RESPONSE OF GROUNDNUT (*Acharis hypogea* L.) GENOTYPES TO YELLOW WITCHWEED (*Alectra vogelii* (Benth.) INFESTATIONS

BY

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DECLARATION

I William Makaza, do hereby declare that this thesis is a result of my original research work except where clearly and specifically acknowledged. This thesis "**RESPONSE OF GROUNDNUT (*Acharis hypogea* L.) GENOTYPES TO YELLOW WITCHWEED (*Alectra vogelii* (Benth) INFESTATIONS"** has not been submitted in any form before for any degree or examination in any other university.

Sign..... Date.....

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This is being submitted for the partial fulfillment of the requirements for a Bachelor of Science Honours degree in Agriculture (Crop Science) with the approval of supervisors.

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ABSTRACT

Witch weed (*Alectra vogelii* Benth) is a parasitic weed of legumes which causes severe decrease in yield of groundnut in Africa, where the crop is an important source of protein for resource poor farmers. The use of *Alectra* resistant groundnut genotypes is one of the sustainable and effective ways to control this weed. A project aiming to establish the response of different groundnut genotypes to *Alectra* infestation and groundnuts level of *Alectra* resistance and tolerance was conducted at the University of Zimbabwe. Seven groundnut genotypes were screened using the laboratory agar-gel technique and pot experiments under glasshouse at the University Zimbabwe during the 2018/19 cropping season. All experiments were laid out in Randomized Complete Block Design. The pot experiment was laid out as a 7(groundnut genotypes)*2(*Alectra* infestation: infested and non-infested) factorial experiment with six replications. In the laboratory, the agar-gel screening experiment revealed significant ($p<0.05$) differences among genotypes in terms of germination percentage and furthest germination distance. Dendera and Nyanda had significantly ($p<0.05$) higher germination percentage and furthest germination distances (2 mm and 3.34 mm) respectively. There were significant ($p<0.05$) genotype x *Alectra* interactions on plant biomass, shoot to root ratio and shelled grain yield. *Alectra* parasitism significantly ($p<0.001$) reduced plant biomass, shoot to root ratio and shelled grain yield across all groundnut genotypes. On *Alectra* attachments on the roots of groundnut genotypes, significant ($p<0.05$) differences were recorded on infested groundnut genotypes. Njiva did not support any haustorial attachment, and had the highest shelled grain yield under all *Alectra* levels which is a good indication for resistance. The groundnut genotypes Ilanda and Guinea fowl seem to be tolerance genotypes based on their plant biomass, shoot to root biomasses produced and shelled grain yield as compared to other genotypes.

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DEDICATION

I dedicate this work to my parents, Mr. L. Makaza and Mrs A. Makaza, whose dreams and ambitions were to see me prosper beyond the ordinary.

LIST OF ABBREVIATIONS

ai	Active ingredient
DPM	Days to Physiological Maturity
DRSS	Department of Research and Specialist Services
DTA	days to 50% anthesis
ETR	Electron Transport Rate
Fm	Maximum fluorescence
Fv	Variable fluorescence
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
NaClO	Sodium Hypochlorite
RCBD	Randomized Complete Block Design
SAFGRAD	Semi-Arid Food, Grain and Development
WACE	Weeks after crop emergence
WAP	Weeks after planting

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CHAPTER ONE

INTRODUCTION

1.1 Background

Parasitic weeds pose increasing threats to rain-fed legume production in Africa. The most economically important species in sub-Saharan Africa is *Alectra vogelii* (Benth) (Rodenburg *et al.,* 2016). Information on the regional spread and economic importance of parasitic weeds in cereal production systems is scant. These weeds depend on other plants for part or all of their nutrition (Riches *et al.,* 1992). They parasitize by making a xylem-to-xylem and/ or phloem connection with the host plant using a specialized organ called a haustorium (Rodenburg *et al.,* 2016). Through this connection the parasite extracts water, nutrients and metabolites and alters the plant growth regulators of the host, resulting in stunted growth and losses in reproductive output of the host plant (Nyakurwa *et al.,* 2018). Known hot-spots of *Alectra* infestation in legumes include most sub-Saharan Africa (SSA) countries, such as Botswana (Fite *et al.,* 2009), Ethiopia (Hussien *et al.,* 2006), Malawi (Mbwaga *et al.,* 2010), Nigeria (Motagi *et al.,* 2014; Singh and Emechebe, 1997) and Tanzania (Mbega *et al.,* 2016) and Africa at large (Kureh and Alabi, 2003; Kureh *et al.,* 2005a). Infestation by *Alectra* has been reported to cause dry matter and grain reduction in cowpea resulting in failure to attain food security and malnutrition (Alonge *et al.,* 2001a; 2001b).

Groundnut (*Acharis hypogeal* L.), which is an annual and widely grown leguminous summer crop with nutritional and health benefits (Motagi *et al.,* 2014) plays a significant role in food security. It empowers women and is a source of income to most resource limited communities in SSA and perhaps is not the first crop one would associate with parasitic weed problems (Rodenburg *et al.,* 2016). The problem is more generally known to occur in leguminous crops, which include cowpeas (*Vigna unguiculata* L. (Walp), common beans (*Phaseolus vulgaris* L.)

and bambaranuts (*Vigna subterrenia* L. (Verdc) in SSA (Mbwaga *et al.,* 2010; Riches and Parker, 1995).

Various strategies have been adopted by farmers to manage the impact of parasitic weeds. Hand pulling and hoe weeding are the most common methods used by farmers. These methods have been ineffective, since much damage would have been done to crops before the parasitic weeds emerge (Kwaga, 2014b; Magani and Lagoke, 2009; Riches *et al.,* 1992). *Alectra* management has been successful in more economically developed countries including United States of America (USA) where there is efficient use of modern technologies that directly impacts *Alectra* seed production and decrease its seed viability in soil (Parker, 2012). These technologies include the use of chemicals, such as ethylene gas and synthetic analogues of strigolactones, which stimulate parasitic seed germination (*Alectra* or *Striga*) in the absence of a host plant (Nyakurwa *et al.,* 2018). Most of the effective technologies and methods, which include the use of herbicides, bio-control options, and genetic host plant improvement that is tolerance or resistance to *Alectra* infestation, used to control *Alectra* are not stretched yet to reach smallholder farmers in SSA. As a result, farmers experience high costs in trying to manage the parasite (Ransom *et al.,* 2012).

Alectra vogelii (Benth) is spreading at an alarming rate such that farmers are abandoning their farmlands; others are shifting from grain legume production. The use of genetics as a defense mechanism, for instance, the use of resistant or tolerant genotypes, has become a feasible and economically useful method that reduces cowpea and soya beans yield losses caused by *Alectra* parasitism (Christopher *et al.,* 2018; Kureh *et al.,* 2005a).

In SSA, there are no groundnut genotypes developed for resistance/ tolerance to yellow witchweed. The reason might be due to lack of interests in breeding programs to concentrate on self-pollinating crops because farmers do not buy groundnuts seed but they keep and retain seeds from previous seasons. Therefore, determining reaction of groundnut genotypes to witchweed (*Alectra vogelii)* infestations in order to achieve maximum yield should be done (Mwaipopo, 2014).

1.2 Problem statement

Groundnut productivity on small scale farming systems is generally low and is under threat due to *A. vogelii* parasitism. This weed is seriously affecting groundnut production and other grain legumes. In SSA, it has reached endemic proportions in the smallholder sector (Kabambe *et al.,* 2008; Kamara *et al.,* 2008; Karanja *et al.,* 2011). *Alectra vogelii* pre-attach to the roots of the host plants through haustorium extracting nutrients thus crop damage and yield losses greater than 80% (Mandumbu *et al.,* 2017; Mbwando *et al.,* 2016*;* Mwaipopo, 2014; Rugare *et al.,* 2013). Its prolificacy is very high and it ranges from 400 000 to 600 000 seeds per plant, with high seed longevity of up to 15 years. *Alectra* damage groundnuts from underground, making it difficult to control; it does not save the current crop from damage (Rugare *et al.,* 2013). *Alectra vogelii* can co-occur simultaneously with other *Striga spp* in arable farmers' fields making it practically impossible to use crop rotations to manage this parasitic angiosperm. Currently, there are no herbicides registered for use in controlling this parasite and if any, farmers do not have the capacity to access them due to financial constraints and small-owned land. As a result, farmers will end up abandoning their infested fields and change the cropping systems which have serious consequences on the farmers' family and food security (Mandumbu *et al.,* 2017). Weed control

is based on mechanical, cultural and physical control methods for smallholder farmers though not effective for *A. vogelii* because the weed causes damage before it emerges. In northern Zimbabwe, about 6% of the farmers use fertilizers to manage *Alectra* but the proportion of farmers using fertilizers is very low because inorganic fertilizers are not within the reach of smallholder farmers (Mandumbu *et al.*, 2017). Lack of known groundnut genotypes with genetic capacity to resist or tolerate *Alectra* infestations exacerbates the situation. So far, few studies have been done on groundnuts response to *A. vogelii.* This indicated that no feasible measures have been developed to control rapid spread and distribution of *A. vogelii* in SSA. Farmers are left with no option in the production of leguminous crops; rather, there is need for evaluation of host resistance within groundnut genotypes as a sustainable method of *Alectra* control.

1.3 Justification

Groundnut is widely grown in SSA by smallholder farmers and is highly valued by the resource poor people. Different control measures have been widely proposed for controlling *A. vogelii* and this includes hand weeding, chemical control, crop rotation and use of trap crops but these methods have had little success. However, use of host plant resistance is an alternative way that is most effective, economical and environmentally friendly to control *Alectra*. This could create awareness that could be used by farmers in making informed decisions in the choice of genotypes to grow since most farmers are interested in the yield and related agronomic performance than nutritional composition which they cannot measure. As a result, comparison of yield and related agronomic performance, which include tolerance or resistance of groundnut genotypes, could help to identify genotypes to recommend to farmers. There is great benefit in identifying and growing groundnut genotypes that can tolerate or resist the effects of *Alectra* as it would aid in regaining *Alectra*-infested land. Thus, boosting the production of groundnuts;

making it most suitable for the SSA farming community which cannot afford other control and advanced production strategies.

1.4 Research hypotheses

1. Groundnut genotypes produce different strigolactones as measured by germination percentage and furthest germination distance between groundnut root and *Alectra*.
2. Related agronomic performance on both infested and non-infested groundnut genotypes do not differ. Physiological attributes; chlorophyll content and chlorophyll fluorescence can differ between groundnut genotypes.
3. Yield and yield components for groundnut genotypes under *Alectra* infestations are be lower than non-infested genotypes.

1.5 Overall objective

The overall objective of this study is to determine the response of groundnut (*Acharis hypogea* L.) genotypes to yellow witchweed (*Alectra vogelii (*Benth)) infestation.

1.6 Specific objectives

1. To determine stimulant production of different groundnut genotypes by assessing germination percentage and the furthest germination distance of *Alectra* from groundnut root using the agar gel technique.
2. To determine the effect of *A. vogelii* infestation on the plant height, plant vigor, days to 50% anthesis, haustorial attachment, chlorophyll content, chlorophyll fluorescence, plant dry weight, grain texture, and grain yield on groundnut.
3. To determine the effect of different groundnut genotypes on the biomass of *Alectra vogelii*.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Groundnut (*Acharis hypogeal* L.) is an important herbaceous legume crop (Ayoola *et al.,* 2012), and about 36% of smallholder farmers in Zimbabwe grow and depend on this crop (ZimVAC, 2014). It was introduced in China only in the 17th century, but today China is its largest producer, followed by India, USA, Nigeria and Indonesia (FAO, 2010). Groundnut can grow under different conditions, between 40° north and 40° south (Ayoola *et al.,* 2012). It is the 5th most widely grown crop in sub-Saharan Africa behind maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), and millet (*Panicum miliaceum* (L.) R. Br.) and cassava (*Manihot esculenta* Crantz) (FAO, 2010). Nigeria produces 30% of Africa's total, followed by Senegal and Sudan with each about 8%, and Ghana and Chad with about 5% each. In most countries groundnut is grown nearly exclusively for domestic use, either for consumption or as cash crop for small farmers (Nautiyal, 2002).In Zimbabwe, groundnuts are an important source of income, food, nutrition, feed and soil amendment and ranks second only to maize in terms of importance and area coverage, and are cultivated by an estimated 36% of the country's smallholder farmers, across the different agro ecological zones (ZimVAC, 2014).

Weeds are important biotic constraints in agro-ecosystems that interfere with crop plants and consequently reduce yield and quality of crops (Lemessa and Wakjira, 2014; Saritha, 2004). An estimated worldwide crop yield loss of about 43% was reported when weeds were left uncontrolled (Kombiok *et al.*, 2012). The menace of weeds can be more devastating and leads to drastic reduction in crop yield especially where parasitic weeds are prevalent. Various strategies have been adopted by farmers to manage the impact of parasitic weeds. Hand pulling and hoe

weeding are the most common methods used by farmers. These methods have been ineffective, since much damage would have been done to host crops before the parasitic weeds emerge (Kwaga, 2014b; Magani and Lagoke, 2009; Riches *et al.,* 1992).

2.2 Origin and Geographical distribution of *A. Vogelii*

Alectra vogelii (Benth) is a parasitic weed which attacks most of the legume crops in sub-Saharan Africa (Ally, 2015). Groundnuts (*Acharis hypogea* L.) and cowpea (*Vigna unguiculata*) are major hosts for this weed (Kureh *et al.,* 2005b). *Alectra vogelii* is an annual weed, which attacks most legume crops in SSA posing yield losses of about 50-100% depending on the severity of infestation (Rugare *et al.,* 2013). *Alectra vogelii* is well distributed throughout semi-arid areas of both tropical and sub-tropical regions in the East, West, Central Africa and on Southern Africa (Kureh *et al.,* 2005b). This parasitic weed is closely associated with cultivation, is occasionally found associated with weeds of fallows but rarely in natural vegetation. High seed production and seed longevity of up to fifteen years in seed banks allow the rapid build-up of infestations when susceptible crop cultivars are planted (Rugare *et al.,* 2013). *Alectra* seed dissemination over the world may increase due to crop-seed contamination during grain legume shipments to markets, commercially sold legume seed or samples being distributed for trials by research organizations (Mwaipopo, 2014). This parasitic weed is widely spread in the Southern African countries including Botswana, Malawi and Tanzania (Fuglie *et al.,* 2012).

2.3 Hosts/species affected with *A. vogelii*

Alectra vogelii has wide range of hosts specifically in crops of *Asteraceae* and *Fabaceae* families (Parker and Riches, 1993). Groundnuts, cowpeas (*Vigna anguiculata* (L.) Walp.) and bambaranuts (*Vigna subterranea* (L.) Verdc.) are major hosts for *A. vogelii* (Mwaipopo, 2014). Other leguminous crops such as common bean (*Phaseolus valguris* L.), soyabean (*Glysine max*

L.), mung bean [*Vigna radiata* (L.) R.] and tepary beans (*Phaseolus acutifolius* A. Gray) are also common hosts. In addition to leguminous cover crops attacked by *Alectra,* which include African *Indigofera* and *Tephrosia* species, lablab (*Lablab purpureus* L.),velvet bean (*Mucuna pruriens* L. DC),and runner bean (*Phaseolus coccineus* L.) it also parasitizes a number of non-legume weeds including upright stabur (*Acanthospermum hispidum* (DC) and *Vernonia poskeana* (Vatke & Hildebr.) (Compositae), spurge (*Euphorbia* (L.C. Leach.) (Euphorbiaceae) and beach hibiscus (*Hibiscus* (Exell) (Malvaceae) species. Host range tests by Riches and Parker (1995) indicated that populations from Mali, Nigeria and Cameroon can attack groundnut and cowpea. Samples from eastern Botswana and northern areas of Northern Province South Africa (Riches, 1988), attack mung bean in addition to cowpea and groundnut (Visser and Beck, 1989). Populations sampled from Kenya, Malawi and eastern areas of Northern Province, South Africa, parasitize bambaranut as well as crops that are susceptible elsewhere (Mwaipopo, 2014; Ndung'u *et al.*, 2013).

2.4 Socio-economic impact of *Alectra vogelii*

Groundnut is an important source of edible oil for millions of people particularly resource poor farmers in the tropics, where there is high food insecurity, malnutrition and income are difficult to mitigate due to climate change (Atokple *et al.,* 1995). High incidence of poverty, hunger and malnutrition were noted in Tanzania due to *Alectra vogelii* (Benth) infestation (World Bank, 2000). *Alectra* infestation reduces yield of grain legumes to families in semi-arid savannahs of SSA areas where their diets are dominated by starchy and protein foods such as millet, maize, cassava, groundnuts, cowpeas and bambaranuts (Jat *et al.,* 2011; Fuglie *et al.,* 2012). The extent of yield loss depends on the susceptibility of the cultivar with greatest losses reported for introduced lines rather than landrace types (Parker, 1991; Riches *et al.,* 1992). For instance, soya

bean genotype TGX1486-2D (Mbega *et al.,* 2010) and groundnut varieties SAMNUT 10, 11 and 22 (Mbega *et al.,* 2010) promote *Alectra* germination and simultaneously give high yields. Such varieties that are able to maintain high yield when infected by Alectra are said to be tolerant.

