of crop residues can lead to weed suppression by posing allelopathic and physical effects (Khaliq *et al*., 2011). Incorporation of isothiocyanates (ITCs) into the soil has been found to be effective in suppressing some weeds (Norsworthy and Meehan, 2005). Homogenized leaves of *Cleome gynandra* have been found to emit significant quantities of biologically active ITCs (Nyalala *et al*., 2013). Glucosinolates in spider plant include methylglucosinolate, cleomin and glucocapparin which give rise to methyl isothiocyanates when hydrolyzed (Silué, 2009). In the current study suppression of germination of *Galinsoga parviflora, G. ciliata* and *Bidens pilosa* by chopped *Cleome gynandra* incorporated into the soil was due to ITCs it introduced to the soil. Weeds with underground structures, like *Oxalis latifolia* which form bulbs, are difficult to manage hence its persistence even under fumigation with Basamid® 0.029 kg m^{-2}

At low concentrations ITCs are beneficial to human health and at high concentrations they are general biocides that act like some commercial pesticides such as Vapam and Dazomet

(University of Idaho, 2013), this explains why biofumigation with *Cleome gynandra* at rates of 6 kg m^{-2} or 8 kg m^{-2} was as effective as with Basamid® 0.029 kg m^{-2} in reducing the total fresh and dry weight of weeds and significantly suppressing *Galinsoga parviflora,* and *G. ciliata* weed populations while at 4 kg m^{-2} it had no significant effect on the same weed species though it was significantly effective than the negative control on control of *Bidens pilosa.* All the three *Cleome gynandra* treatments; 8, 6 and 4 kg m^{-2} respectively suppressed *Bidens pilosa* weed species to levels significantly similar to that of Basamid® 0.029 kg m^{-2} treatment. Treatments that resulted in higher weed numbers also had high weed fresh and dry biomass as compared to those that suppressed weed growth more. Plants compete for space by occupying space, the first plant that occupies an area tends to exclude all the others and have a competitive advantage (Zimdahl, 2007). The suppressive treatments effect on the weeds gave the turfgrass first priority to occupy the area hence outdoing the weeds and therefore also contributing to reduction in the total fresh and dry weed biomass. Prevention is the best weed control strategy when establishing new lawn; weeds should be prevented from getting a foothold (Thurn *et al*., 1994).

5.2 Effect of biofumigation with African spider plant (*Cleome gynandra*) on Turfgrass Growth

Glucosinolates (GSLs) from decomposing biofumigant plant materials break down to form isothiocyanates (ITCs) in soil which suppress soil pathogens, insects and germinating weed seeds (Karavina and Mandumbu, 2012) providing a healthier crop growing environment. According to University of Idaho (2013), at high concentrations ITCs are general biocides that act like some commercial pesticides such as Vapam (metam sodium) and Basamid® (dazomet). Competition from weeds could also have contributed to low growth rate under the untreated negative control during both seasons one and two as it was the treatment with highest weed numbers. Weeds compete with the desired turfgrass for water, nutrients, light and space (Dernoeden, 2005).

Crop residues are also important sources for supplying nutrients to crops and improving soil health by replenishment of soil fertility and improvement of physical, chemical and biological properties of the soil (Babu *et al*. 2014). These could be the reason why there was no significant differences during both seasons one and two in measurements taken on the sprig

internode length, leaf length and leaf width among the three *Cleome gynandra* treatments; 8, 6 and 4 kg m^{-2} respectively which were all significantly higher than growth under Basamid® 0.029 kg m^{-2} treatment; crop residues have been found to result in higher crop yields (Kamkar *et al*. 2014).

