AN INVESTIGATION INTO THE ROLE OF ALLELOPATHY IN INFLUENCING PLANT DIVERSITY AROUND *LANTANA CAMARA* GROVES IN LUSAKA

By

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A dissertation submitted to the University of Zambia in partial fulfillment of the
requirements for the degree of
Master of Science in Tropical Ecology and Biodiversity

THE UNIVERSITY OF ZAMBIA
LUSAKA

2008

DECLARATION

I, Catherine Lwando -Tembo, declare that this report represents my own work. It has not previously been submitted for a degree or any award at this University or any other institution. All published work or materials from other sources incorporated in this report have been specifically acknowledged and adequate reference thereby given.

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APPROVAL

This dissertation of Catherine Lwando – Tembo has been approved as fulfilling part of the requirements for the award of the degree of Master of Science in Tropical Ecology and Biodiversity by the University of Zambia

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ABSTRACT

Invasive alien species have become a serious threat to plant biodiversity in many parts of the world. Globally the threat to biodiversity due to invasive alien species is considered second only to that of habitat loss. Invasive species are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. *Lantana camara* L. is one of the many invasive alien species and has been rated by the IUCN Invasive Species Specialist Group among the world's 100 worst invasive alien species. Zambia's National Biodiversity Strategy and Action Plan of 1998 has identified *Lantana camara* as one of the introduced invasive plants that negatively impacts on ecosystems and indigenous plant diversity.

The overall objective of the study was to investigate *L. camara*'s allelopathic effects on indigenous plants in Zambia. Specific objectives of the study were (i) to determine the effect of *L. camara* on seed germination of some indigenous plants. (ii) to investigate how *L. camara* affects growth of seedlings in terms of leaf production, root length, root biomass, shoot length and shoot biomass of *Bauhinia petersiana*, a woody species that appeared to be negatively influenced by *L. camara* in the field.

The study was conducted in two phases. Phase one involved a field survey to determine whether there was a gradient in indigenous woody plant diversity caused by *L. camara* invasion and to identify species that appeared to be negatively affected by *L. camara*. The second phase involved laboratory experiments to determine mechanisms by which *L.*

camara negatively affects *B. petersiana* seedling growth with regard to leaf production, root length, root biomass, shoot length and shoot biomass .

The results in this study showed that *L. camara* did not necessarily influence plant diversity in its neighborhood. The reasons for *L. camara* not influencing plant diversity could be that its influence significantly depends on its density and age. It can be assumed that the influence of *L. camara* occurs at very high density beyond the density of 4 groves per ha at Lilayi Game Ranch where the field survey was conducted. It was also noted that possibly the size of the *L. camara* groves need to be quite large, beyond the diameter of 4.9 m and 5.3 m for the study groves used in order to have an influence on the floristic diversity at Lilayi Game Ranch study site.

The experimental results revealed that germination and seedling growth in terms of leaf production, root biomass, shoot length and shoot biomass of *Bauhinia petersiana* was reduced by the addition of *L. camara* leaf and root material to soil which is consistent with results of other studies that have shown that the allelopathic effect of *L. camara* results in severe reductions in seedling recruitment of nearly all species under its influence. The differences in seedling emergence among the treatments were significant ($F = 3.96$, $p < 0.05$) with the Bonferroni all – pairwise comparison test revealing that seedling emergence under the LMT was significantly lower than under the RMT and control but was not significantly different from the LRMT. The findings in this study clearly show that *L. camara* has allelopathic properties that reduce seed germination and seedling growth in terms of leaf production, root length, shoot length and shoot biomass of *B. petersiana.*

Since *L. camara* appears to have allelopathic properties that reduce seed germination and seedling growth of some native woody plants, such as *B. petersiana,* it is therefore recommended that there is prevention of its spread into uninfested areas as this will be the most cost – effective way of conserving indigenous biodiversity. There is also need to use an integrated approach to biodiversity conservation that uses a variety of control methods with a range of methods including herbicides, mechanical removal, fire and biological control. Biological control may not eradicate *L. camara* but could reduce the plant from a weed to a non-weed status which is then maintained in a steady dynamic equilibrium with the control agent species. In this way, biodiversity may be maintained. In addition, there is need for future studies to consider the effect of *L. camara* on herbaceous plants and ecosystem functions since these were not considered by the present study.

DEDICATION

To my parents Mr. & Mrs. Lwando, my husband Capt. Charles Tembo, my children Daniel, Isubilo and Malumbo and my brothers and sisters for their tolerance, love and encouragement during the duration of my study.

ACKNOWLEDGEMENTS

This project would not have been possible without the support of many people. Special thanks to God Almighty for granting me his mercy and grace to complete this study. Thanks to my supervisor, Professor Emmanuel N. Chidumayo for giving me invaluable professional guidance and for assisting me with his statistical softwares for data analysis. I am thankful to Professor Keith Mbata for his unending words of encouragement through out my period of study. I also wish to thank Mr. Allan Miller of Lilayi Game Ranch for having allowed me to carry out the field research at Lilayi Game Ranch.