In Kenya, 20% yield losses were reported in cowpea and groundnuts (Bagnall-Oakeley *et al.,* 1991), in Botswana, non-infested fields of the cowpea cultivar Blackeye, introduced from the USA, produced an average grain yield of 602 kg/ha while in *Alectra*-infested fields had less than 20% yield harvested (Riches, 1988). Losses in groundnut of 15% have been recorded due to *Alectra* parasitism in Nigeria (Salako, 1984) and yield reduction in bambaranut in South Africa of 30-50% has been observed. Sometimes yield losses were correlated to late sowing. In soya bean, late sowing resulted in a significant destruction of the crop by the *Alectra* in northern Nigeria (Alonge *et al.,* 2001a; 2001b; Yohanna *et al.,* 2010). *Alectra* is also a constraint to common bean production in the Blantyre Shire Highlands (Riches and Parker, 1995) and Lilongwe and Dowa districts of Malawi (Kabambe *et al.,* 2013; Mbwaga *et al.,* 2010); introduced cowpeas are often very susceptible to *A. Vogelii.* The parasite is common in Mwanza, Shinyanga, Dodoma, Ismani and Ruvuma regions with yield losses of up to 50% in Tanzania (Mbega *et al.,* 2016; Mbwaga *et al.,* 2010).

2.5 Strategies to improve resistance or tolerance in groundnuts

There is need for fast track release of new stress resilient, nutrient dense varieties with suitable post-harvest handling and food safety qualities as well as ensuring continuous supply of breeder and foundation seed of improved groundnut varieties, following market demand (Adagba *et al.,* 2002). Sustainable massive production, bulking and distribution of certified high-quality legume

seeds through different inspections, with high adoption by smallholder farmers is crucial to reduce rapid yield losses in *Alectra*-infested fields in SSA.

2.6 Control methods and their limitations

2.6.1 Agronomic practices

Cultural methods of control are involving the manipulation of all agronomic activities without the application of synthetic herbicides. These are crop management techniques, which reduce *Alectra vogelii* numbers to very low levels and give farmers an economic yield with a long-term solution to the *Alectra* problem. Growing groundnut together with trap crops such as sunflower (*Helianthus annus* L.) either in rotation or as intercrops helps to alleviate *Alectra* problem (Lemessa and Wakjira, 2014). Trap crops induce *Alectra* seed germination but do not support its subsequent growth and development. In the absence of suitable host, there is suicidal germination of *Alectra* seedling (Magani and Lagoke, 2008). Studies show that the incidence of *Alectra* infestations on groundnuts maybe reduced when N-fertilizer is applied (Kwaga, 2014a; 2014b).

2.6.2 Crop rotation with trap crops.

Crop rotation is practiced where crops are cultivated in succession with or without a rest period (fallow) in between. As continuous cropping of legumes increases, some problems of declining in soil fertility due to monoculture and pest build-up might be encountered. Even though crop rotation offers no means of eradicating *Alectra,* its adoption as a farm practice in conjunction with the use of trap crops may accelerate natural depletion of the reservoir of the seed in the soil. Rotating susceptible grain legumes with sunflower (trap crop) and/ or catch crop for instance sunnhemp (*Crotalaria juncea* L.) increases yields of susceptible species (Berner *et al.*, 1993). Yoneyama *et al.* (2015) reported an increase in cowpea yield when the crop was grown after sunflower in fields infested by *Alectra*. The rotations of grain legumes with sunflower and/ or

other soil improving cover crops such as sunnhemp will contribute towards keeping down *Alectra* infestation levels. The success or failure of eradicating *Alectra* by rotation depends on the longevity of the seed in the seed bank and the capacity of the trap crop to produce strigolactones.

2.6.3 Intercropping with trap crops.

Associating grain legumes with cereal species such as sorghum (*Sorghum bicolor* L.) and sunflower was found to decrease *A. vogelii* impact on naturally infested fields. Singh and Emechebe (1997) also emphasized the use of cowpea in association with sorghum, as a promising technique for increasing productivity in *Striga* and *Alectra* infested fields. Reduced incidence of *Alectra* and *Striga* was associated with high yields produced on cowpea and sorghum especially in the in-row intercropping pattern (Mbega *et al.,* 2010). In-row intercropping allows grain legume roots to be very close to sunflower or sorghum roots than those between rows (Mbega *et al.,* 2010). Singh *et al.* (1991) observed that intercropping legumes with cereals may be effective in increasing overall crop productivity under *Alectra* or *Striga* infestation. There is a scope to test whether intercropping groundnuts, bambaranuts, cowpea or soya bean with any cereal crop is effective in controlling *Alectra* in Zimbabwe's smallholder farming sector.

2.6.4 Ridges and Furrows

The creation of ridges and furrows plays a vital role in *Alectra* management. Ridges have the capacity to hold water for a long time; thus, improving moisture status in the field and enhance high groundnut yield and reduced *Alectra* infestation. Many options reported in the management of *Striga* were reported to be effective in *Alectra* management. A study by Singh *et al.* (1994)

reported reduced number of *Striga hermonthica* and high maize grain yield from grain planted on ridges compared to that planted on gentle flat slope. This could be due to improved moisture status under ridge and furrow system which causes low germination of the parasite. The possibility of adopting this technique for *Alectra* management offers a major prospect for sustainable crop production (Munguri, 1996).

2.7 Chemical control

Herbicides are substances that are toxic to plants, used to kill or destroy unwanted vegetation (Monaco *et al.,* 2002), which can be classified based on time of application, formulation, chemical structure and mode of action. In *Alectra* management, the application of pre-emergence herbicides containing pree (metazochlor + antidote) followed by imazaquin at 0.18 kg a.i ha^{-1} resulted in significantly lower number of infected plants (Magani and Lagoke, 2008). Pendimethalin and imazaquin are post emergence herbicides applied at 0.85 +0.15 and 1.09 + 0.19 kg a.i ha^{-1} and pendimethalin + imazethapyr at 1.58 + 0.12 kg a.i. ha^{-1} resulted in lower number of cowpea plants infested by *Alectra* (Johnson *et al.,* 2001). Imazaquin was reported to be used in cowpea seed treatment for *Alectra* and *Striga gesneroides* control. Preliminary experiments by Berner *et al*. (1994) indicated that cowpea seed treatments of five minutes in aqueous solutions of ammonium salt of imazaquin significantly reduced the number of attached (emerged and unemerged) parasite by 90 % when comparing to control treatments. Increase in time of soaking also increase good parasitic control (Magani and Lagoke, 2008). This mechanism of control is known as post-attachment mortality of the parasite because it does not reduce parasite seed germination (Berner *et al.,* 1993). Metolachlor and pendimethalin are two pre-emergence herbicides that were recommended particularly in an integrated approach although can be useful when used alone alone in suppressing *Alectra* attachment (Eplee *et al.,* 1991, Magani *et al.,* 2009). Pendimethalin is a soil applied herbicide that can be translocated

apoplastically (Monaco *et al.,* 2002) and is applied pre-emergence at 1.7 kg a.i. ha^{-1}. Results by Eplee *et al.* (1991) indicated that it has 100 % reduction to early *Striga* and *Alectra* emergence (Lagoke *et al.,* 1993). However, the control measures recommended for *Striga* were generally applicable to *Alectra* control. Also, herbicide application is recommended to be one in conjunction with supplementary hoe weeding as this indicated high pod weight and grain yield in cowpea production (Magani *et al.,* 2009; Magani and Lagoke, 2008).

A study by Eplee *et al.* (1991) revealed that the application of pendimethalin herbicide at 1.7 kg a.i ha^{-1} to the soil surface decrease early *Striga* emergence by 100 %. Therefore, the use of pre and post emergence herbicides can suppress and/ or prevent *Alectra* germination, emergence and seed production. The use of antidotes which are soil applied herbicides is highly recommended for the parasitic weed management because of low phytotoxicity compared to imidazolinones. Dinitroanilines herbicides which are recommended however need extra caution when applying them because they are highly volatile and photo-decomposable therefore they need incorporation within 12 hours of application.

There are certain germination stimulants, which can work as chemical control measures which include strigol and strigol analogues such ethylene and ethephon that can stimulate *Alectra* seed germination without a suitable host and consequently reduce soil seed reserves (Mandumbu *et al.,* 2019). The synthesis of strigolactones by the host plant in dicotyledonous plant species could be reduced if sufficient minerals are available (Lopez-Raez *et al.,* 2008).

2.8 Soil fertility Management

Alectra vogelii is more destructive with more impact in low-input farming; subsistent farming systems and many farmers' fields have been infested. The damage is aggravated by poor soil nutrient status and unreliable rainfall (Kureh and Alabi, 2003). Soil nutrient deficiency especially N and P deficiency, and water stress impacts *Alectra vogelii* severity to host plants. This parasitic weed is sometimes considered as a pest which can highly adapt to inherently infertile soil. The sufficient application of soil nutrients particularly N and P usually decrease the infection (Adagba *et al.*, 2002; Teka, 2014).

The application of organic and/ or inorganic fertilizers is highly appreciated by many people when managing *Alectra* infestation. High Nitrogen and Phosphorous fertilizers are the most recommended fertilizers in the management of *Alectra* infestation as well as poultry manure (Kamara *et al.*, 2013, Kureh and Alabi, 2003). Nitrogen metabolism has been studied; addition of Nitrogen fertilizers and/ poultry manure reduces the production of germination stimulants in the host and can compensate for lack of gibberellic acid in the host as well as indicating the stress on host nitrogen resources (Musselman, 1980). This gibberellic acid is a growth hormone that stimulates cell elongation and cause plants to grow taller, vigorous and healthy (Kwaga, 2014a). The direct relationship between sugar sink caused by parasite and the nitrogen starvation has been reported (Musselman, 1980). Nitrogen is carried from roots to the aerial portions of plants in the phloem but when more sugars are drained from the host; there is less Nitrogen translocated, and thus resulting in a decrease in amino acid synthesis, growth and sugar production in the crop plants (Kwaga, 2014a). The efficacy of Nitrogen fertilizer and poultry droppings was evaluated in ameliorating the effects of *Alectra* parasitism on groundnut genotypes such as SAMNUT 10, SAMNUT 11, SAMNUT 22 and Kampala (Kwaga, 2014b).

Nitrogen and poultry droppings increase groundnut vigor; therefore, higher ability to support higher parasitic infestation as it develops a haustorium which invades the root of the host to create a conductive bridge that withdraws water, ions and nutrients. Poultry manure supply adequate Nitrogen, Phosphorous, Potassium and Sulphur which are major nutrient elements and can improve crop yield (Kwaga *et al.,* 2010). Low germination stimulant production by groundnut was reported after application of 25 and 50 kg Nitrogen per hectare.

The synthesis of germinating stimulants can be due to nitrogen and phosphorous deficiency or incorrect application of phosphorous and nitrogen fertilizers. But however, nitrogen fertilizer application may not be a practically successful option because many smallholder farmers seldom use nitrogenous fertilizers on legume crop production. Phosphorus fertilizers were known to limit the synthesis of strigolactones thereby decreased *Alectra* seed germination (Chitagu *et al.,* 2014). Manyong *et al. (*2008) reported the importance of manure application in the management of the parasitic weeds. They revealed the increase in the nutrients after manure application in the soil for crops to grow well thus adequate supply of nutrients but do not decrease the parasitic weed seed bank. The assumption was that the crop becomes tolerant to *Alectra*; and resources were adequately available to support both the weed and the crop (Kabambe *et al*., 2013). Parker and Riches (1993) reported that the suppression of parasitic weeds development, inhibition of its germination has to do with the lethal effect of nutrients. Just as contact between young crop seedlings and nitrogen fertilizers can be lethal to the crop, contact between nitrogenous fertilizers and root parasites which are tender herbs, can be debilitating on the herbaceous weed (Magani, 1994).

Table 2. 1 Response of legume crops to different fertilizer applications under *Alectra* infestation

Fertilizer application	**Response**	**References**
Poultry manure	Inhibition of parasitic weed germination, low germination stimulant production, increased crop yield	(Kwaga *et al.*, 2010, Kwaga 2014a, Kwaga, 2014b)
Cattle manure	May increase *Alectra* germination, Increase crop yield	(Atera *et al.*, 2013, Kamangira *et al.*, 2016, Khan *et al.*, 2013, Mandumbu *et al.*, 2016)
Nitrogen and Phosphorous fertilizers (inorganic)	Low stimulant production, low *Alectra* germination, attachment and development, increase in photosynthetic rates Limit production of Strigolactones, decrease parasitic weed seed germination	(Adagba *et al.*, 2002, Fernández-Aparicio *et al.*, 2011, Khan *et al.*, 2013)
Organic residues	Inhibit conditioning *Alectra* for germination, decrease *Alectra* seed viability, produce ethylene which cause death of seedlings in the absence of host	(Gacheru and Rao, 2001)

2.9 Integrated Weed Management

Integrated weed management involve use of all control measures; cultural, physical, biological, and chemical whereby two or more compatible techniques are used to control weeds. Integrated approach has been developed and it involves timely destruction of legume crop residues to reduce parasite seed production after harvest and trap-crops should be included in the rotation to reduce the soil seed bank (Magani and Lagoke, 2009; Mwaipopo, 2014). Uprooting the emerged *A. vogelii* shoots helps to reduce *Alectra* seed rain (Fuglie *et al.*, 2012). Genetic resistance or tolerant cultivars of groundnuts can help to reduce amount of seed deposited into the seed bank and can be used in combination with other control measures. Nutrition management is vital because witchweeds are endemic in depleting nutrients especially nitrogen and phosphorous, hence the need to balance nutritional composition of the soil. Intercropping can be done to

increase productivity where catch/trap/cover crops are being used in association with other weeds. Rotations with agroforestry trees including tephrosia (*Tephrosia vogelii* Benth), river hemp (*Sesbania sesban* (L.) Merr.)) during integrated management can reduce the impact parasitic weeds (Musselman, 1980).

2.10 Host plant Resistance and breeding for *A. vogelii* resistance in groundnuts

Little progress has been made in Africa in controlling *Alectra* on groundnuts by host plant resistance through screening and breeding programmes. This work has to be done among scientists at national, regional and international levels. Initial work was conducted by IITA scientists in Burkina Faso working in a joint project with International Development Research Centre (IDRC), Canada, the Semi- Arid Food Grain and Development (SAFGRAD) project of the organization of Africa Unity and ICRISAT (Kouakou *et al.*, 2008) recommended the use and breeding of resistant and or tolerant genotypes in the control of *Alectra* in grain legume crop production (Hussien *et al.,* 2006; Singh, 2002). The mechanism of resistance to *A. vogelii* has been studied (Rambakudzibga *et al.,* 2002; Kouakou *et al.,* 2008; Ngwako and Mwashungwa, 2011). Results showed that, there are at least two mechanisms of resistance but neither of them reduces parasite germination nor prevents haustorial formation at the potential host. Parasite seeds germinate as usual and the radicles attached to the roots, but the resistant roots do not permit haustorium development (Visser *et al.,* 1977). *Alectra* depends on chemical signals in the rhizosphere which trigger certain stages to occur in the life cycle. Therefore, any genetic differences that occur during biosynthesis and/or release of stimulants can decrease *Alectra* seed viability and/ or potentially conferred pre-attachment.

The use of host plant resistance in *Alectra* management is now a promising control option for parasitic weeds, which is feasible and environmentally friendly. The use of biotechnological approaches, which include biochemistry, tissue culture, plant genetics and breeding and molecular biology play a significant role in the progression made to develop screening methodologies and new laboratory assays, which lead to the proper identification and screening of sources of *Alectra*-host resistance (Diana *et al.,* 2018; Ejeta, 2007).The resistant groundnut cultivars, produce little or no stimulants, can be used under different environmental conditions, which include unreliable or erratic rainfall, low soil fertility and primitive agriculture. There are other factors involved in the resistance mechanism such as time of maturation of the host relative to infection. Most of the grain legume crops including cowpea, soya beans and bambaranuts were screened and evaluated for resistance to *Alectra* parasitism. The same conditions are occurring in the management of *Striga* species in sorghum, pearl millet, rice, tomato, eggplant and tobacco (Chitagu *et al*., 2014). Legume crops are capable of biological nitrogen fixation (BNF), therefore tolerant or resistance genotypes exhibit high growth and high nodulation under the influence of *Alectra* (Kureh and Alabi, 2003). It has been reported that susceptible legume cultivars (for example soya bean) have non-viable nodules due to *Alectra* infestation as it interferes with rhizobium nodulation (Kureh and Alabi, 2003) but resistant genotypes have the capacity to maintain rhizobium nodulation as they have high photosynthetic capacity. Therefore, the use of resistant or tolerant cultivars is a more plausible approach for parasitic weed management (Li and Timko, 2009).