The positive biological activity of the GSL degradation products has been proven effective against weeds, plant diseases and nematodes (Van Dam *et al*. 2009) hence enhanced crop growth. The three *Cleome gynandra* treatments; 8, 6 and 4 kg m^{-2} respectively had significantly similar fresh and dry weights which though numerically higher were not significantly different from weight under the positive control, Basamid® 0.029 kg m^{-2} treatment. The negative control had the lowest plug and sprig growth rates in both seasons and also the lowest fresh and dry sprig weight respectively. Biofumigation with spider plant at all the three rates; 8, 6 and 4 kg m^{-2} had more impact on sprig growth than both the negative and positive controls (untreated and Basamid® 0.029 kg m^{-2} treatment). Although sprig biomass of the three *C. gynandra treatments* were respectively not significantly different from the positive control; numerically they were higher. This may be attributed to increased organic matter as a result of incorporating spider plant residues into the soil. With the global focus on sustainability in agricultural environment for production of healthy, safe and good quality crops there is a bigger drive towards the development of alternative management tools with a lower impact on natural predators and the environment (Kruger *et al*. 2013).

5.3 Effect of biofumigation with African spider plant (*Cleome gynandra*) on Turfgrass Aesthetic Quality

Crop residues supply nutrients to crops and improve soil health (Babu *et al*. 2014) resulting in enhanced crop performance (Kamkar *et al*. 2014). This could be the reason why overall quality of paspalum turfgrass grown on plots biofumigated with *Cleome gynandra* at 8 and 6 kg m^{-2} were respectively as good as that fumigated with Basamid® at 0.029 kg m^{-2} (positive control) which were significantly rated higher than *C. gynandra* at 4 kg m^{-2}. Untreated (negative control) displayed the lowest overall quality during both seasons; this can be explained by weed prevalence. Weeds mar the lawn appearance if left uncontrolled (Chalmers and

McAfee, 2009). Untreated (negative control) had the highest number of weeds during both seasons followed by *C. gynandra* 4 kg m^{-2} treatment.

Synthetic pesticides are easy to handle and apply uniformly hence the rating of the turfgrass under Basamid® 0.029 kg m^{-2}treatment as the highly uniform. Although rated second in uniformity turfgrass under *Cleome gynandra* 8 kg m^{-2} treatment had no significant difference from *C. gynandra* 6 kg m^{-2} which was followed by *C. gynandra* 4 kg m^{-2}. The positive biological activity of the GSL degradation products has been proven effective against weeds, plant diseases and nematodes (Van Dam *et al*. 2009) hence enhanced crop growth. At high concentrations i.e. 8 and 6 kg m^{-2}, *Cleome gynandra* was a general biocide that acted like commercial pesticides hence the higher rating in comparison to *C. gynandra* 4 kg m^{-2} which also had comparatively higher weed numbers. The untreated negative control was the least uniform because of higher weed numbers and species.

Highest turfgrass colour and density respectively realized under *Cleome gynandra* 8 kg m^{-2}, *C. gynandra* 6 kg m^{-2} and Basamid® 0.029 kg m^{-2} (positive control) during both seasons could have been as a result of turfgrass growth. The trend was somehow similar to that of treatments effect on turfgrass sprig growth rate and weed numbers; negative control with highest weed prevalence was rated lowest in both colour and density followed by *C. gynandra* 4 kg m^{-2}. A healthy dense lawn help reduce weed invasion (Hulett, 2004). Weed invasion is a problem in especially the bare spaces between newly planted grasses (Cameroon, 2006). Plants compete for space and the first plant that occupies an area tends to exclude all the others and have a competitive advantage (Zimdahl, 2007). Treatments that suppressed weed growth gave the paspalum turfgrass competitive advantage.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Based on the findings of this study, it can be concluded that:

1. Biofumigation with *Cleome gynandra* at 6 or 8 kg m^{-2} is as effective as Basamid at 29 g m^{-2} in significantly suppressing *Galinsoga parviflora*, *G. ciliata* and *Bidens pilosa* weed populations
2. Biofumigation with *Cleome gynandra* enhances growth of paspalum turfgrass
3. Biofumigation with *C. gynandra* significantly improves aesthetic quality of paspalum turfgrass

6.2 Recommendations

The following recommendations can be made:

1. Biofumigation with *Cleome gynandra* can be used as an alternative to synthetic herbicides for weed control during establishment of lawn.
2. Lawn developers can biofumigate plots for turfgrass establishment with *Cleome gynandra* for enhanced growth and aesthetic quality
3. Cost-benefit study comparing biofumigation with *Cleome gynandra* and Basamid should be conducted
4. More research is needed with a wider range of weed species and assessment of soil properties due to biofumigation with *Cleome gynandra*.