I am greatly indebted to the World Wide Fund for Conservation of Nature (WWF) and the Ministry of Science and Technology for their financial support in my M.Sc. Study.

I thank the laboratory assistants in the Department of Biological Sciences, Ms Brenda Mwenya, Mr. Sitwala Wamunyima and Mr. Abel Siampale of Forest /Department for assisting me during the data collection period. I am so grateful to Mr. Gabriel Mushinge for having spared his time to assist with the location map of the study area.

My special gratitude go to my husband Capt Tembo and my three children for accepting the challenge of living alone during most of the time of my studies and for all their support and encouragement.

Thanks to the Department of Biological Sciences at the University of Zambia for providing the necessary facilities. Thanks to my course mate Musonda Ng'onga and

numerous friends for their moral support. Lastly, I thank all those people too numerous to mention who assisted me in one way or another in my research project.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARMC – ANZ:	Agriculture and Resource Management Council of Australia and New Zealand
CSIR:	Council for Scientific and Industrial Research
GPS:	Global Positioning System
IUCN:	International Union for the Conservation of Nature
LMT:	Leaf material treatment
LRMT:	Leaf and root material treatment
MENR:	Ministry of Environment and Natural Resources
NEAP:	National Environment Action Plan
NBSAP:	National Biodiversity Strategy and Action Plan
RMT:	Root material treatment
UNEP:	United Nations Environment Programme
WWF:	World Wide Fund for Conservation of Nature

SECTION ONE: INTRODUCTION AND LITERATURE REVIEW

CHAPTER 1: INTRODUCTION

1.1 Background

Cronk and Fuller (2001) defined an invasive plant species as an alien plant spreading naturally or through other means in a natural or semi natural habitat to produce significant changes in terms of composition, structure or ecosystem processes. Invasive alien species have become a serious threat to plant biodiversity in many parts of the world. Globally the threat to biodiversity due to invasive alien species is considered second only to that of habitat loss. Invasive species are thus a serious impediment to conservation and sustainable use of global, regional and local biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems (UNEP, 2003).

Lantana camara L. is one of the many invasive alien species and has been rated by the IUCN Invasive Species Specialist Group (IUCN, 2001) among the world's 100 worst invasive alien species. In addition, Batianoff and Butler (2003) have rated *L. camara* among the highest ranked invasive species in Queensland, Australia.

Zambia's National Biodiversity Strategy and Action Plan of 1998 has identified *Lantana camara* as one of the introduced invasive plants that negatively impacts on ecosystems and indigenous plant diversity and this plant species can cause significant irreversible environmental and socio-economic impacts at the genetic, species and ecosystem levels of indigenous plants (MENR, 1998).

Lantana camara was probably introduced in Zambia as a hedging plant in the pre-1950s. The introduction and invasiveness of *L. camara* was associated with urbanization and European settlements and farms. Thus a number of statutory instruments were issued between 1959 and 1963 declaring *L. camara* as a noxious weed in most urban centers. Chishiba (2004) suggests that the spread of *L. camara* has been of concern for the past forty years in the Mosi-oa-Tunya National Park in Livingstone and grazing areas and other agricultural lands particularly near urban centers. It has invaded the Copperbelt Foresty Company Plantations and is also interferring with the Pine project at Zambia Forestry College. *L. camara* is displacing indigenous plants in the Mosi-oa-Tunya National Park and is affecting the aesthetic view of the Victoria Falls Gorges.

Lantana camara having been classified as an invasive alien species has the general characteristics that make it a successful invader. These characteristics include its ability to disperse from the original population, establish in the new environment, increase population size and then spread. The ability to disperse requires either inherent dispersability of propagules, or the presence of co-evolved or opportunistic biotic dispersal agents. Physiological factors such as drought resilience and water-use efficiency may be important determinants for the success or failure of an introduced species in a new environment. *Lantana camara* invades the ecosystem by out - competing other plant species. Competition in living organisms occurs when individuals attempt to obtain a resource that is inadequate to support all the individuals seeking it. To gain access to this resource, *L. camara* has evolved some form of chemical aggression or allelopathy. Allelopathy involves the production of chemicals that inhibit or kill competing plants. These allelochemicals may alter the nutrient cycling processes of the soil, change soil pH, or act as phyto-toxins. Crawley (1987) observed that allelopathy is most likely to take the form of suppression of germination or growth of neighboring plants by secondary compounds, which are leached or volatilized from the allelopathic plant.