Although it is difficult to access resistance against weed parasite, significant successes have been achieved in some groundnut, cowpea, soyabean and bambaranut genotypes where there is scarcity of complex nature of low heritability. Host plants escape infestation by reduced biomass

and by root architecture; that avoids soil layer in which seeds of parasites are common. Hosts limit damage (tolerance) through the influence of source-sink relationship which include the osmotic pressure and those tolerant genotypes produce good crops despite the severity of the pathogen. Low germination stimulant production successfully exploited in groundnut genotypes (SAMNUT 10, 11 and 22) thus revealing tolerance or resistance (Kwaga *et al.,* 2010). The understanding of the escape and resistance factors can help in detecting existing genetic diversity for mechanisms that interfere with the infestation. Combining different resistance mechanisms into a single cultivar will provide a long-lasting result (Fernández-Aparicio *et al.,* 2011). These mechanisms involve *invitro* screening methods to allow identification of highly heritable resistance components and the adoption of marker-assisted selection techniques (Perez-de-Luque *et al.,* 2004).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Site

The pot and agar-gel experiments were conducted at the Department of Crop Science, University of Zimbabwe. The University of Zimbabwe is located at longitude 31.05^{o}E and latitude of 17.48^{o}S, and 1 525 metres above sea level. The glasshouse pot experiment was carried out in the glasshouse where temperature ranges between 30-35^{o}C and relative humidity of 80% in the summer rainy season of 2018 / 2019 using sandy soil to fill the five litre pots in order to mimic edaphic conditions under which the parasitic weed exerts its dominance.

3.2 Plant materials

Witchweed seed were collected from Rushinga communal areas in Mashonaland Central Province in 2012 and thus was ideal for this work. A total of seven groundnut genotypes that include Tern from Zimbabwe super seed (ZimSuperSeed), Ilanda and Jessa from the Department of Research and Specialist Services (DRSS), Njiva, Guinea Fowl, Dendera, and Nyanda, from ICRISAT Zimbabwe were evaluated. The attributes of the genotypes used are shown in Table 3.1.

Table 3. 1 Attributes of groundnut genotypes that were used in the study

Genotype	Source	Attributes
Tern	Zim-Super Seed	A medium size pale coloured seed of medium season variety that exhibits high yield potential, high kernel/seed potential, tolerance to dry spells/drought conditions, fair tolerance to early and late leaf spot diseases.
Ilanda	DRSS	A medium size pale coloured seed of medium season variety that exhibits high yield potential, high kernel/seed potential, tolerance to dry spells/drought conditions, fair tolerance to early and late leaf spot diseases.
Jessa	DRSS	Medium size pale coloured seed, short season variety, high pod yield potential (4 t/ha), high kernel yield potential (2.8 t/ha), escapes Cercospora leaf spots and late season drought.
Njiva	ICRISAT Zimbabwe	An early maturing variety to reach physiological maturity, high pod yield potential (4.3t/ha**)** and seed yield (2.85t/ha),drought tolerant genotype with moderately to highly tolerant to leaf spot diseases and rust, good tolerance to aphids and *Hilda patruelis.*
Guinea fowl	ICRISAT Zimbabwe	A medium maturing variety, very high pod yield potential (4.5t/ha) and potential seed yield (3.3t/ha), tolerant to drought, highly tolerant to leaf spot diseases and rust and good tolerance to aphids and *Hilda patruelis.*
Dendera	ICRISAT Zimbabwe	A pale coloured seed variety exhibiting medium maturing variety, potential pod and yield potential, has high tolerant to Groundnut Rosette Disease (GRD) and leaf spot diseases and rust, with good tolerance to aphids and *Hilda patruelis.*
Nyanda	ICRISAT Zimbabwe	Pale coloured seed variety exhibiting medium maturing variety, potential pod and yield potential, can tolerate early and late leaf spot diseases and rust.

3.3 Crop establishment, management and experimental design

3.3.1 Experiment one: Agar gel experiment

The seven groundnut genotypes were evaluated using a Randomized Complete Block Randomized Design (RCRD) with six blocks. The study was conducted using standard procedures developed at IITA (Hess *et al.,* 1992).The seven groundnut genotypes were tested for stimulant production and haustorium initiation by *Alectra vogelii* using the agar-gel method, as described by the IITA (Berner *et al.*, 1997). Groundnuts and *Alectra* seed used in this experiment was the same material that was used in the pot experiments. Sterilization of *Alectra* seeds was achieved by immersing them in 1% sodium hypochlorite (NaClO) solution for 25 minutes before setting up the assay and rinsed three times with distilled water. A total of 0.2 g (approximately 12 250 seeds) of *Alectra* seeds was placed in 50 ml flasks and rinsed three times in 10 ml double-distilled water. The seeds were then placed in 9 cm diameter Petri dishes, sealed with Parafilm, and placed in the dark at 25°C for 14 days. Groundnut seeds were soaked in 1% NaClO solution for 25 minutes and rinsed three times with distilled water. The groundnut seeds were transferred to 9 cm diameter Petri dishes lined with one moist Whatman no. 2 filter paper disc and incubated in the dark at 28°C for 48 hours. Only the healthy-looking, germinated groundnut seeds were selected for the agar-gel assay. The conditioned *Alectra* seeds (50 µl) were pipetted into 9diameter Petri dishes. A total of 30 ml (1.05 g of agar) of autoclaved water agar in 150 ml double-distilled water was poured onto the *Alectra* seeds in each Petri dish before the agar solidified. Each germinating groundnut seed was submerged in the solidifying agar near the edge of the Petri dish, with the root tip pointing across the Petri dish as described by Reda *et al*. (1994).The Petri dishes were incubated at room temperature for 72 hours before the first data was recorded.

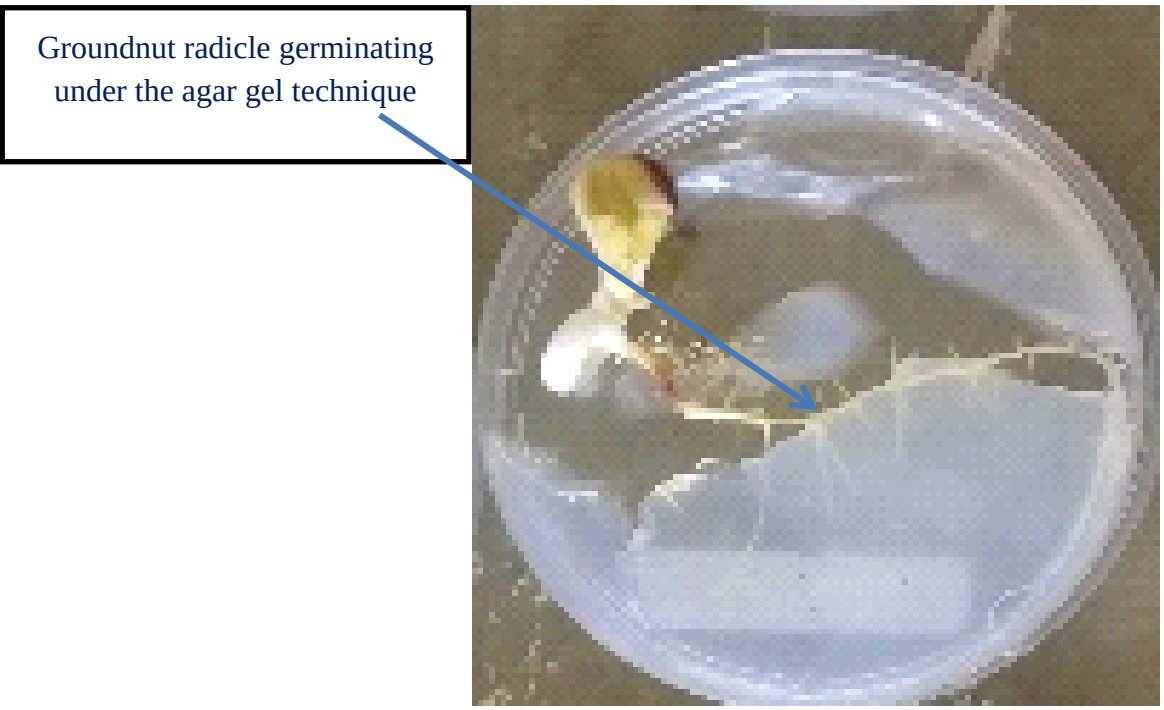

Figure 3. 1: Agar gel technique assay set up in the Weed Science laboratory, University of Zimbabwe. Photo was taken by William Makaza on 25/01/2019.

3.4 Data collection

Data were collected on the germination percentage and the farthest distance (mm) of *Alectra* seed from the groundnut radicle using a graduated dissecting microscope focused from the bottom of the Petri dishes. Germination percentage was assessed only on the point where the scope of the microscope was focusing, and it was focusing from four random positions. Germination percentage was expressed as mean number of germinated *Alectra* seeds divided by the total number of visible *Alectra* seeds from the four positions where the dissecting microscope was focusing. The furthest or maximum germination distance (mm) of germinating seeds from the root of groundnut seedling was used as an index for stimulant production by the host plant, and the number of germinated *Alectra* seeds was recorded as described by Reda *et al*. (1994) and Berner *et al*. (1997).

3.5 Experiment two: Pot experiment

3.5.1 Experimental design

The experiment was laid out as a 7*2 factorial experiment arranged in a Randomized Complete Block Design (RCBD) with six replications with groundnut genotypes and *Alectra* infestations as the factors. The seven levels for groundnut genotypes are listed and described in Table 3.1whilst *Alectra* infestation had two levels namely; infested and non-infested. In total eighty-four4-litre plastic pots measuring 15 cm in diameter and 25 cm height were three quarter field with sandy soil from Henderson Research station In each pot, five centimeters of dry sandy soil was thoroughly mixed with 2 g of compound D (7% N: 14%P_2O_5: 7% K_2O). Soil in forty-two pots was inoculated with witchweed seeds. In the process of inoculation, due care was taken and was achieved by physically separating half (42 pots) of the pots in space. A total 0.05 g of witchweed seeds (approximately 40 000 seeds) were thoroughly mixed with the top five centimeters of the soil. This was achieved through vigorously shaking the witchweed seeds and the required top soil in a separate transparent mixing bag and thereafter returned to respective pots. All the pots were watered to field capacity and maintained as such for a week to precondition the seed. Planting was done at the same time in both inoculated and un-inoculated pots. Three kernels were planted at a depth of 5 cm and seeds were placed 3 cm apart. Two grams of ammonium nitrate (34.5%N) was applied to all pots at four weeks after planting (WAP) as top-dressing fertilizer to achieve an application rate of 250-300kg/ha (Magani, 1994). Pots were initially watered to field capacity and subsequently irrigated with 800 ml/pot tap three times per week 800. Other weeds except *Alectra* seed were controlled through physical hand-pulling. Two pesticide sprays at 4 WAP and 6 WAP were done using a 16 litre knapsack sprayer using Carbaryl (50% WP). Pots were spaced as 35 cm between rows and 10 cm in-row.

3.6 Data Collection

3.6.1 Groundnut vegetative and yield parameters

Data was collected and recorded as per Table 3.2. Groundnut growth parameters, which include plant height, were measured on weekly basis following the procedure described by Iman *et al.* (2014). Plant height was measured from 2 to 14 weeks after crop emergence (WACE). Other groundnut traits such as plant vigor or *Alectra* syndrome rating was determined using the rating scale of 1 to 5 once a week, from 10 to 13 WACE, where 1 = total leaf scorching, stunted growth, dead of plants (very weak plants) and 5 = normal groundnut growth, no chlorosis, no blotching, no leaf scorching (very vigorous plant exhibiting flourish normal growth) and days to 50% anthesis was measured following a procedure described by Kwaga (2014). Number of days to physiological maturity for groundnut was recorded.

Data on groundnut aboveground biomass (leaf and stems) as well as below ground biomass (roots and pods) were recorded. Individual groundnut plants were cut at the base of the stem. Leaves and stems of each groundnut genotype were dried individually in labelled khaki envelopes in an oven at 80^{o}C for 72 hours and weighed. The groundnut root biomass was recorded as the biomass of washed groundnuts minus soil particles and all parasite attachments. The roots were dried in the same manner as the shoot biomass. Information on the number of pods and seeds per crop were obtained by physically counting number of pods per genotype. One hundred (100) kernel weight, haulm yield, shelled and unshelled grain yield per hectare was determined by using a scale (Compact Scales & Balances - Adam Equipment USA).

3.6.2 Groundnut physiological parameters

Physiological parameters; chlorophyll content and chlorophyll florescence, were measured on groundnut crops as described by Nyakurwa *et al.* (2018). Chlorophyll content was measured using SPAD-502 (Minolta Corporation) chlorophyll and readings were taken at 8 WACE on young, fully developed leaves between 1200 hours and 1300 hours. Chlorophyll florescence (F_v/F_m) and quenching analysis for measuring electron transport rate (ETR), all were measured using a portable, pulse-modulated OS-30p$^+$ chlorophyll fluorometer (Opt-Sciences), where Fv = the variable fluorescence, Fm = the maximal fluorescence value, J= is *ETR*, , , 0.5 = factor that accounts for the partitioning of energy between PSII and PSI. Measurements were taken on the youngest, fully developed leaves after 30 minutes of dark adaptation using clips provided with the instrument (Nyakurwa *et al.,* 2018). The readings were recorded at 8, 10, 12, 14, 15 and 16 WACE between 1300 hours and 1500 hours.

3.6.3 *Alectra* traits

Alectra traits recorded include number of days to first *Alectra* emergence at 9-15WACE and haustorial root attachments, which were recorded as physical counts of visible attachments of *Alectra* to the groundnut root at 14 WACE. Measurements were obtained by gently washing away all the soil surrounding the root area and recording all successful visible attachments.

Table 3. 2: Description of traits recorded in the pot experiment

Trait	Description
Growth parameters	
Plant height	Measured as the height between the base of a plant to the top of the same plant by measuring the major stem in centimeters (cm) using a tape measure.
Number of primary branches	Physical counting of groundnut primary branches on a weekly basis from 2WACEup to physiological maturity.
Groundnut phenology	
Plant vigor	Rated on a scale from 1 (very poor/weak vigor crops) to 5 (very vigorous crops exhibiting normal growth).
Days to 50% anthesis	Measured as the number of days that 50% of the plants shed pollen in a pot
Days to first anthesis	Measured as the number of days that each groundnut genotype shed pollen in a pot.
Days to second anthesis	Measured as the number of days that each groundnut genotype shed pollen in a pot.
Alectra/ haustorial root attachment	Measured by physical counting of visible *Alectra* attached to its host at 15 WACE.
Days to 1st *Alectra* emergence	Recorded number of days taken from day after planting (DAP) to first *Alectra* emergence.
Days to groundnut physiological maturity	Measured as the number of days from planting to the day when 50% of the plant pods showed fully developed shell.
Yield components	
Plant dry weight	Measured as the total of both the root and shoot biomass and expressed in t/ha.
Shoot biomass	Measured as total weight of all aboveground biomass (stems and leaves) converted to t/ha.
Root biomass	Measured as total weight of all below ground biomass (roots and pods) converted to t/ha.
Number of pods per crop (pod yield)	Physical counting of the number of pods per groundnut crop genotype.
Number of seeds per crop (seed/kernel yield)	Physical counting of the number of kernels per groundnut crop genotype.
100 kernel weight	Weight of 100 kernels chosen at random from a particular genotype recorded using a scale (Compact Scales & Balances - Adam Equipment USA).
Unshelled groundnut yield (t/ha)	Shelled grain per plot adjusted to 18 % grain moisture and converted to t/ha.
Shelled groundnut yield (t/ha)	Shelled grain per pot adjusted to 12.5% grain moisture and converted to tonnes per hectare
Physiological parameters	
Chlorophyll content	Measured using SPAD-502 (Minolta Corporation) chlorophyll at 8 WACE on young, fully developed leaves between 1200 hours and 1300 hours.
Chlorophyll florescence	Measured using a portable, pulse-modulated OS-30p$^+$ chlorophyll fluorometer (Opt-Sciences) and electron transport rate was calculated using Figures obtained by JIP protocol

3.7 Data analyses

Analysis of variance (ANOVA) was conducted and means were separated using Fisher's protected LSD at the 5% significance level using GenStat 18th version (GenStat, 2015). To fulfill ANOVA assumptions, data on *Alectra* germination percentage and furthest germination distance were transformed using the $\log_{10}(X + C)$, where X is the untransformed trait value and *C* is 1.0.

The following model was used: $Y_{jmi} = \mu + r_i + s_j + g_m + s_j g_m + e_{jmi}$,

Where Y_{jmi} is the response of the mth genotype and jth witchweed in the ith replication, r_i is the effect of the ith replication, s_j and g_m are the main effects of the witchweed level, and genotype, respectively, $s_j g_m$, is the interaction between genotype and which weed level and e_{ij} is the pooled error term. The terms i= 1, 2, 3, 4, 5, 6; j= 1, 2; and m= 1, 2, 3…,6. Ordinal data, which include plant vigor or syndrome rating was analyzed using the non-parametric, Kruskal Wallis H-test using Genstat 18th version. Repeated measures ANOVA were performed for plant height and number of branches, which was measured on a weekly basis. R-statistical package version 1.0.136 was used in the graphical presentation of the seven groundnut genotypes data (RStudio, 2009).