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APPENDICES

Appendix I: Treatment of plots

Appendix II: Visual rating of the lawn plots

Appendix III: Supervisors visit to the experimental site

Appendix IV: Effect of biofumigation with African spider plant (*Cleome gynandra*) on days to weed emergence after establishment of Paspalum turfgrass ANOVA trial one

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	5.0487	1.2622	1	0.4449
Block	3	3.7865	1.2622	1	0.4262
Error	12	1.5146	1.2622		
Total	19	10.3498			

Appendix V: Effect of biofumigation with African spider plant (*Cleome gynandra*) on days to weed emergence after establishment of Paspalum turfgrass ANOVA trial two

Source	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	4	148.7	37.175	120.568	1.404e-09 ***
Block	3	2.8	0.933	3.027	0.07124
Error	12	3.7	0.308		
Total	19	155.2			

Appendix VI: Effect of biofumigation with African spider plant (*Cleome gynandra*) on gallant soldier (*Galinsoga parviflora*) 0.09 m^{-2}on different days after establishment of Paspalum turfgrass ANOVA trial one

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	12.20	3.0500	3.327	0.0472 *
Block	3	5.75	1.9167	2.091	0.1549
Error	12	11.00	0.9167		
Total	19	28.95			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	140.8	35.20	7.940	0.00228 **
Block	3	93.8	31.27	7.053	0.00547 **
Error	12	53.2	4.43		
Total	19	287.8			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	183.70	45.93	7.111	0.00356 **
Block	3	29.75	9.92	1.535	0.25598
Error	12	77.50	6.46		
Total	19	290.95			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	803.8	200.95	9.716	0.000963 ***
Block	3	45.8	15.27	0.738	0.549328
Error	12	248.2	20.68		
Total	19	1097.8			

Appendix VII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on gallant soldier (*Galinsoga parviflora*) 0.09 m^{-2} on different days after establishment of Paspalum turfgrass ANOVA trial two

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	290.7	72.675	44.2690	4.326e-07 ***
Block	3	2.8	0.933	0.5685	0.6463
Error	12	19.7	1.642		
Total	19	313.2			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	403.80	100.950	2.6461	0.08578.
Block	3	8.95	2.983	0.0782	0.97060
Error	12	457.80	38.150		
Total	19	870.55			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	970.3	242.575	240.570	2.418e-11 ***
Block	3	3.4	1.133	1.124	0.3781
Error	12	12.1	1.008		
Total	19	985.8			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	1222.30	305.575	138.3736	6.275e-10 ***
Block	3	11.75	3.917	1.7736	0.2056
Error	12	26.50	2.208		
Total	19	1260.55			

Appendix VIII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Galinsoga ciliata* weed species 0.09 m^{-2} on different days after establishment of Paspalum turfgrass ANOVA trial one

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	3.00	0.7500	2.647	0.0857
Block	3	1.35	0.4500	1.588	0.2437
Error	12	3.40	0.2833		
Total	19	7.75			

Day21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	103.30	25.825	4.820	0.015 *
Block	3	40.95	13.650	2.547	0.105
Error	12	64.30	5.358		
Total	19	208.55			

Day28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	222.50	55.62	6.629	0.00469 **
Block	3	28.55	9.52	1.134	0.37449
Error	12	100.70	8.39		
Total	19				

Day35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	739.3	184.83	12.008	0.00037 ***
Block	3	97.8	32.60	2.118	0.15128
Error	12	184.7	15.39		
Total	19	1021.8			

Appendix IX: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Galinsoga ciliata* weed species 0.09 m^{-2} on different days after establishment of Paspalum turfgrass ANOVA trial two

Day14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	256.8	64.200	60.1875	7.691e-08 ***
Block	3	4.2	1.400	1.3125	0.3157
Error	12	12.8	1.067		
Total	19	273.8			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	962.20	240.550	209.1739	5.526e-11 ***
Block	3	2.95	0.983	0.8551	0.4905
Error	12	13.80	1.150		
Total	19	988.95			