1.2 Problem statement

In Zambia, *L. camara* has been identified as a serious invasive alien plant and literature has shown that wherever *L. camara* has invaded, there is a reduction in the floristic diversity in its neighborhood and this has been attributed, among other things, to the allelopathic properties of the species (Gentle and Duggin, 1997a).

1.3 Objectives

The overall objective of the study was to investigate *L. camara*'s allelopathic effects on indigenous plants in Zambia. Specific objectives of the study were:

(a) To determine the effect of *L. camara* on seed germination of some indigenous plants

(b) To investigate how *L. camara* affects growth of seedlings of some indigenous plants especially those whose seed germination is negatively affected.

1.4 Hypothesis

The study tested the following hypotheses:

i) *Lantana camara* has allelopathic properties that reduce seed germination of indigenous plants in Zambia

ii) *Lantana camara* has allelopathic properties that reduce seedling growth in terms of leaf production, root length, root biomass, shoot length and shoot biomass of some indigenous plants of Zambia

1.5 Significance of the study

There is no available information on the allelopathy of *L. camara* in Zambia, therefore the findings of this study would generate new information on whether indeed *L. camara* reduces native plant diversity and the mechanisms through which this is achieved.

1.6 Study Approach

The study was conducted in two phases. Phase one involved a field survey to determine whether there was a gradient in indigenous woody plant diversity caused by *L. camara* invasion and to identify species that appeared to be suppressed by *L. camara*. The second phase involved laboratory experiments to determine mechanisms by which *L. camara* negatively affects selected indigenous plant species.

1.7 Assumptions

The study was based on three assumptions. The first assumption was that allelopathy of *L. camara* operates through the soil system via substances released from decaying leaf litter and/or root exudates of the species. The second assumption was that seeds of inhibited indigenous plants were available for laboratory experiments on allelopathy. The third assumption was that drying of the roots would not affect the exudates from the roots and therefore potency would still be maintained.

CHAPTER 2: LITERATURE REVIEW

.1 Description of *Lantana camara*

antana camara (family Verbenaceae) is a 2 – 4 m tall profusely branching, scrambling romatic shrub with square-sectioned, often prickly cane-like stems. The leaves are opposite, vate and often toothed, 2 – 6 cm long. Flowers are produced in clusters of 20 - 40 compact eads of 2-3 cm diameter. Flower colour is variable, from cream and yellow to orange, red, ink, and mauve (Figure 2.1.1). Fruits are single-seeded berries that measure about 4 to 8 ım in diameter and are purplish-black when ripe (Day *et al.,* 2003).

igure 2.1.1: Picture of *L. camara* showing the leaves and the flowers. Photo by author

. camara is an 'aggregate species', or 'species complex' of tropical American origin that was riginally imported to other countries as an ornamental garden shrub. There are several atural variants of *L. camara* across its presumed native range in the tropical Americas, and n addition, some hundreds of horticultural colour and habit varieties have been developed

around the world, with over 650 varietal names coined (Smith and Smith, 1982; Howard 1969), some as a result of hybridisation with species in other related complexes, such as *L. urticifolia* (Day *et al.*, 2003). Some of these variants in turn may have hybridised to form new feral wild-types. There are 29 variants of *L. camara* generally accepted to be naturalised in Australia (Smith and Smith, 1982; Day *et al.*, 2003), and new forms or biotypes may be evolving. The variants differ in morphology and distribution, and in as yet imperfectly understood aspects of habitat preference, rates of fruit set, bio-control susceptibility and weediness.

2.2 Ecology of *Lantana camara*

The diverse and broad geographic distribution of lantana is a reflection of its wide ecological tolerances. It occurs in diverse habitats and on a variety of soil types. It generally grows best in open unshaded areas, such as wastelands, rainforest edges, beachfronts, and forests recovering from fire or logging. Disturbed areas, such as roadsides, railway tracks and canals are also favourable for the species (Thaman, 1974; Winder, 1980; Thakur *et al.*, 1992; Munir, 1996).

Lantana camara grows under a wide range of climatic conditions. It does not appear to have an upper temperature or rainfall limit and is often found in tropical areas receiving 3000 mm of rainfall per year, provided that soils are sufficiently well drained. It occurs where there is a moderate to high summer rainfall. *Lantana camara* seldom occurs where temperatures frequently fall below 5°C and in South Africa it is found in areas with a mean annual surface temperature greater than 12.5°C (Day *et al.*, 2003). Some varieties can withstand minor frosts, provided these are infrequent. Prolonged freezing temperatures kill aerial woody branches and cause defoliation.

Most variants have a preference for fertile organic soils, but some or all can survive on siliceous sands and sandstone-derived soils where these are of moderate depth and other conditions, especially year-round moisture, are suitable. *Lantana camara* does not tolerate waterlogging, salinity, prolonged drought and dense shading by overstorey species.