CHAPTER FOUR

RESULTS

3.1 Agar-gel experiment

The summary of mean square values for *Alectra vogelii* germination and furthest germination distance are shown in Table 4.1.

Table 4. 1 Mean square values for *A. vogelii* parameters recorded on different groundnut genotypes evaluated under laboratory and glasshouse conditions at the University of Zimbabwe.

Source	***Alectra* germination %**	***Alectra* furthest germination distance (mm)**
Block	1263.9	19.1
Genotypes	1268.5***	30.4***
Residuals	68.3	1.9

The agar gel screening revealed significant ($p<0.05$) differences among the genotypes in terms of *A. vogelii* germination percentage and furthest *A. vogelii* germination distance from the groundnut root (Table 4.1). Genotype Njiva did not support any *A. vogelii* germination thereby no furthest germination distance was recorded compared to other genotypes. Dendera and Nyanda had significantly higher germination percentage and furthest germination distances than the other genotypes.

Table 4. 2 Effects of strigolactones produced by different groundnut genotypes on *A. vogelii* germination percentage and furthest germination distance.

Genotype	***Alectra* Germination %**	***Alectra* furthest germination distance (mm)**
Dendera	12.4^{c}	2^{b}
Guinea fowl	3.2^{ab}	0.7^{a}
Ilanda	7.7^{b}	0.8^{a}
Jessa	6.7^{b}	0.7^{a}
Njiva	0.00^{a}	0.00^{a}
Nyanda	22.2^{d}	3.34^{c}
Tern	5.2^{b}	0.8^{a}
p-value	**<0.001**	**<0.001**
SED	**2.386**	**0.393**
LSD	**4.712**	**0.777**

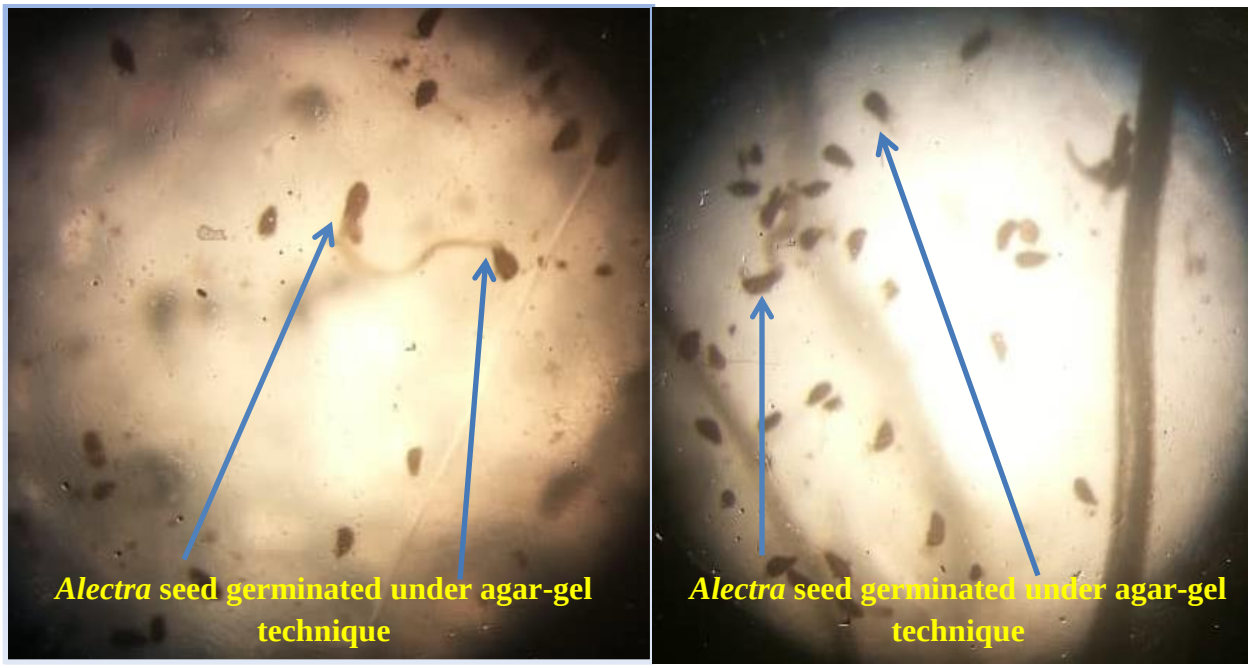

Figure 4. 1 *Alectra* seed germination as seen under graduated microscope: Magnification X40. Photo was taken by William Makaza on 29/01/2019.

4.2 Glasshouse experiment.

4.2.1 *Alectra* effects on groundnut growth

The summary of mean square values for *Alectra* effects on groundnut plant height and number of primary branches recorded under glasshouse are shown in Table 4.3.

Table 4. 3 Mean square values for plant height and number of branches recorded under glasshouse conditions at the University of Zimbabwe.

Source	Plant height (cm)	Number of branches
Block	98	9.04
Genotype	751.6***	59.53*
Alectra	254.7^{ns}	703.1***
Genotype**Alectra*	68.1^{ns}	9.64^{ns}
Residual	135.3	24.84
Time	5764.5***	1449.05***
Time*Genotype	9.02***	3.19**
Time**Alectra*	8.6*	27.72***
Time*Genotype**Alectra*	2.6^{ns}	1.62^{ns}

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively.
ns-not significant at 5% probability level.

4.2.1.1 Plant height

There was no significant ($p>0.05$) interaction amongst Time*Genotype**Alectra*. Similarly, the Genotype**Alectra* interaction was not significant ($p>0.05$). However, genotype significantly ($p<0.05$) affected plant height among the different genotypes (Fig 4.2) but *Alectra* infestation level did not ($p>0.05$) (Table 4.3). Figure 4.2show that *Alectra* infestation decreased the height of all groundnut genotypes except Guinea fowl and Ilanda. Njiva recorded the highest plant height under all levels of *Alectra* infestation (Figure 4.2).

4.2.1.1 Primary branches

The time x genotype x *Alectra* and genotype x *Alectra* were not significant ($p>0.05$) on groundnut number of branches. *Alectra* infestation significantly ($p<0.05$) reduced the number of groundnut primary branches (Table 4.3). *Alectra* infestation significantly reduced the number of branches of the all groundnut genotypes under infestation. Non-infested groundnut genotypes recorded more numbers of primary branches than infested groundnut genotypes over a period of time (Figure 4.3).

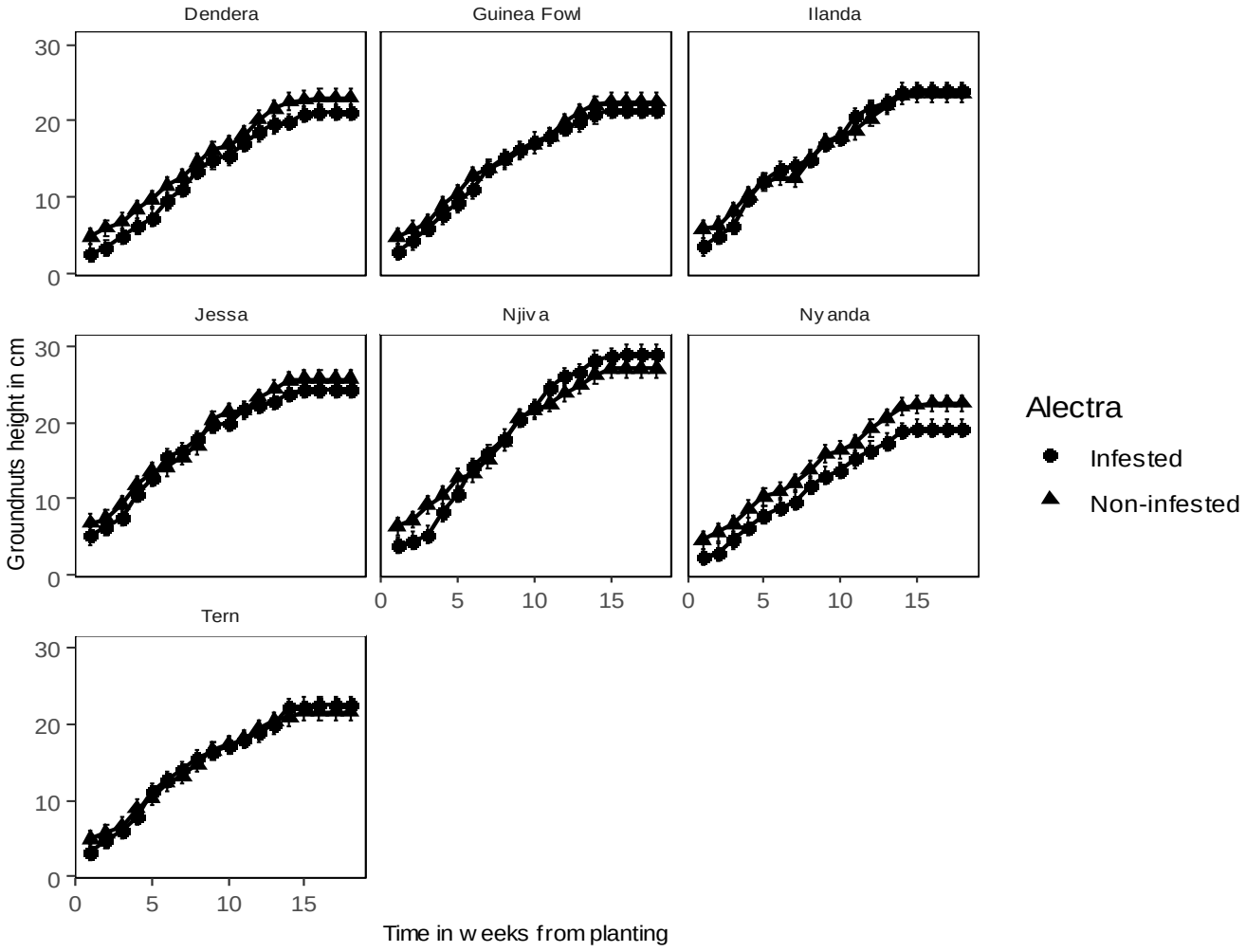

Figure 4. 2 Groundnut plant heights (cm) recorded from 2 to 16 WACE in a glasshouse experiment conducted at the University of Zimbabwe, during the 2018/2019 cropping season. Error bars represent the standard error of the difference (sed) at $p<0.05$.

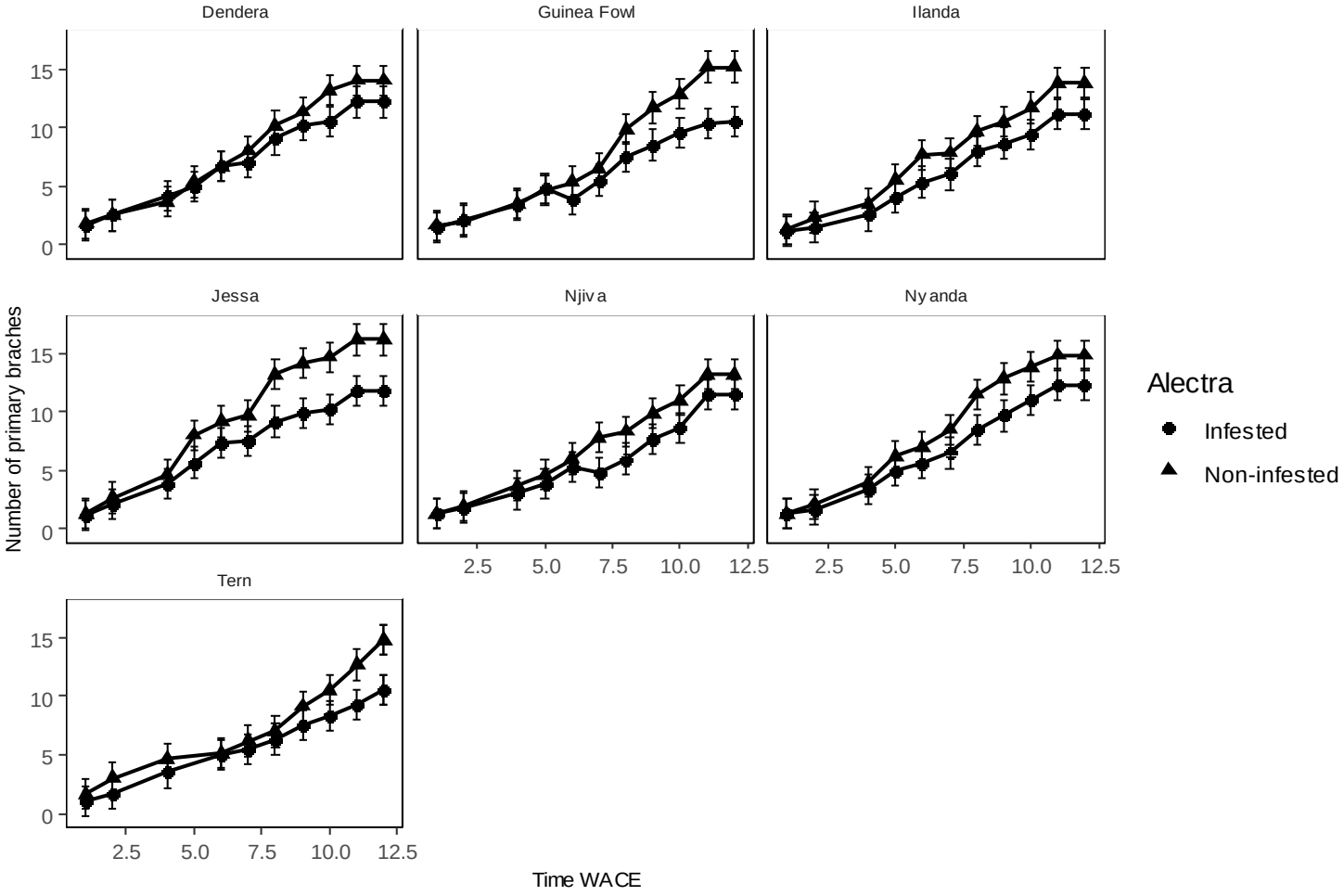

Figure 4. 3 The number of primary branches recorded from 2 to 12 WACE in a glasshouse experiment conducted at the University of Zimbabwe, during the 2018/2019 cropping season. Error bars represent the standard error of the difference (sed) at $p<0.05$.

4.2.2 *Alectra* effects on chlorophyll content, chlorophyll fluorescence and electron transport rate.

Mean square values for physiological parameters of groundnut genotypes recorded under glasshouse conditions are shown in Table 4.4.

Table 4. 4 Mean square values for groundnut genotypes physiological parameters recorded under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Source	**Chlorophyll content (mmol m^2)**	**Chlorophyll fluorescent (mmol m2 s^{-1})**	**ETR (µmol photon m^2 s^{-1})**
Block	351.7^{ns}	0.02188	24451
Genotype	331.3^{ns}	0.004875^{ns}	12757***
Alectra	3197.2***	0.246219***	2357^{ns}
Genotype**Alectra*	251.2^{ns}	0.001486^{ns}	3697^{ns}

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively. ns-not significant at 5% probability level.

4.2.2.1 Chlorophyll content (mmol m^2)

There was no significant ($p>0.05$) interaction amongst Genotype x *Alectra*. *Alectra* infection significantly($p<0.001$) affected all groundnut genotypes on chlorophyll content. *Alectra* infection reduced chlorophyll content of infested groundnut genotypes compared to non-infested groundnut genotypes (Table 4.4).*Alectra* infection overall reduced chlorophyll content across all infested groundnut genotypes (Table 4.4, Figure 4.4 and Figure 4.5). All groundnut genotypes did not vary significantly ($p>0.05$) in terms of chlorophyll content in both infested and non-infested.

4.2.2.2 Chlorophyll fluorescence

There were no significant ($p>0.05$) interactions between Genotype*_Alectra_ on chlorophyll fluorescence. All infested and non-infested groundnut genotypes did not significantly ($p>0.05$) vary on chlorophyll fluorescence. However, _Alectra_ infestation significantly ($p<0.05$) decreased chlorophyll fluorescence (Figure 4.6).