Day28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	1162.20	290.550	215.2222	4.67e-11 ***
Block	3	0.55	0.183	0.1358	0.9368
Error	12	16.20	1.350		
Total	19	1178.95			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	1058.20	264.550	97.3804	4.86e-09 ***
Block	3	4.15	1.383	0.5092	0.6834
Error	12	32.60	2.717		
Total	19	1094.95			

Appendix X: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Bidens pilosa* weed species 0.09 m $^{-2}$ on different days after establishment of Paspalum turfgrass ANOVA trial one

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	0	0		
Block	3	0	0		
Error	12	0	0		
Total	19				

Day21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	12.0	3.0000	4.737	0.0159 *
Block	3	3.4	1.1333	1.789	0.2027
Error	12	7.6	0.6333		
Total	19	23.0			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	11.5	2.875	2.851	0.0713
Block	3	5.4	1.800	1.785	0.2035
Error	12	12.1	1.008		
Total	19	29.0			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	27.80	6.95	5.148	0.0119 *
Block	3	2.55	0.85	0.630	0.6097
Error	12	16.20	1.35		
Total	19	46.55			

Appendix XI: Effect of biofumigation with African spider plant (*Cleome Gynandra*) on mean number of *Bidens pilosa* weed species 0.09m^{-2} on different days after establishment of Paspalum turfgrass ANOVA trial two

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	0.19737	0.049342	0.9109	0.4910
Block	3	0.15417	0.051389	0.9487	0.4505
Error	12	0.59583	0.054167		
Total	19	0.94737			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	19.7368	4.9342	69.2889	9.962e-08 ***
Block	3	0.2167	0.0722	1.0142	0.4233
Error	12	0.7833	0.0712		
Total	19	20.7368			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	9.6711	2.41776	12.2984	0.0004787 ***
Block	3	0.5875	0.19583	0.9961	0.4306078
Error	12	2.1625	0.19659		
Total	19	12.4211			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	26.5263	6.6316	26.6881	1.302e-05 ***
Block	3	1.2667	0.4222	1.6992	0.2246
Error	12	2.7333	0.2485		
Total	19	30.563			

Appendix XII: Effect of African spider plant (*Cleome gynandra*) on mean number of *Oxalis latifolia* weed species 0.09 m-*2* on different days after establishment of Paspalum turfgrass ANOVA trial one

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	2.3	0.5750	1.211	0.357
Block	3	0.8	0.2667	0.561	0.651
Error	12	5.7	0.4750		
Total	19	8.8			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	6.5	1.6250	0.604	0.667
Block	3	0.2	0.0667	0.025	0.994
Error	12	32.3	2.6917		
Total	19	39.0			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	22.70	5.675	2.176	0.134
Block	3	6.95	2.317	0.888	0.475
Error	12	31.30	2.608		
Total	19	60.95			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	5.30	1.325	0.319	0.860
Block	3	11.35	3.783	0.910	0.465
Error	12	49.90	4.158		
Total	19	66.55			

Appendix XIII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on mean number of *Oxalis latifolia* weed species 0.09 m^{-2} on different days after establishment of Paspalum turfgrass ANOVA trial two

Day 14

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	11.5	2.87500	3.0531	0.05967
Block	3	5.2	1.73333	1.8407	0.19351
Error	12	11.3	0.94167		
Total	19	28.0			

Day 21

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	14.7	3.6750	4.7419	0.01583 *
Block	3	5.2	1.7333	2.2366	0.13649
Error	12	9.3	0.7750		
Total	19	29.2			

Day 28

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	22.0	5.5000	7.1739	0.003438 **
Block	3	1.8	0.6000	0.7826	0.526191
Error	12	9.2	0.7667		
Total	19	33.0			

Day 35

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	7.70	1.92500	2.7831	0.07576
Block	3	2.95	0.98333	1.4217	0.28476
Error	12	8.30	0.69167		
Total	19	18.95			

Appendix XIV: Effect of biofumigation with African spider plant (*Cleome gynandra*) on Weed Biomass ANOVA trial one

Fresh Weed Biomass

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	89166	22292	10.239	0.000764 ***
Block	3	3454	1151	0.529	0.670901
Error	12	26124	2177		
Total	19				

Dry Weed Biomass

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	539.3	134.82	8.519	0.0017 **
Block	3	19.0	6.33	0.400	0.7558
Error	12	189.9	15.83		
Total	19				

Appendix XV: Effect of biofumigation with African spider plant (*Cleome gynandra*) on Weed Biomass ANOVA trial two

Fresh Weed Biomass

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	161244	40311	7945.3	0.065 < 2e-16 ***
Block	3	45	15	2.9468	0.07589
Error	12	61	5		
Total	19				

Dry Weed Biomass

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	1171.22	292.804	55.9184	1.167 ***
Block	3	43.59	14.531	2.7751	0.08707
Error	12	62.84	5.236		
Total	19				

Appendix XVI: Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug width (Days after establishment of Paspalum turfgrass) ANOVA trial one

Day 49

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	155.76	38.940	22.571	5.201e-13 ***
Block	3	180.68	60.227	34.910	3.722e-15 ***
Error	12	158.72	1.725		
Total	19	495.16			

Day 63

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	94.34	23.585	13.735	8.053e-09 ***
Block	3	150.32	50.107	29.180	2.394e-13 ***
Error	12	157.98	1.717		
Total	19	402.64			

Day 77

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	76.76	19.1900	15.2988	1.26e-09 ***
Block	3	17.95	5.9833	4.7701	0.003898 **
Error	12	115.40	1.2543		
Total	19	210.11			

Day 91

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	47.04	11.7600	13.3769	1.244e-08 ***
Block	3	1.47	0.4900	0.5574	0.6445
Error	12	80.88	0.8791		
Total	19	129.39			

Appendix XVII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug width (Days after establishment of Paspalum turfgrass) ANOVA trial two

Day 49

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	70.54	17.6350	12.142	5.743e-08 ***
Block	3	65.23	21.7433	14.971	5.157e-08 ***
Error	12	133.62	1.4524		
Total	19	269.39			

Day 63

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	102.70	25.675	20.937	2.689e-12 ***
Block	3	153.23	51.077	41.651	2.2e-16 ***
Error	12	112.82	1.226		
Total	19	368.75			

Day 77

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	139.50	34.875	29.120	1.212e-15 ***
Block	3	149.32	49.773	41.561	2.2e-16 ***
Error	12	110.18	1.198		
Total	19	399.00			

Day 91

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	179.66	44.915	31.319	2.2e-16 ***
Block	3	148.16	49.387	34.437	5.176e-15 ***
Error	12	131.94	1.434		
Total	19	459.76			

Appendix XVIII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug height (Days after establishment of Paspalum turfgrass) ANOVA trial one

Day 49

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	155.76	38.940	22.571	5.201e-13 ***
Block	3	180.68	60.227	34.910	3.722e-15 ***
Error	12	158.72	1.725		
Total	19	495.16			

Day 63

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	10.34	2.5850	3.1735	0.01722 *
Block	3	29.16	9.7200	11.9327	1.139e-06 ***
Error	12	74.94	0.8146		
Total	19	114.44			

Day 77

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	69.86	12.465	6.6819	9.121e-05 ***
Block	3	72.80	20.933	6.5713	0.0004489 ***
Error	12	273.10	3.838		
Total	19	415.76			

Day 91

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	24.76	6.1900	3.5460	0.009762 **
Block	3	20.40	6.8000	3.8954	0.011404 *
Error	12	160.60	1.7457		
Total	19	205.76			

Appendix XIX: Effect of biofumigation with African spider plant (*Cleome gynandra*) on plug height (Days after establishment of Paspalum turfgrass) ANOVA trial two

Day 49

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	8.44	2.1100	3.0970	0.01934 *
Block	3	6.67	2.2233	3.2633	0.02494 *
Error	12	62.68	0.6813		
Total	19	77.79			

Day 63

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	17.40	4.3500	4.8972	0.001263 **
Block	3	11.88	3.9600	4.4581	0.005707 **
Error	12	81.72	0.8883		
Total	19	111.00			

Day 77

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	33.34	8.3350	6.3468	0.0001483 ***
Block	3	6.83	2.2767	1.7336	0.1655820
Error	12	120.82	1.3133		
Total	19	160.99			