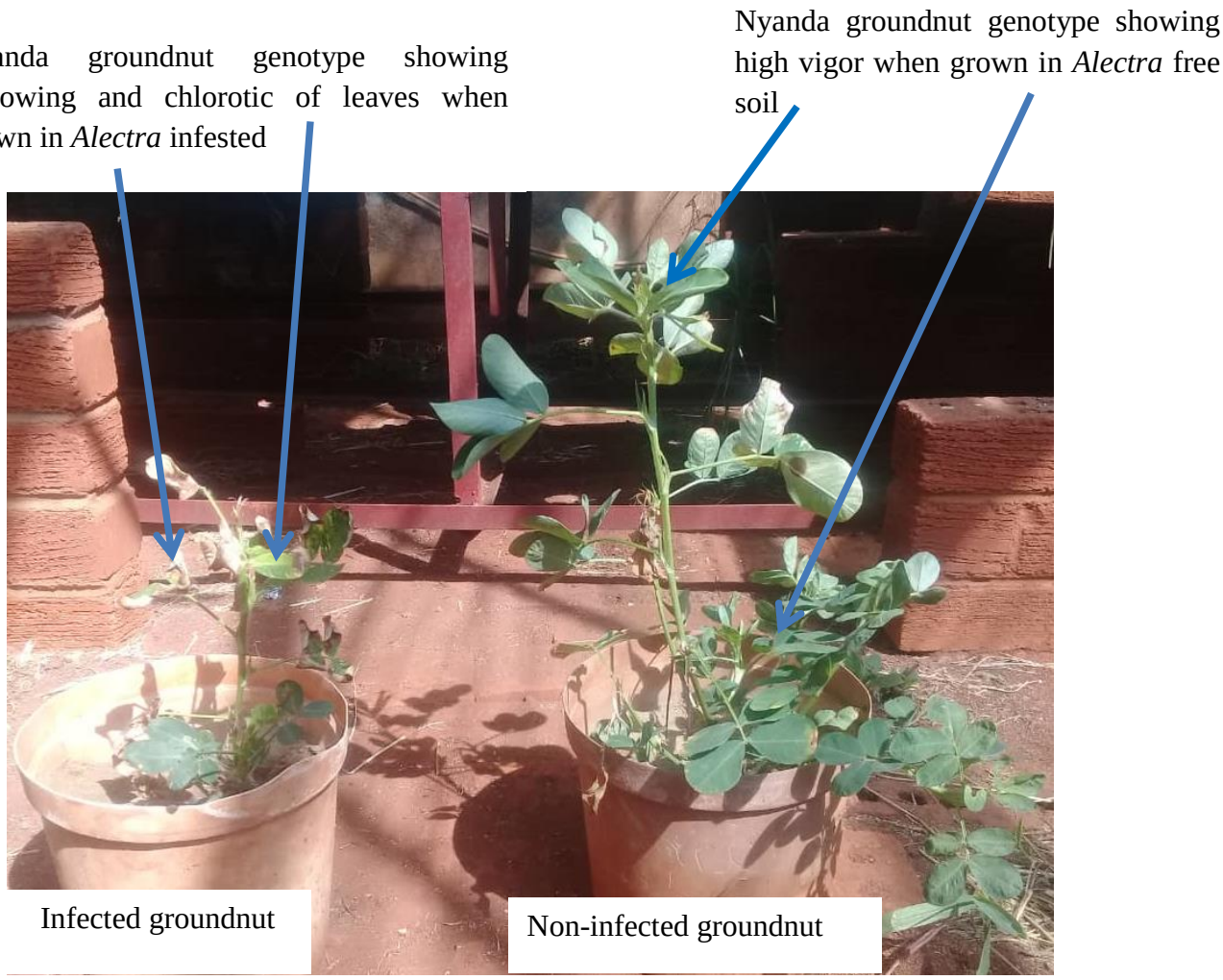

Figure 4. 4 The effect of _Alectra_ levels on groundnut genotypes under glasshouse conditions during 2018/2019 season.

4.2.2.3 Electron Transport Rate (ETR).

Significant differences were recorded on electron transport rate ($p<0.05$) for all genotypes (Table 4.4). Genotype x *Alectra* did not significantly ($p>0.05$) affect electron transport rate in groundnut genotypes in this study. There were no variations recorded on the electron transport rate due to *Alectra* infestation level (Figure 4.7).

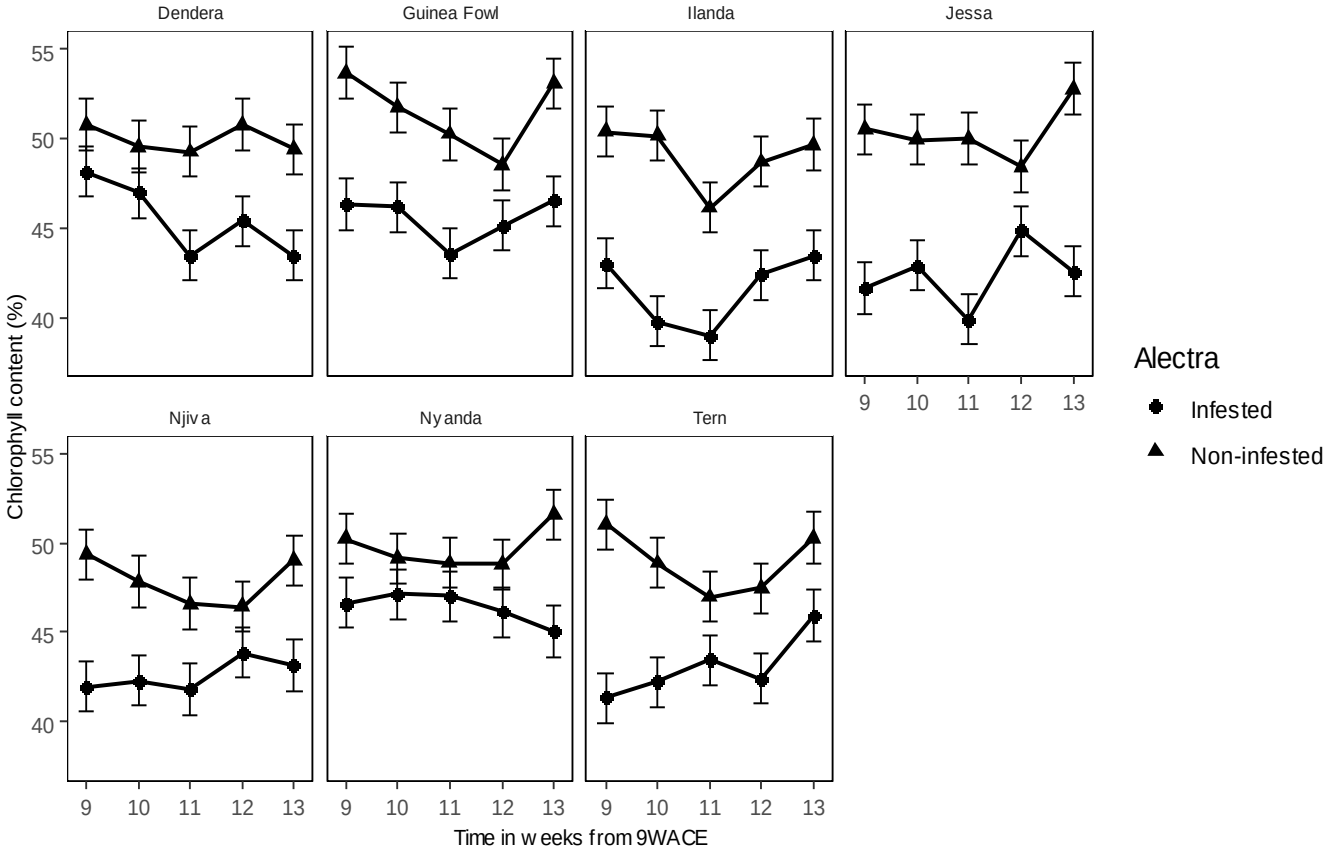

Figure 4. 5 Effects of *Alectra* on the chlorophyll content of different groundnut genotypes in a glasshouse experiment at the University of Zimbabwe during 2018/2019 season. Error bars represent the standard error of the difference (sed) at $p<0.05$.

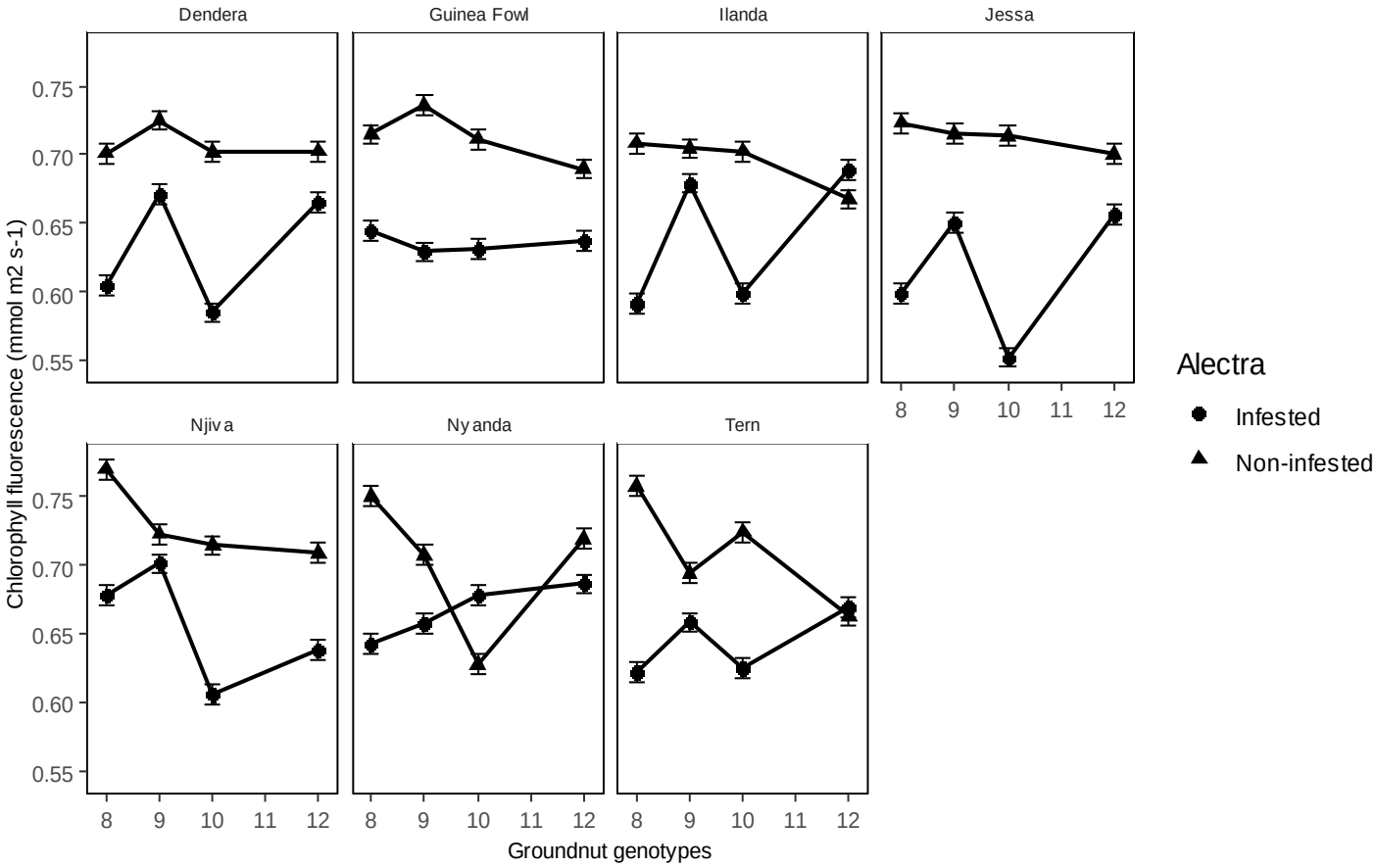

Figure 4. 6 Effects of *Alectra* on the chlorophyll fluorescence (mmol m^2 s^{-1}) of different groundnut genotypes in a glasshouse experiment at the University of Zimbabwe. Error bars represent the standard error of the difference (sed) at $p<0.05$.

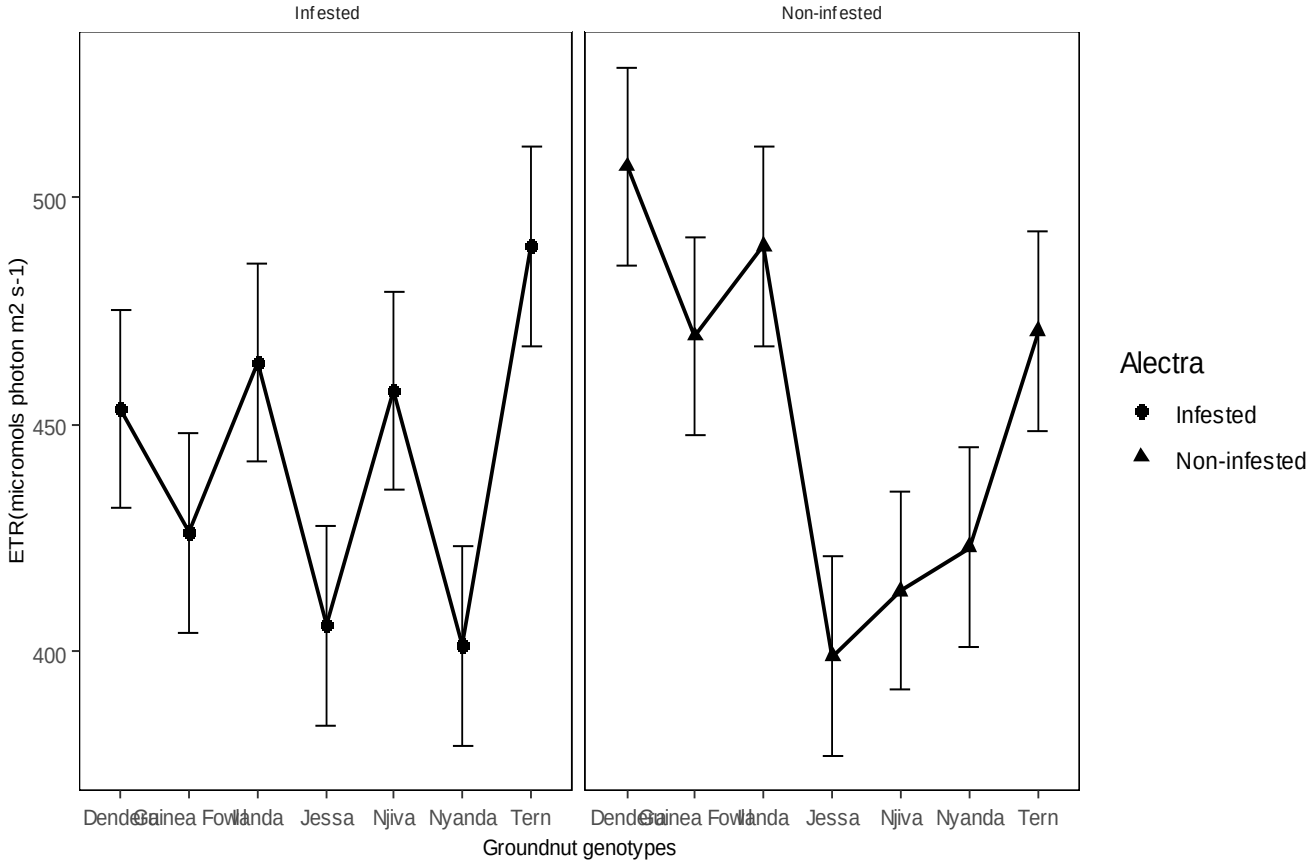

Figure 4. 7 Effects of *Alectra* on the electron transport rate (ETR) of different groundnut genotypes a glasshouse experiment at the University of Zimbabwe. Error bars represent the standard error of the difference (sed) at $p<0.05$.

4.2.3 *Alectra* effects on groundnut phenolology

The summary for mean square values for *Alectra* effects on groundnut phenology recorded under glasshouse conditions are shown in Table 4.5.

Table 4. 5 Mean square values for different groundnut phenological traits evaluated under glasshouse conditions at the University of Zimbabwe

Source	Days to 50% anthesis	Days to first anthesis	Days to second anthesis	Days to physiological maturity
Block	33.2	39.5	39.2	26.7
Genotype	621.6***	628.01***	260.8***	302.7***
Alectra	186.0*	312.4*	19.05^{ns}	3.1^{ns}
Genotype**Alectra**	22.8^{ns}	17.9^{ns}	13.9^{ns}	10.6^{ns}

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively.
ns, not significant at 5% probability level.

4.2.3.1 Days to 50% anthesis

There were no significant ($p>0.05$) interactions between Genotype*_Alectra_ on days to 50% anthesis. Genotype significantly ($p<0.05$) affected days to 50% anthesis across all seven genotypes (Table 4.5). Guinea fowl recorded significantly more days to 50% anthesis than the other genotypes. On the other hand, *Alectra* infestation significantly ($p<0.05$) affected the number of days to 50% anthesis on groundnut genotypes (Table 4.5 and Table 4.7). Infected groundnut genotypes took more days to 50% anthesis compared to non-infested genotypes (Table 4.5, 4.6 and 4.7).

4.2.3.2 Days to first anthesis

The genotype x *Alectra* interactions was not significant ($p>0.05$) on days to first anthesis (Table 4.5). Both main factors: genotypes and *Alectra* were significant ($p<0.05$) on the number of days to first anthesis. Table 4.7 shows that infected genotypes took more days to first anthesis than non-infested genotypes. Guinea fowl took significantly more days to first anthesis compared to the other genotypes (Table 4.6).