Day 91

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	72.54	18.1350	6.1825	0.0001884 ***
Block	3	26.44	8.8133	3.0046	0.0343978 *
Error	12	269.86	2.9333		
Total	19	368.84			

Appendix XX: Effect of biofumigation with African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig internode length ANOVA trial one

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	47.830	11.9575	12.850	2.743e-09 ***
Block	3	49.855	16.6183	17.858	2.896e-10 ***
Error	12	178.670	0.9306		
Total	19	276.355			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	60.07	15.0175	8.6450	1.951e-06 ***
Block	3	16.22	5.4067	3.1124	0.02748 *
Error	12	333.53	1.7371		
Total	19	409.82			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	52.85	13.2125	6.5903	5.446e-05 ***
Block	3	64.09	21.3650	10.6567	1.637e-06 ***
Error	12	384.93	2.0048		
Total	19	501.87			

Appendix XXI: Effect of biofumigation with African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig internode length ANOVA trial two

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	23.32	5.8300	5.3496	0.0004178 ***
Block	3	1.36	0.4533	0.4160	0.7417224
Error	12	209.24	1.0898		
Total	19	233.92			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	26.87	6.7175	8.7685	1.601e-06 ***
Block	3	6.76	2.2533	2.9413	0.03433 *
Error	12	147.09	0.7661		
Total	19	180.72			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	34.520	8.6300	6.5601	5.721e-05 ***
Block	3	59.495	19.8317	15.0751	7.517e-09 ***
Error	12	252.580	1.3155		
Total	19	246.595			

Appendix XXII: Effect of biofumigation with African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig leaf length of (cm) ANOVA trial one

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	8.69	2.1729	0.8696	0.48318
Block	3	24.25	8.0831	3.2350	0.02342 *
Error	12	479.75	2.4987		
Total	19	512.69			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	10.9	2.737	1.0236	0.3963
Block	3	28.2	6.073	1.4766	0.2222
Error	12	891.9	1.520		
Total	19	831.0			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	13.75	3.4363	0.7001	0.5928
Block	3	22.30	7.4350	1.5147	0.2121
Error	12	942.47	4.9087		
Total	19				

Appendix XXIII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig leaf length (cm) ANOVA trial two

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	49.50	12.3747	6.8107	3.799e-05 ***
Block	3	6.60	2.2011	1.2115	0.3068
Error	12	348.85	1.8169		
Total	19	404.95			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	55.730	13.9325	8.5662	2.213e-06 ***
Block	3	9.961	3.3205	2.0415	0.1095
Error	12	312.277	1.6264		
Total	19	377.968			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	70.64	17.660	6.3295	8.348e-05 ***
Block	3	134.47	44.824	16.0653	2.332e-09 ***
Error	12	535.71	2.790		
Total	19	740.82			

Appendix XXIV: Effect of biofumigation with African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig leaf width (mm) ANOVA trial one

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	10.900	2.72500	3.6163	0.007238 **
Block	3	4.295	1.43167	1.8999	0.130990
Error	12	144.680	0.75354		
Total	19	158.975			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	3.330	0.8325	1.5032	0.2028
Block	3	2.295	0.7650	1.3814	0.2498
Error	12	106.330	0.5538		
Total	19	111.955			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	4.880	1.2200	2.0594	0.08771
Block	3	4.135	1.3783	2.3267	0.07602
Error	12	113.740	0.5924		
Total	19	123.755			

Appendix XXV: Effect of biofumigation using African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig leaf width (mm) ANOVA trial two

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	13.58	3.3950	5.5703	0.0002905 ***
Block	3	6.68	2.2267	3.6534	0.0135487 *
Error	12	117.02	0.6095		
Total	19	137.28			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	36.88	9.2200	6.4683	6.65e-05 ***
Block	3	9.02	3.0067	2.1093	0.1004
Error	12	273.68	1.4254		
Total	19	319.58			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	10.850	2.7125	3.8001	0.005356 **
Block	3	7.975	2.6583	3.7242	0.012349 *
Error	12	137.050	0.7138		
Total	19	155.875			

Appendix XXVI: Effect of biofumigation using African spider p[lant (*Cleome gynandra*) on *Paspalum notatum* sprig fresh weight (g) ANOVA trial one