4.2.3.3 Days to second anthesis

Genotype x *Alectra* interaction was not significant ($p>0.05$) on the number of days to second anthesis (Table 4.5). *Alectra* infestation did not significantly ($p>0.05$) affect number of days to second anthesis on all groundnut genotypes (Table 4.5 and Table 4.7). Conversely, there were significant variations among genotypes. Guinea fowl recorded significantly more days to second anthesis but was not significantly different from Dendera, Ilanda, Jessa, Njiva, Nyanda and Tern.

4.2.3.4 Days to physiological maturity

There was no significant ($p>0.05$) interaction between groundnut genotype x *Alectra* on days to physiological maturity. *Alectra* infestation did not significantly ($p>0.05$) affect number of days to physiological maturity (Table 4.5 and Table 4.7). However, there were significant ($p<0.001$) variations on the groundnut genotypes. Genotypes varied because some were short, medium or long season varieties. Guinea fowl is a late maturing genotype and took 84 days to physiological maturity compared to other short and medium maturing genotypes (Njiva, Jessa, Tern, Ilanda, Nyanda and Dendera) (Table 4.6). *Alectra* parasitism did not significantly ($p>0.05$) differ on both infested and non-infested groundnut genotypes (Table 4.7).

Table 4. 6 Response of groundnut physiological traits to *Alectra* infestation

Genotype	Days to 50% anthesis	Days to first anthesis	Days to second anthesis	Days to physiological maturity
Dendera	43.3^{ab}	37.5^{bc}	64.6^{a}	70.8^{a}
Guinea fowl	57.8^{d}	52.7^{d}	76.5^{b}	84.3^{ab}
Ilanda	38.2^{a}	32.8^{ab}	65.1^{a}	71.5^{a}
Jessa	36^{a}	30.8^{a}	63.3^{a}	70.7^{a}
Njiva	41^{abc}	34.9^{abc}	63.6^{a}	70.4^{a}
Nyanda	44.5^{c}	38.7^{c}	65.2^{a}	71^{a}
Tern	39.2^{ab}	34.5^{abc}	64.1^{a}	71.7^{a}
p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**
SED	**2.541**	**2.402**	**1.140**	**1.250**
LSD	**5.075**	**4.789**	**2.276**	**2.496**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

Table 4. 7 Means of *Alectra* infestation levels recorded for different groundnut phenological traits evaluated under glasshouse conditions at the University of Zimbabwe

Alectra	**Days to 50% anthesis**	**Days to first anthesis**	**Days to second anthesis**	**Days to physiological maturity**
Infested	44.3^{b}	39.3^{b}	65.2	73.1
Non-infested	41.4^{a}	35.5^{a}	64.1	72.7
p-value	**0.032**	**0.004**	**0.123**	**0.570**
SED	**1.358**	**1.284**	**0.609**	**0.668**
LSD	**2.713**	**2.565**	**Ns**	**Ns**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

4.2.4 *Alectra* effects on groundnut biomass production

Mean square values for *Alectra* effects on groundnut biomass recorded under glasshouse conditions are shown in Table 4.8.

Table 4. 8 Mean square values for groundnut biomass production recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Source	**Total plant biomass (kg)**	**Shoot biomass (kg)**	**Root biomass (kg)**	**Shoot/Root ratio**
Block	0.0012	0.0008	0.0004	0.1
Genotype	0.0009*	0.0006*	0.0004*	1.7***
Alectra	0.004***	0.001*	0.000007^{ns}	0.6^{ns}
Genotype**Alectra*	0.0007*	0.0001^{ns}	0.0002^{ns}	1.1*

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively.
ns, not significant at 5% probability level.

4.2.4.1 Total plant biomass

Genotype x *Alectra* interaction was significant ($p<0.05$) on plant biomass (Table 4.8). Plant biomass was significantly lower in infested pots in the genotypes Dendera, Nyanda and Tern (Figure 4.8). Plant biomass was not significantly affected by *Alectra* infestation across genotypes.

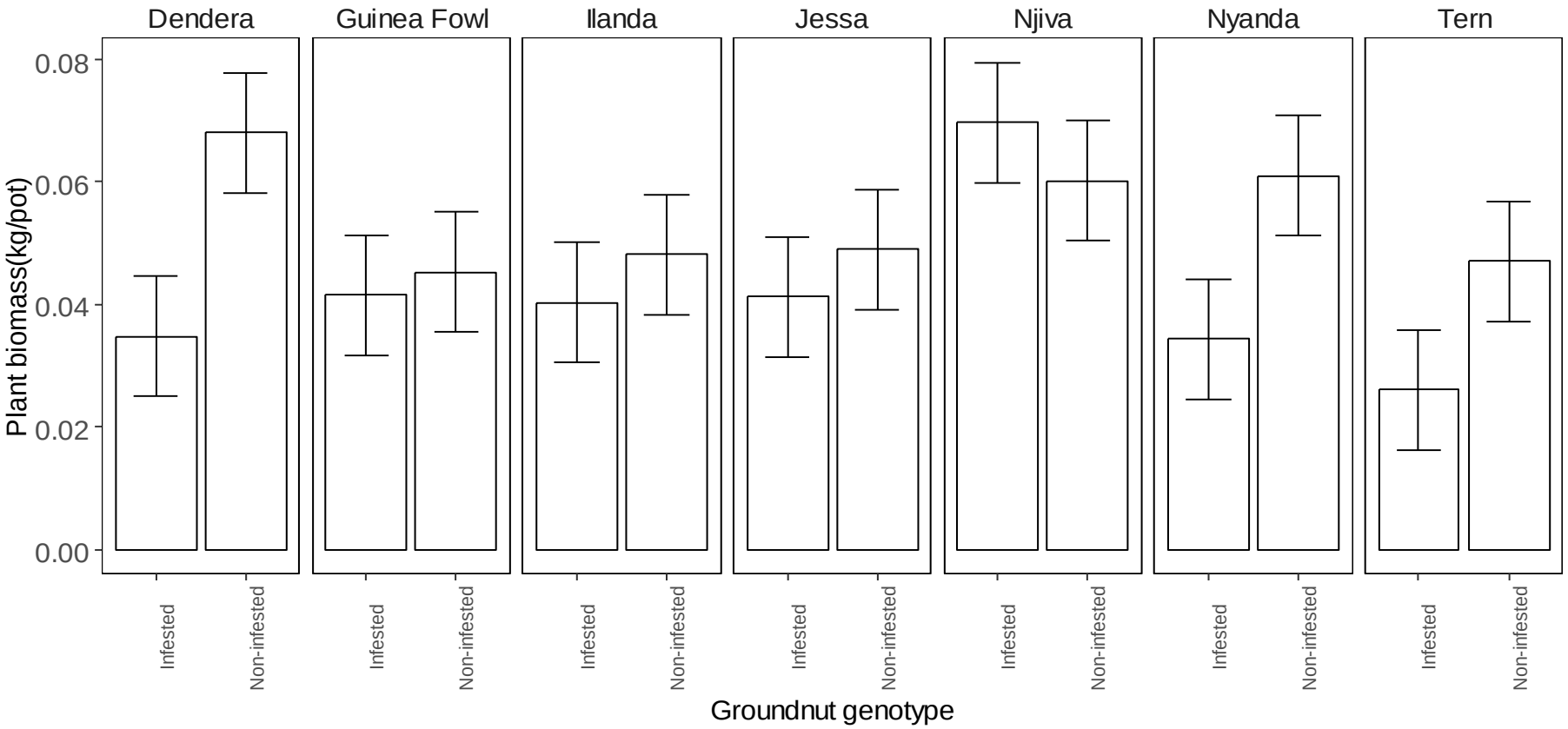

Figure 4. 8 The interaction between groundnut genotypes and *Alectra* infestation level relative to total plant biomass evaluated under glasshouse conditions at the University of Zimbabwe. Error bars represent the standard error of the difference (sed) at $p<0.05$.

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4.2.4.2 Shoot biomass

There was no significant ($p>0.05$) interactions between Genotype x *Alectra* on groundnut shoot biomass (Table 4.8). *Alectra* infestation significantly ($p<0.05$) reduced shoot biomass on infested groundnut genotypes (Table 4.9 and Table 4.10). All groundnut genotypes had significant ($p<0.05$) differences on the shoot biomass (Table 4.8).

4.2.4.3 Root biomass

The genotype x *Alectra* interaction on root biomass was not significant (p>005). Similarly, *Alectra* infestation did not significantly ($p>0.05$) affect shoot biomass(Table 4.8, Table 4.9 and Table 4.10). Groundnut genotypes performed significantly ($p<0.05$) different across all *Alectra* levels of infestation (Table 4.8). Njiva recorded high shoot biomass compared to other groundnut genotypes (Table 4.9).

4.2.4.4 Shoot/root ratio

There was a significant ($p<0.05$) interaction between Genotype x *Alectra* on shoot to root ratio where groundnut genotypes performed differently on the distribution of assimilates (Table 4.8). Generally, Njiva had significantly higher than all groundnut genotypes on both *Alectra* infestation levels and Jessa recorded the least shoot/root ratio. Figure 4.8 shows the interaction between groundnut genotypes and *Alectra* levels of infestation. The performance of groundnut genotypes was directly influenced by *Alectra* parasitism. *Alectra* infestation decreased shoot to root biomass across all groundnut genotypes genotypes.

Table 4. 9 Means of groundnut biomass production recorded on different groundnut genotypes evaluated under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Genotype	Shoot biomass (kg)	Root biomass (kg)
Dendera	0.03^{b}	0.036^{c}
Guinea fowl	0.02^{ab}	0.022^{ab}
Ilanda	0.03^{ab}	0.02^{ab}
Jessa	0.025^{b}	0.03^{abc}
Njiva	0.04^{c}	0.022^{ab}
Nyanda	0.02^{ab}	0.022^{ab}
Tern	0.02^{a}	0.02^{a}
p-value	**0.003**	**0.004**
SED	**0.005**	**0.004**
LSD	**0.01**	**0.0084**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

Table 4. 10 Means of *Alectra* infestation levels for groundnut shoot and root biomass production recorded on the groundnut genotypes evaluated under the glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Alectra level	Shoot biomass (kg)	Root biomass (kg)
Infested	0.022^{a}	0.024
Non infested	0.03^{b}	0.024
p-value	**0.014**	**0.8**
SED	**0.003**	**0.002**
LSD	**0.005**	**ns**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

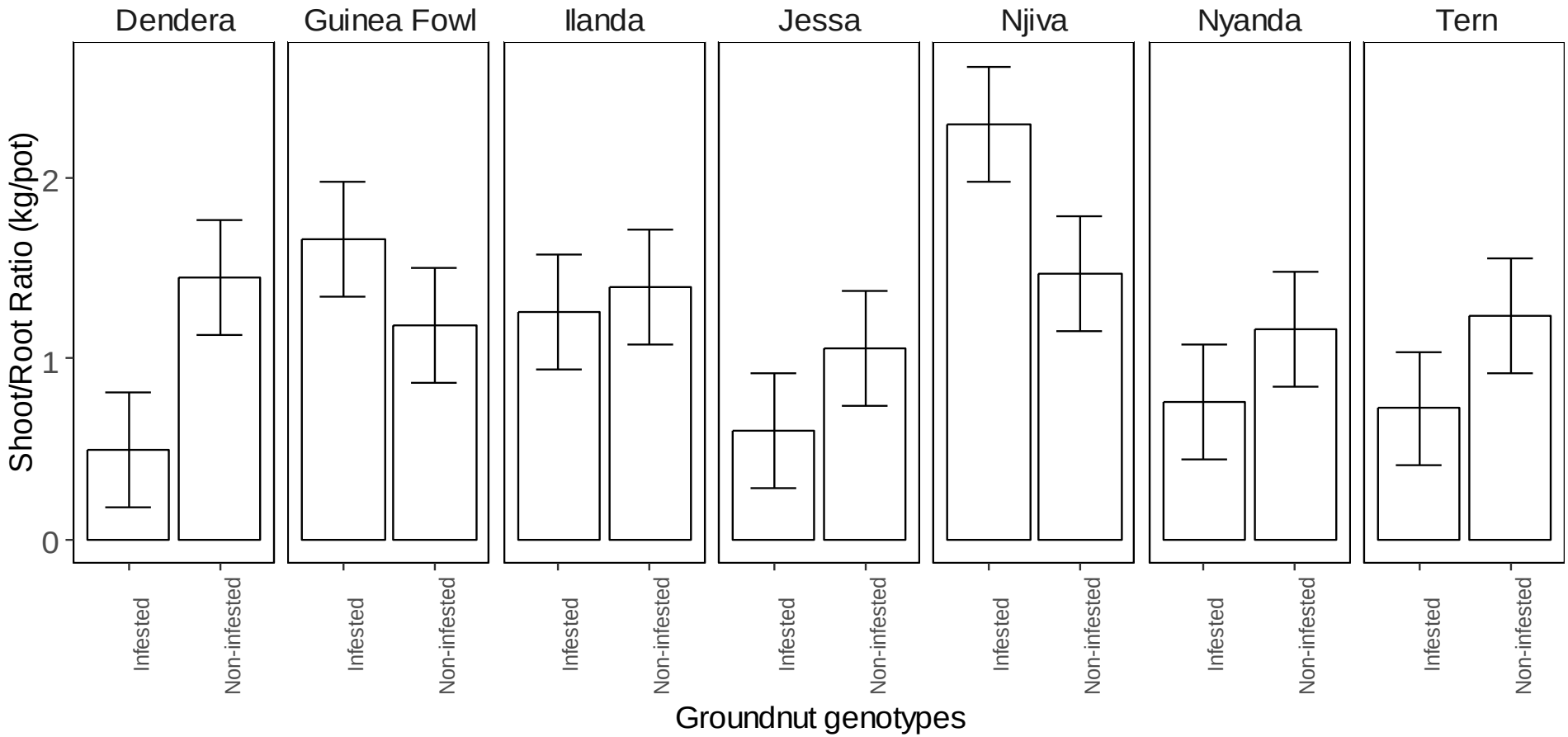

Figure 4. 9 The interaction between groundnut genotypes and *Alectra* infestation level relative to shoot: root ratio evaluated under glasshouse conditions at the University of Zimbabwe. Error bars represent the standard error of the difference (sed) at $p<0.05$.

4.2.5 *Alectra* effects on groundnut yield components

The summary of mean square values for the effect of *Alectra* on groundnut yield and yield components recorded under glasshouse conditions are shown in Table 4.11.

Table 4. 11 Mean square values for yield components recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Source	DF	Number of pods per plant	Number of seeds per plant	100 kernel weight (kg)	Shelled grain weight (kg)	Unshelled grain weight (kg)	Haulm weight (kg)
Block	5	77.9	27.1	0.005	0.0002	0.00009	0.0002^{ns}
Genotype	6	32.7^{ns}	60.3***	0.002^{ns}	0.0002*	0.0002^{ns}	0.0001^{ns}
Alectra	1	356.3***	980.6***	0.04***	0.002***	0.004***	0.0003^{ns}
Genotype **Alectra*	6	10.1^{ns}	12.1^{ns}	0.002^{ns}	0.00007^{*}	0.0002^{ns}	0.00006^{ns}
Residual	65	27.9	8.8	0.002	0.00007	0.00008	0.00008

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively.
ns, not significant at 5% probability level.

4.2.5.1 Number of pods per plant

There was no significant ($p>0.05$) interaction on genotype x *Alectra* on the number of pods per plant (Table 4.11). Groundnut genotypes were did not differ significantly ($p>0.05$) on the number of pods per plant (Table 4.11 and Table 4.12). *Alectra* infestation significantly ($p<0.05$) decreased the number of pods per plant on infested groundnut genotypes compared to non-infested genotypes (Table 4.13).

4.2.5.2 Number of seeds per plant

The genotype x *Alectra* interaction was not significant ($p>0.05$) on the number of seeds per plant. Groundnut genotypes significantly ($p<0.05$) affected the number of seeds per plant (Table 4.11). Njiva recorded significantly higher number of seeds per plant compared to other groundnut genotypes (Dendera, Guinea fowl, Ilanda and Nyanda) whilst Jessa and Tern recorded the least number of seeds per plant (Table 4.12). *Alectra* infestation significantly ($p<0.001$) decreased the number of seeds per plant on groundnut genotypes (Table 4.11 and Table 4.13).

4.2.5.3 100 kernel weight

There was no significant interaction ($p>0.05$) on genotype x *Alectra* on groundnut one hundred kernel weight. However, groundnut genotypes did not significantly ($p>0.05$) differ in their performance on 100 kernel weight (Table 4.11). *Alectra* infestation significantly ($p<0.001$) affected 100 kernel weight (kg) (Table 4.11 and Table 4.13). Non-infested groundnut genotypes had significantly higher 100 kernel weight than infested genotypes (Table 4.13).

4.2.5.4 Shelled grain yield

There was a significant genotype x *Alectra* interaction ($p<0.05$) on shelled grain yield (Table 4.11). Shelled grain yield of all genotypes was significantly lower in infested pots than in non-infested pots except in the genotype Njiva where there were no significant differences (Figure 4.10).

4.2.5.5 Unshelled grain yield

There was no significant ($p>0.05$) interaction recorded on genotype x *Alectra* on unshelled groundnut yield. *Alectra* infestation significantly ($p<0.001$) reduced the weight of unshelled groundnuts across all genotypes (Table 4.11). However, infested groundnut genotypes recorded high unshelled grain weight due to increased number of empty pods which increased the weight of unshelled groundnuts. However, there were no significant ($p>0.05$) differences in unshelled grain yield in all the groundnut genotypes (Table 4.12).

4.2.5.6 Haulm weight

Genotype x *Alectra* interactions was not significant (p>0.05) on haulm weight across all groundnut genotypes. Groundnut genotypes produced haulm which was not significantly (p>0.05) different across all groundnut genotypes (Table 4.11, Table 4.12). *Alectra* infestation did not significantly (p>0.05) affect haulm weight of groundnut genotypes (Table 4.11 and Table 4.13).

Table 4. 12 Means of groundnut yield components for different groundnut genotypes evaluated under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Genotype	Number of pods per plant	Number of seeds per plant	100 kernel weight (kg)	Unshelled grain weight (kg)	Haulm weight (kg)
Dendera	12.4	8.4^{ab}	0.05	0.02	0.02
Guinea fowl	13.2	9.9^{b}	0.02	0.01	0.01
Ilanda	14.8	10.6^{b}	0.02	0.01	0.01
Jessa	11.5	6.7^{a}	0.05	0.02	0.02
Njiva	14.0	13.3^{c}	0.03	0.01	0.02
Nyanda	12.3	8.3^{ab}	0.02	0.01	0.01
Tern	9.8	7.5^{a}	0.02	0.01	0.01
p-value	**0.3**	**<0.001**	**0.502**	**0.054**	**0.153**
SED	**2.16**	**1.2**	**0.02**	**0.004**	**0.004**
LSD	**ns**	**2.4**	**Ns**	**ns**	**Ns**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

Table 4. 13 Means of *Alectra* infestation levels for yield components recorded on the groundnut genotypes evaluated under the glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Alectra level	Number of pods per plant	Number of seeds per plant	100 kernel weight (kg)	Unshelled grain weight (kg)	Haulm weight (kg)
Infested	5.8^{a}	5.8^{a}	0.0083^{a}	0.02^{b}	0.012
Non infested	12.7^{b}	12.7^{b}	0.053^{b}	0.004^{a}	0.015
p-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.08**
SED	**1.15**	**0.6**	**0.01**	**0.002**	**0.002**
LSD	**2.30**	**1.3**	**0.02**	**0.004**	**Ns**

Means followed by the same letter within the column are not significantly different at 5% probability level.
ns-not significant at 5% probability level.

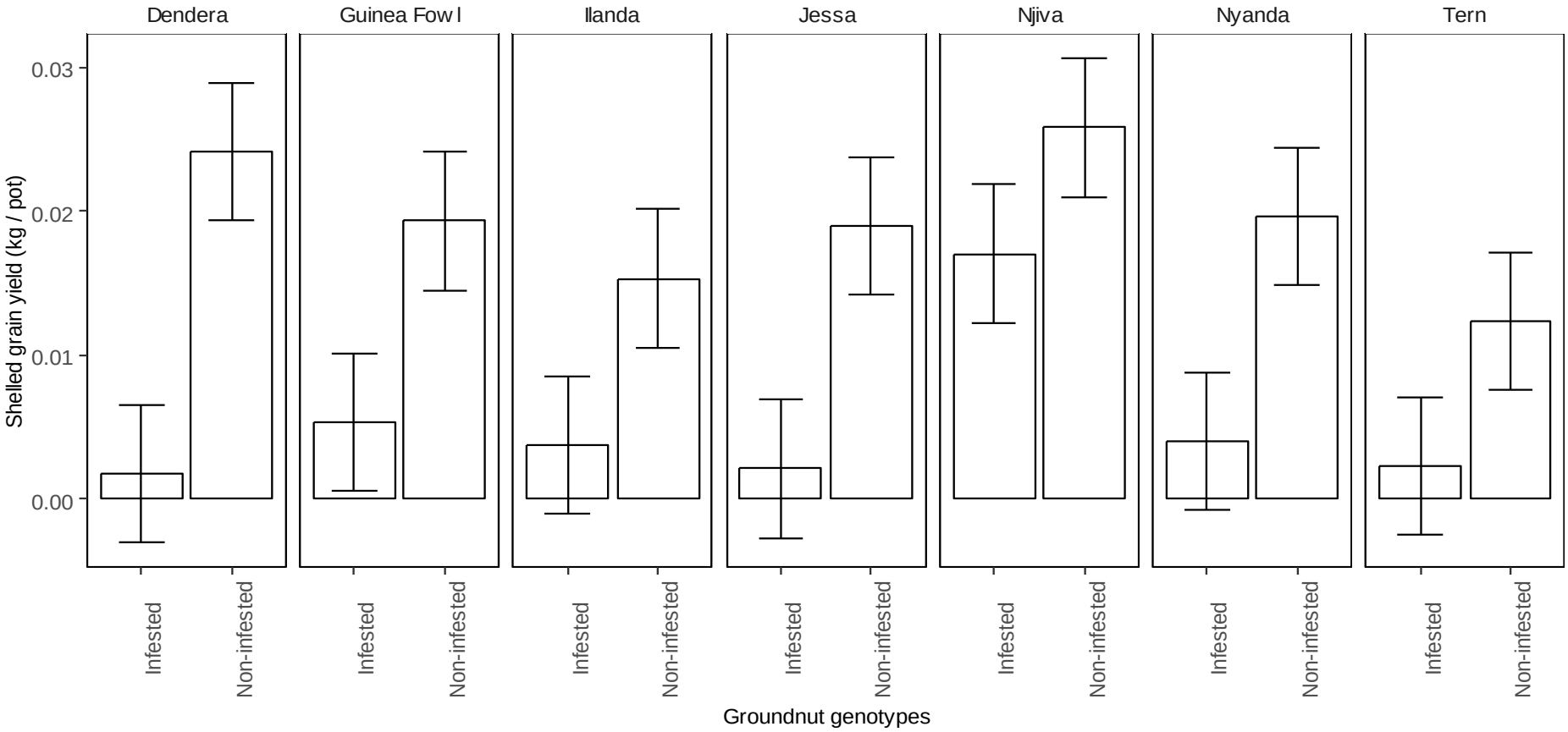

Figure 4. 10 The interaction between groundnut genotypes and *Alectra* infestation level relative to shelled grain yield evaluated under glasshouse conditions at the University of Zimbabwe. Error bars represent the standard error of the difference (sed) at $p<0.05$.

4.2.6 Groundnut genotype effects on *Alectra* attachment and biomass

Summary of mean square values for *A. vogelii* parameters is shown in Table 4.14

Table 4. 14 Mean square values for *Alectra vogelii* parameters recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season.

Source	Degrees of freedom	*Alectra* attachment	*Alectra* root biomass
Block	5	1.5667	3.1060
Genotype	6	2.4127*****	2.6030*****
Residual	30	0.4889	0.6321

*, ** and *** represent significance at the 5%, 1% and 0.1% probability levels, respectively.

Significant variations ($p<0.05$) were recorded among *Alectra* infested genotypes on *Alectra* root attachment (Table 4.18). Genotypes Dendera, Guinea fowl and Ilanda did not significantly differ on haustorial attachment (Table 4.13). Njiva did not support *Alectra* attachment. *Alectra* biomass significantly ($p<0.05$) differed across genotypes (Table 4.18) *Alectra* root biomass was significantly higher in genotypes Ilanda, Jessa and Nyanda compared to the other genotypes.

Table 4. 15 Means for *Alectra* attachment and *Alectra* biomass evaluated for different groundnut genotypes under the glasshouse conditions at the University of Zimbabwe.

Genotype	Haustorial/*Alectra* attachment	*Alectra* root biomass (g)
Dendera	1.17^{bc}	0.58^{ab}
Guinea fowl	0.83^{bc}	0.67^{ab}
Ilanda	1.00^{bc}	1.33^{bc}
Jessa	1.33^{cd}	1.75^{c}
Njiva	0.00^{a}	0.00^{a}
Nyanda	2.00^{d}	1.67^{c}
Tern	0.50^{ab}	0.52^{ab}
p-value	**0.001**	**0.004**
SED	**0.404**	**0.459**
LSD	**0.824**	**0.937**

Alectra root attachment on the groundnut roots

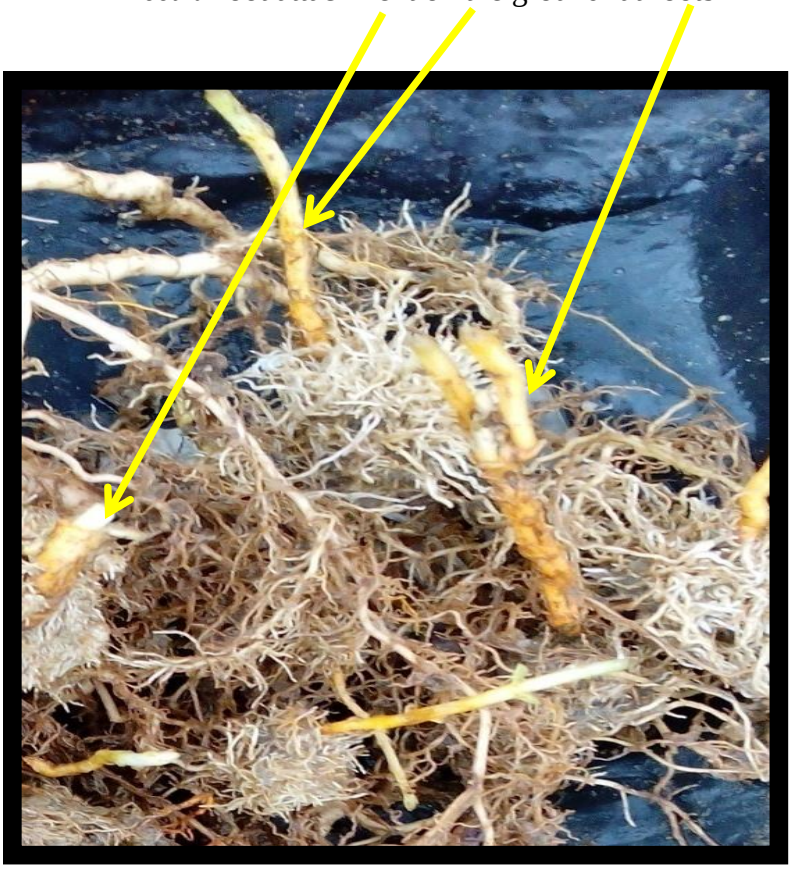

Figure 4. 11 *Alectra* root attachment on the groundnut roots under glasshouse experiment conducted at the University of Zimbabwe during 2018/2019 season. Photo was taken by William Makaza on 22/4/2019.

CHAPTER FIVE

DISCUSSION

The objective of the study was to determine the groundnut genotypes which have the capacity to produce lowest strigolactones and relate strigolactones production to grain yield of groundnuts for their resistance/ tolerance to *Alectra* parasitism under greenhouse experiment. Germination of *Alectra* is elicited by strigolactones released from the host plant. An agar-gel experiment identified Njiva with no germination distance and no *Alectra* germinated. This revealed that the genotype produced very low strigolactones which did not support *Alectra* germination. On the other hand, the groundnut genotypes, Dendera and Nyanda produced large quantities of *Alectra* strigolactones as shown by the longest germination distances from the groundnut root. The high *Alectra* seed germination percentage in the root exudates of Dendera and Nyanda could suggest that genotypes might be highly susceptible (Berner *et al.,* 1997).

The levels of susceptibility to *Alectra* infestation varied across genotypes. For example, Nyanda had the highest germination percentage compared to other groundnut genotypes with the exception of Njiva. Based on the stipulations that any genotype with maximum germination distance of greater than one millimeter (>1 mm) is susceptible and less than one millimeter (<1mm) is tolerant(Hess *et al.,* 1992), it could be concluded that that Njiva, Jessa, Guinea fowl, Ilanda and Tern were tolerant(0, 0.7, 0.7, 0.8, 0.8 mm) whereas Dendera and Nyanda were susceptible with mean maximum germination distance of 2 mm and 3.34 mm, respectively. Genetic variations within genotypes potentially confer pre-attachment resistance (Kamara *et al.,* 2013). Identification of groundnut genotypes which have little/ no strigolactones production

could be an important factor when recommending genotypes to grow in *Alectra* endemic areas These results complimented findings on groundnuts in Nigeria (Kwaga *et al.,* 2010; Motagi *et al.,* 2014) where they recommended resistant groundnut cultivars with low stimulant production.

In this study groundnut height varied across all genotypes. However, *Alectra* parasitism did not significantly differ between *Alectra* infested and non-infested genotypes on groundnut height. Significant variations occurred over time where these genotypes responded differently under different levels of *Alectra* infestation. The reduction in groundnut plant height is attributed to stunted growth, which is one of the major symptoms of *Alectra* infection (Kwaga, 2014a). Low sensitivity of these genotypes to *Alectra* infection might be due late attachment of *Alectra* on the host plants as well as genetic variation among groundnut genotypes (Mandumbu *et al.,* 2019).Plant height is considered as one of the most sensitive parameters, which indicates the effect of *Alectra* on groundnut(Kamara *et al.,* 2013).From this study, *Alectra* parasitism decreased groundnut plant height amongst all *Alectra* levels of infestation.

These variations occurring over time on plant height between infested and non-infested groundnut genotypes may be due to increased concentrations of the growth hormone-abscise acid (ABA), which result in closure of stomata thereby limited biochemical processes occurred in *Alectra* infested groundnut genotypes and eventually decreased groundnut plant height (Alonge *et al.,* 2001a). Moreover the significant reduction in groundnut height due to *Alectra* infection that was observed in this study could be attributed to uneven distribution of photo-assimilates. This is after attached of *Alectra* to the groundnut root, it a sink for all photo-assimilates produced

by the crop which concomitantly results in reduced growth of the host (Alonge *et al.,* 2001b). Groundnut heights had significant variations observed over time where groundnut genotypes responded differently under different levels of *Alectra* infestation. Insignificant sensitivity of some of the groundnut genotypes to *Alectra* might be due late attachment of *Alectra* on the host plants as well as genetic variation among groundnut genotypes (Mandumbu *et al.,* 2019).

Generally, *Alectra* infestation decreased number of primary branches on groundnut genotypes and was one of the most sensitive parts to *Alectra* parasitism. Once the number of branches decreased, the performance of *Alectra* infested genotypes is reduced. The reason being that, there were reduced canopies/ aboveground biomass to support photosynthesis and synthesis of photo-assimilates leading to reduced dry matter accumulation on host plants as well as shelled grain yield (Kwaga *et al.,* 2010; Kabambe *et al.,* 2013). The results concur with Kwaga (2014a) who reported that number of primary branches is one of the most sensitive traits to *Alectra* parasitism. Njiva and Dendera had small variation on the number of primary branches which signified high shoot biomass under infestation with genetic capacity to tolerate *Alectra* (Phiri *et al.,* 2018).*Alectra* infected genotypes did not reproduce more branches, the rate of photosynthesis and other biochemical reactions were highly decreased, which interfered with the chlorophyll content, chlorophyll fluorescence and the electron transport rate (Nyakurwa *et al.,* 2018).

Infested genotypes had low chlorophyll content compared to non-infested ones. *Alectra* infestation strongly decreased the performance of groundnut genotypes particularly on the biochemical process when genotypes tried to mitigate the effects of *Alectra*. Kwaga (2014a)

reported that chlorophyll, which is a light harvesting complex pigments were altered under *Alectra* infection and the rate of photosynthesis decreased. This could have resulted in a reduction of photosynthetic rate such that uneven distribution of assimilates recorded and affected all light dependent and independent reactions due to decreased carbon dioxide assimilation (Ejeta, 2007). It is postulated that all susceptible groundnut genotypes (Jessa, Tern, Dendera and Nyanda) to *Alectra* allowed haustorial attachment; penetration and development of phloem and/ or xylem connection thereby low chlorophyll content, low shoot biomass and grain yield (Fite *et al.*, 2009).*Alectra* decreased electron transport rate of *Alectra* infested susceptible groundnut genotypes compared to non-infested groundnut genotypes (Figure 4.4 and Figure 4.6). This is due to photo-inhibition, which is the inactivation of the PSII reaction centre, which caused a decrease in photosynthetic rate (Gurney *et al.*, 1999). However, tolerant groundnut genotypes (Njiva, Ilanda and Guinea fowl) showed tolerance to photo-inhibition under infestation.

In this case, *Alectra* became a sink and the host became the source; thus interfere with the biomass partitioning on susceptible genotypes particularly Nyanda and Dendera which recorded high *Alectra* attachment and low shelled grain yield. It could be suggested that Strigolactones produced by these genotypes regulated the aboveground biomass by inhibiting distribution of assimilates (Nyakurwa *et al.*, 2018). This is in line with comments by Monaco *et al.* (2002) who mentioned some changes occurred within enzymes involved in the carbon fixation, which contributed to the decrease of photosynthetic rate on Nyanda and Dendera. As a result, photorespiration could occur, which may interfered with RUBISCO, which oxygenated ribulose biphosphate (RuBP), wasting energy produced by photosynthesis- instead of driving reactions

that produced carbohydrates, the enzyme drove reactions that destroy carbohydrates (Rodenburg *et al.,* 2017).