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	4.880	1.2200	2.0594	0.08771
Block	3	4.135	1.3783	2.3267	0.07602
Error	12	113.740	0.5924		
Total	19	112.755			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	79.220	19.805	5.9102	0.007254 **
Block	3	49.806	16.602	4.9544	0.018288 *
Error	12	40.212	3.351		
Total	19	16.238			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	43.771	10.9427	3.3278	0.04719 *
Block	3	25.039	8.3462	2.5382	0.10573
Error	12	39.459	3.2882		
Total	19	108.269			

Appendix XXVII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig fresh weight (g) ANOVA trial two

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	8.1791	2.0448	16.585	7.855e-05 ***
Block	3	9.8741	3.2914	26.696	1.353e-05 ***
Error	12	1.4795	0.1233		
Total	19	18.5327			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	85.160	21.2900	27.84	5.436e-06 ***
Block	3	31.659	10.5530	13.80	0.0003393 ***
Error	12	9.177	0.7647		
Total	19	115.996			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	83.699	20.9247	246.485	2.094e-11 ***
Block	3	9.664	3.2213	37.946	2.113e-06 ***
Error	12	1.019	0.0849		
Total	19	94.382			

Appendix XXVIII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig dry weight (g) ANOVA trial one

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	0.5871	0.14678	1.4467	0.278364
Block	3	4.3371	1.44570	14.2494	0.000293 ***
Error	12	1.2175	0.10146		
Total	19	6.1417			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	2.9080	0.72699	3.7207	0.03419 *
Block	3	2.6422	0.88075	4.5076	0.02445 *
Error	12	2.3447	0.19539		
Total	19	6.8949			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	6.3432	1.58581	3.6611	0.03587 *
Block	3	2.6380	0.87934	2.0301	0.16342
Error	12	5.1978	0.43315		
Total	19	14.1790			

Appendix XXIX: Effect of biofumigation using African spider plant (*Cleome gynandra*) on *Paspalum notatum* sprig dry weight (g) ANOVA trial two

Day 68

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	3.9092	0.97729	9.067	0.001301 **
Block	3	6.7377	2.24590	20.837	4.751e-05 ***
Error	12	1.2934	0.10779		
Total	19	12.403			

Day 96

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	3.9005	0.9751	1.3457	0.3093420
Block	3	28.9354	9.6451	13.3104	0.0003997 ***
Error	12	8.6956	0.7246		
Total	19	41.5315			

Day 124

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	84.200	21.0499	232.739	2.941e-11 ***
Block	3	9.507	3.1689	35.038	3.242e-06 ***
Error	12	1.085	0.0904		
Total	19				

Appendix XXX: Effect of biofumigation using African spider plant (*Cleome gynandra*) on uniformity of *Paspalum notatum* turfgrass ANOVA trial one

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	18.617	4.6542	4.2523	0.003054 **
Block	3	9.167	3.0556	2.7918	0.043741 *
Error	12	122.583	1.0945		
Total	19	150.367			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	65.833	16.4583	21.9010	2.263e-13 ***
Block	3	6.500	2.1667	2.8832	0.03898 *
Error	12	84.167	0.7515		
Total	19				

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	305.967	76.492	128.1855	2.2e-16 ***
Block	3	9.167	3.056	5.1205	0.002343 **
Error	12	66.833	0.597		
Total	19				

Appendix XXXI: Effect of biofumigation using African spider plant (*Cleome gynandra*) on uniformity of *Paspalum notatum* turfgrass ANOVA trial two

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	161.543	40.386	76.8460	2.2e-16 ***
Block	3	12.057	4.019	7.6474	9.422e-05 ***
Error	12	69.371	0.526		
Total	19	242.971			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	247.386	61.846	141.206	2e-16 ***
Block	3	3.686	1.229	2.805	0.04227 *
Error	12	57.814	0.438		
Total	19	308.886			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	144.400	36.100	115.0221	2e-16 ***
Block	3	0.714	0.238	0.7586	0.5193
Error	12	41.429	0.314		
Total	19	186.543			