Tolerant genotypes (Njiva, Ilanda and Guinea fowl) proved that they adjusted on chlorophyll content and become independent to keep photosynthesis at optimal rates as well as electron transport rate. It was suggested that genotypes with high shoot/ root ratio produced low strigolactones, contained more starch and non-reducing sugars which are required for the growth and development of the parasite; therefore, the capacity to produce adequate carbohydrates to sustain both parasite and host (Rugare *et al.,* 2013; Nyakurwa *et al.,* 2018). Electron transport rate strongly varied across all genotypes but not between *Alectra* infestation levels.

Chlorophyll content and electron transport rate give an indication that groundnut genotypes intercept light differently under stress due to inhibition of other biochemical process (Rambakudzibga *et al.,* 2002). Small differences were recorded on chlorophyll fluorescence across genotypes but *Alectra* infestation significantly affected chlorophyll fluorescence. The parasite interferes with PSII where light harvesting compounds are found and may become inactivated due to parasite induced stress resulting in decreased electron transport rate across all genotypes (Rodenburg *et al.,* 2017). Jessa had the least ETR could result in limited N assimilation (Kabambe *et al.,* 2013)and in turn decreased chlorophyll synthesis under *Alectra* infestation (Mbega *et al.,* 2010). Generally, *Alectra*-parasitized groundnut genotypes tend to have low chlorophyll content and fluorescence.

On groundnut phenology, number of days to 50% anthesis, days to first and second anthesis and days to physiological maturity significantly varied across all genotypes. This is a result of genetic variation across all genotypes where some genotypes exhibited early maturity (Jessa and Njiva), medium maturity (Nyanda, Tern, Dendera and Ilanda) and late maturity (Guinea fowl). Minimum and maximum days to 50% anthesis were recorded on Jessa and Guinea fowl which took mean days of 36 and 58 respectively. Based on the findings by Alonge *et al.* (2001b), *Alectra* infestation decreased the number of day to 50% anthesis on legume crop such as cowpea. This contradicted with findings from this study were there is no significant differences on infested and non-infested groundnut genotypes.

It took 31 days for Jessa to first anthesis and 52 days for Guinea fowl and these were minimum and maximum days respectively. These results were based on the phenological characteristics as well. From the experiment done, infected plants exhibited late flowering compared to non-infested and they varied with about 3-4 days across genotypes. *Alectra* induced pod filling before actual physiological time such that the size of the grain became very small and had a negative effect on the grain yield where under infestation, there was reduced grain yield compared to non-infested plants(Kwaga *et al.,* 2010; Rugare *et al.*, 2013).

The genotype x *Alectra* interactions were significant on plant biomass, shoot/root ratio and shelled grain yield. The shoot/root ratio indicates the direction of movement of carbohydrates. High shoot to root ratio values under *Alectra* infection means less carbohydrates were translocated to the roots were the parasite is found. The genotypes with this trait tolerated *Alectra*

infection, for example, Njiva, Guinea Fowl and Ilanda. In contrast, Dendera, Jessa, Nyanda and Tern were susceptible, because they lost a lot of biomass to *Alectra* which was acting as a sink. This could be the reason for reduced shelled kernel yield of susceptible infected groundnut genotypes. The fact that Njiva produced the highest biomass under *Alectra* infection confirms its tolerance. This indicated that both levels (Genotype and *Alectra*) contributed to biomass production. *Alectra* parasitism significantly reduced the shoot biomass of infested groundnut genotypes as compared to the non-infested genotypes. The biomass of the shoot appeared to be very sensitive parameter to infection by *Alectra*. Similar results were reported for *Alectra* effects in other cowpeas (Kabambe *et al.,* 2008; Rugare *et al*, 2013). Tern had the least total plant biomass, shoot biomass and root biomass. *Alectra* parasitism resulted in re-allocation of dry matter to below ground parts rather than aboveground biomass hence leading to lower shoot to root ratio in *Alectra* infested groundnut genotypes (*al.*, 2016).

Groundnut genotypes responded differently on *Alectra* attachment and its biomass. Njiva did not support any haustorial attachment and Nyanda recorded highest number of attachments. This was an indicator of the quality and quantity of strigolactones produced. There was relationship between agar-gel screening technique and the greenhouse experiment on the germination of *Alectra* parasite. In the agar-gel technique, Nyanda recorded highest germination percentage and maximum germination distance (mm) which was also noted in the pot experiment in the glasshouse. Although *Alectra* reduced grain biomass, it increased shoot and root biomass. As the parasite depends on the host for its survival, its attachment to the host plant roots induces the formation of lateral roots by the host for effective nutrient supply. Increased shoot biomass

shows some level of tolerance as the plants did not suffer the effects of *Alectra* infestation which leads to increased leaf senescence and abscission (Kebab *et al.,* 2008).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Groundnut genotype Njiva was identified as a resistant genotype based on its capacity not to support any *Alectra* germination through production of strigolactones as measured by germination percentage and furthest germination distance between groundnut root and *Alectra*. These results were supported by the pot experiment where Njiva did not support *Alectra* attachment. All the physiological attributes: chlorophyll content and chlorophyll fluorescence differ across all seven groundnut genotypes. The related agronomic performance on both infested and non-infested groundnut genotypes have small difference. Yield and yield components (plant biomass, shoot biomass, root biomass, 100 kernel yield and shelled grain yield) for groundnut genotypes under *Alectra* infestations were lower than non-infested genotypes. The groundnut genotypes: Ilanda and Dendera were identified as tolerant based on their desirable levels of stability under *Alectra* infestation and shelled kernel yield compared to Nyanda, Dendera, Jessa and Tern. These genotypes (Njiva, Ilanda and Guinea fowl) may provide a better option to farmers in *Alectra* endemic areas of SSA as they produce better yields under infestation. Other genotypes may only suite arable lands with little/ no obligate parasites. Tolerant genotypes particularly Njiva might be the potential donor parent for breeding towards resistance/ tolerance against *Alectra vogelii* infestation.

6.2 Recommendations

The search for reduced strigolactones producers should continue so that groundnut production may be attainable even under *Alectra* stricken areas. Further research should be conducted with other groundnut genotypes available on the market and assess for their performance under laboratory, greenhouse and *Alectra*-stricken areas.

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APPENDICES

Appendix 1 Analysis of variance for the effects of strigolactones produced by different groundnut genotypes on A. vogelii germination percentage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3791.66	1263.89	18.51	
Genotype	6	7611.17	1268.53	18.57	<.001
Residual	158	10791.05	68.30		
Total	**167**	**22193.88**			

Appendix 2 Analysis of variance for the effects of strigolactones produced by different groundnut genotypes on the furthest germination distance (mm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	57.384	19.128	10.29	
Genotype	6	182.513	30.419	16.37	<.001
Residual	158	293.563	1.858		
Total	**167**	**533.460**			

Appendix 3 Analysis of variance for the effects of *Alectra* infestation on groundnut plant height under glasshouse experiment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	490.207	98.041	0.72	
Genotype	6	4509.613	751.602	5.55	<.001
Alectra	1	254.725	254.725	1.88	0.175
Genotype**Alectra*	6	408.312	68.052	0.50	0.804
Residual	65	8794.766	135.304	48.56	
Time	17	63996.515	3764.501	1351.20	<.001
Time*Genotype	102	919.832	9.018	3.24	<.001
Time**Alectra*	17	145.444	8.556	3.07	0.042
Time*Genotype**Alectra*	102	261.925	2.568	0.92	0.536
Residual	1190	3315.394	2.786		
Total	**1511**	**83096.733**			

Appendix 4 Analysis of variance for the effects of *Alectra* infestation on the number of primary branches of groundnut genotypes under glasshouse experiment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	45.325	9.065	0.37	
Genotype	6	357.203	59.534	2.40	0.037
Alectra	1	703.069	703.069	28.31	<.001
Genotype**Alectra*	6	57.810	9.635	0.39	0.884
Residual	65	1614.281	24.835	16.76	
Time	10	14490.485	1449.048	978.09	<.001
Time*Genotype	60	191.273	3.188	2.15	0.005
Time**Alectra*	10	277.169	27.717	18.71	<.001
Time*Genotype**Alectra*	60	97.286	1.621	1.09	0.359
Residual	700	1037.061	1.482		
Total	**923**	**18870.961**			

Appendix 5 Analysis of variance for the effects of *Alectra* infestation on chlorophyll content of groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	1758.3	351.7	1.66	
Genotype	6	1987.8	331.3	1.56	0.172
Alectra	1	3197.2	3197.2	15.09	<.001
Genotype**Alectra*	6	1507.0	251.2	1.19	0.325
Residual	65	13773.1	211.9	1.04	
Time	5	397.0	79.4	0.39	0.552
Time*Genotype	30	6020.7	200.7	0.98	0.446
Time**Alectra*	5	883.6	176.7	0.87	0.364
Time*Genotype**Alectra*	30	6402.2	213.4	1.05	0.405
Residual	350	71428.7	204.1		
Total	**503**	**107355.5**			

Appendix 6 Analysis of variance for the effects of *Alectra* infestation on chlorophyll fluorescence rate of groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.093464	0.018693	4.40	
Genotype	6	0.028456	0.004743	1.12	0.363

Alectra	1	0.400062	0.400062	94.15	<.001
Genotype**Alectra*	6	0.028232	0.004705	1.11	0.368
Residual	65	0.276212	0.004249	0.54	
Time	3	0.052637	0.017546	2.22	0.095
Time*Genotype	18	0.062478	0.003471	0.44	0.969
Time**Alectra*	3	0.075907	0.025302	3.21	0.030
Time*Genotype**Alectra*	18	0.093813	0.005212	0.66	0.828
Residual	210	1.656478	0.007888		
Total	**335**	**2.767739**			

Appendix 7 Analysis of variance for the effects of *Alectra* infestation on electron transport rate of groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	122256.	24451.	8.48	
Genotype	6	76544.	12757.	4.43	<.001
Alectra	1	2357.	2357.	0.82	0.369
Genotype**Alectra*	6	22180.	3697.	1.28	0.278
Residual	65	187328.	2882.		
Total	**83**	**410667.**			

Appendix 8 Analysis of variance for the effects of *Alectra* infestation on days to 50% anthesis of groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	166.06	33.21	0.86	
Genotype	6	3729.74	621.62	16.05	<.001
Alectra	1	186.01	186.01	4.80	0.032
Genotype**Alectra*	6	137.07	22.85	0.59	0.737
Residual	65	2518.11	38.74		
Total	**83**	**6736.99**			

Appendix 9 Analysis of variance for the effects of *Alectra* infestation on days to first anthesis on groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	197.38	39.48	1.14	
Genotype	6	3768.07	628.01	18.13	<.001
Alectra	1	312.43	312.43	9.02	0.004
Genotype.Alectra	6	107.40	17.90	0.52	0.793
Residual	65	2250.95	34.63		
Total	**83**	**6636.24**			

Appendix 10 Analysis of variance for the effects of *Alectra* infestation on days to second anthesis on groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	196.095	39.219	5.03	
Genotype	6	1564.810	260.802	33.46	<.001
Alectra	1	19.048	19.048	2.44	0.123
Genotype**Alectra*	6	83.286	13.881	1.78	0.117
Residual	65	506.571	7.793		
Total	**83**	**2369.810**			

Appendix 11 Analysis of variance for the effects of *Alectra* infestation on the number of days to physiological maturity on groundnut genotypes evaluated under glasshouse experiment during 2018/2019 season at the University of Zimbabwe

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	133.095	26.619	2.84	
Genotype	6	1816.071	302.679	32.29	<.001
Alectra	1	3.048	3.048	0.33	0.570
Genotype.*Alectra*	6	63.786	10.631	1.13	0.353
Residual	65	609.238	9.373		
Total	**83**	**2625.238**			

Appendix 12 Analysis of variance for the effects of *Alectra vogelii* groundnut total plant biomass production recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.0062451	0.0012490	4.32	
Genotype	6	0.0056608	0.0009435	3.27	0.007
Alectra	1	0.0035127	0.0035127	12.16	<.001
Genotype**Alectra*	6	0.0039160	0.0006527	2.26	0.048
Residual	65	0.0187777	0.0002889		
Total	**83**	**0.0381123**			

Appendix 13 Analysis of variance for the effects of *Alectra vogelii* groundnut shoot biomass production recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.0037833	0.0007567	4.92	
Genotype	6	0.0035174	0.0005862	3.81	0.003
Alectra	1	0.0009738	0.0009738	6.33	0.014
Genotype**Alectra*	6	0.0008731	0.0001455	0.95	0.469
Residual	65	0.0099990	0.0001538		
Total	**83**	**0.0191466**			

Appendix 14 Analysis of variance for the effects of *Alectra vogelii* ongroundnut root biomass production recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.0017588	0.0003518	3.35	
Genotype	6	0.0022257	0.0003709	3.54	0.004
Alectra	1	0.0000069	0.0000069	0.07	0.799
Genotype**Alectra*	6	0.0010405	0.0001734	1.65	0.147
Residual	65	0.0068159	0.0001049		
Total	**83**	**0.0118477**			

Appendix 15 Analysis of variance for the effects of *Alectra vogelii* on groundnut shoot to root ratio recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.5711	0.1142	0.38	
Genotype	6	9.9241	1.6540	5.47	<.001
Alectra	1	0.5795	0.5795	1.92	0.171
Genotype**Alectra*	6	6.8188	1.1365	3.76	0.003
Residual	65	19.6646	0.3025		
Total	**83**	**37.5581**			

Appendix 16 Analysis of variance for the effects of *Alectra vogelii* on the number of groundnut pods per plant recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	389.63	77.93	2.80	
Genotype	6	195.95	32.66	1.17	0.333
Alectra	1	356.30	356.30	12.78	<.001
Genotype**Alectr*a	6	60.62	10.10	0.36	0.900
Residual	65	1812.20	27.88		
Total	**83**	**2814.70**			

Appendix 17 Analysis of variance for the effects of *Alectra vogelii* on the number of groundnut seeds per plant recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	135.679	27.136	3.10	
Genotype	6	362.000	60.333	6.89	<.001
Alectra	1	980.583	980.583	112.05	<.001
Genotype**Alectra*	6	72.667	12.111	1.38	0.234
Residual	65	568.821	8.751		
Total	**83**	**2119.750**			

Appendix 18 Analysis of variance for the effects of *Alectra vogelii* on 100kernel yield the number of groundnut pods per plant recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.024542	0.004908	2.31	
Genotype	6	0.011452	0.001909	0.90	0.502
Alectra	1	0.040985	0.040985	19.27	<.001
Genotype.Alectra	6	0.013286	0.002214	1.04	0.407
Residual	65	0.138218	0.002126		
Total	**83**	**0.228483**			

Appendix 19 Analysis of variance for the effects of *Alectra vogelii* on the shelled grain yield recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.00066480	0.00013296	1.93	
Genotype	6	0.00195305	0.00032551	4.72	<.001
Alectra	1	0.00287516	0.00287516	41.71	<.001
Genotype**Alectra*	6	0.00099693	0.00016616	2.41	0.036
Residual	65	0.00448040	0.00006893		
Total	**83**	**0.01097034**			

Appendix 20 Analysis of variance for the effects of *Alectra vogelii* on unshelled grain yield recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.00044459	0.00008892	1.15	
Genotype	6	0.00102346	0.00017058	2.21	0.054
Alectra	1	0.00397086	0.00397086	51.34	<.001
Genotype**Alectra*	6	0.00094621	0.00015770	2.04	0.073
Residual	65	0.00502767	0.00007735		
Total	**83**	**0.01141280**			

Appendix 21 Analysis of variance for the effects of *Alectra vogelii* on haulm yield recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	0.00123668	0.00024734	3.23	
Genotype	6	0.00074829	0.00012471	1.63	0.153
Alectra	1	0.00025030	0.00025030	3.27	0.075
Genotype**Alectra*	6	0.00033595	0.00005599	0.73	0.626
Residual	65	0.00497282	0.00007650		
Total	**83**	**0.00754404**			

Appendix 22 Analysis of variance for groundnut genotype effects on *Alectra* attachment recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	7.8333	1.5667	3.20	
Genotype	6	14.4762	2.4127	4.94	0.001
Residual	30	14.6667	0.4889		
Total	**41**	**36.9762**			

Appendix 23 Analysis of variance for groundnut genotype effects on *Alectra* root biomass recorded on different groundnut genotypes under glasshouse conditions at the University of Zimbabwe during 2018/2019 season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	5	15.5298	3.1060	4.91	
Genotype	6	15.6181	2.6030	4.12	0.004
Residual	30	18.9619	0.6321		
Total	**41**	**50.1098**			