Appendix XXXII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on colour of *Paspalum notatum* turfgrass ANOVA trial one

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	4.283	1.07083	1.1076	0.3566
Block	3	2.425	0.80833	0.8361	0.4768
Error	12	108.283	0.96682		
Total	19	115.91			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	5.717	1.42917	3.4835	0.01012 *
Block	3	0.300	0.10000	0.2437	0.86563
Error	12	45.950	0.41027		
Total	19	51.967			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	3.633	0.90833	2.8902	0.02547 *
Block	3	0.092	0.03056	0.0972	0.96142
Error	12	35.200	0.31429		
Total	19	38.925			

Appendix XXXIII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on colour of *Paspalum notatum* turfgrass ANOVA trial two

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	9.829	2.45714	4.0085	0.004218 **
Block	3	4.943	1.64762	2.6879	0.049078 *
Error	12	80.914	0.61299		
Total	19	95.686			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	27.671	6.9179	22.7073	2.738 ***
Block	3	1.000	0.3333	1.0941	0.354
Error	12	40.214	0.3047		
Total	19	68.885			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	16.7857	4.1964	18.0769	7.341 ***
Block	3	1.1071	0.3690	1.5897	0.1949
Error	12	30.6429	0.2321		
Total	19				

Appendix XXXIV: Effect of biofumigation using African spider plant (*Cleome gynandra*) on density of *Paspalum notatum* turfgrass ANOVA trial one

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	22.383	5.5958	4.6964	0.001532 **
Block	3	5.092	1.6972	1.4244	0.239428
Error	12	133.450	1.1915		
Total	19	160.925			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	17.533	4.3833	6.9967	4.587e-05 ***
Block	3	0.292	0.0972	0.1552	0.9262
Error	12	70.167	0.6265		
Total	19	87.992			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	41.883	10.4708	15.6887	3.196e-10 ***
Block	3	0.292	0.0972	0.1457	0.9323
Error	12	74.750	0.6674		
Total	19	116.925			

Appendix XXXV: Effect of biofumigation using African spider plant (*Cleome gynandra*) on density of *Paspalum notatum* turfgrass ANOVA trial two

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	16.7857	4.1964	18.0769	7.341e-12 ***
Block	3	1.1071	0.3690	1.5897	0.1949
Error	12	30.6429	0.2321		
Total	19	48.4357			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	97.171	24.2929	89.0032	2.2e-16 ***
Block	3	4.936	1.6452	6.0278	0.0007032 ***
Error	12	36.029	0.2729		
Total	19	138.136			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	55.500	13.8750	67.3699	2e-16 ***
Block	3	0.707	0.2357	1.1445	0.3336
Error	12	27.186	0.2060		
Total	19	83.393			

Appendix XXXVI: Effect of biofumigation using African spider plant (*Cleome gynandra*) on overall quality of *Paspalum notatum* turfgrass ANOVA trial one

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	24.950	6.2375	6.1923	0.0001541 ***
Block	3	3.225	1.0750	1.0672	0.3660401
Error	12	112.817	1.0073		
Total	19	140.992			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	20.050	5.0125	11.6352	6.163e-08 ***
Block	3	1.292	0.4306	0.9994	0.396
Error	12	48.250	0.4308		
Total	19	69.592			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	96.617	24.1542	45.403	2e-16 ***
Block	3	3.500	1.1667	2.193	0.09282
Error	12	59.583	0.5320		
Total	19	159.700			

Appendix XXXVII: Effect of biofumigation using African spider plant (*Cleome gynandra*) on overall quality of *Paspalum notatum* turfgrass ANOVA trial two

Day 76

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	80.171	20.0429	46.2990	2.2e-16 ***
Block	3	7.107	2.3690	5.4725	0.001414 **
Error	12	57.143	0.4329		
Total	19	144.421			

Day 106

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	122.314	30.5786	119.8244	2e-16 ***
Block	3	1.886	0.6286	2.4631	0.0653
Error	12	33.686	0.2552		
Total	19	157.886			

Day 140

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	4	70.214	17.5536	100.3061	2e-16 ***
Block	3	1.221	0.4071	2.3265	0.07762
Error	12	23.100	0.1750		
Total	19	94.535			