Lantana camara readily invades disturbed sites and communities, including edges and canopy breaks in dense forest communities, including various types of rainforest and dry rainforest. In open forests and woodlands, given suitable soils and moisture, *L. camara* often becomes a dominant understorey species. In warmer, moister areas *L. camara* often becomes dominant in regenerating pastures. It typically forms dense thickets, suppressing less competitive native vegetation and seedlings through shading (Swarbrick *et al.*, 1995; ARMC-ANZ, 2001) surface-soil nutrient sequestration and allelopathy (Gentle and Duggin 1998; CRC Weed Management, 2003; Lamb, 1988).

According to Sharma *et al.* (2005), *L. camara* reaches reproductive maturity at 4 to 5 months old and has the potential to flower all year if adequate moisture and light are available but peak flowering occurs in wet summer months. Plants can flower as early as the second growing season. Initially, lepidopteran species were thought to be the primary pollinators of *L. camara* (Day *et al.*, 2003). Some butterfly species visit certain *Lantana* taxa more frequently than others due to differences in corolla length, inflorescence diameter and number of flowers per inflorescence. According to this view, different varieties of *Lantana* may have different species of pollinators. There are conflicting reports over *Lantana*'s ability to self pollinate. Fruit-set rates in weedy forms are variously reported, ranging in various studies from about 37 per cent to 50 per cent (Swarbrick *et al.*, 1995) and 85 per cent (Hilje, 1985).

Lantana camara's seeds need high light conditions for germination and early growth and seedlings are unlikely to survive beneath parent bushes. Seeds germinate at any time of the year given sufficient soil moisture (Day *et al.*, 2003). Seed dispersal is primarily by fruit-eating birds, and to a lesser degree by foxes and other vertebrate foragers (Day *et al.,* 2003). Birds play a critical role in exacerbating the weed problem. By feeding on *L. camara* fruits, birds may increase the density and distribution of the weed at the expense of native vegetation thereby displacing other bird species.

Seed longevity in the soil is not well documented, but 50 per cent seed viability after 6 months dry shelf-storage has been recorded (ARMC-ANZ, 2001), and seeds "are thought to remain viable for several years under natural conditions" (CRC Weed Management, 2003). Germination is favoured by removal of fruit pulp (CRC Weed Management, 2003), and by warm temperatures, light, and high soil moisture. Germination rates even under favourable conditions are sometimes reported as fairly low (<45 per cent or less), but as fruits may set at rates of several thousand /m^2 there is a considerable soil seedbank. Gentle and Duggin (1997b) reported that in-situ "burning, biomass removal, and soil scarification, either singly or in any combination, significantly increased germination", and most combinations of these disturbances, all associated with cattle grazing and fire, favoured *L .camara* seedling growth rates.

antana camara is tolerant of occasional fire and mechanical damage to the aerial stems, eing capable of resprouting vigorously from the stem-base and of 'layering' (i.e. vegetative ropagation by development of roots from stems in contact with soil). Reports of an ability of *. camara* to sucker from broken roots probably relate to resprouting from layered stem ragments, although some bush regenerators have reported true root suckering (Day *et al.*, 003).

.3 Invasive characteristics of *Lantana camara*

antana camara possesses a number of attributes in its life cycle that characterize it as an nvader. Based on the available information, the biological attributes conferring invasiveness or *L. camara* can be summarized in seven ways according to Sharma *et al.*, (2005), namely: i) fitness homeostasis and phenotypic plasticity, (ii) interaction with animals, (iii) eographical range, (iv) vegetative reproduction, (v) fire tolerance (vi) competitive ability nd (vii) allelopathy.

.3.1 Fitness homeostasis and phenotypic plasticity

he ability of an individual or population to maintain relatively constant fitness over a range f environments is known as homeostatic fitness. Phenotypic plasticity is the ability of a enotype to modify its growth and development in response to changes in the environment Dorken and Barrett, 2004). Accordingly, plastic responses in vegetative structure are hought to promote survival and propagation of an exotic species in the new heterogeneous nvironment (Santamaria, 2002). Values such as mean “relative physiological performance” r mean “relative ecological performance” across environmental gradients can be used as an lternative for population fitness homoeostasis (Austin *et al.*, 1985). Artificial defoliation of

L. camara during spring compared to defoliation in autumn produces more stems and results in a greater allocation of biomass to reproductive structures. This suggests that *L .camara* compensates for defoliation, exhibiting its invasive potential (Broughton, 2003).

2.3.2 Interaction with animals

The success of *L .camara* may be attributed to the presence of a range of pollinators, accounting for the high percentage of fruit-set. Once formed in high numbers, the seeds of *L. camara* are dispersed efficiently through the participation of a variety of animal dispersal agents that feed on its fruit. The process of invasion is further improved by nutrient additions, with animal droppings, canopy removal, and soil disturbance creating a good seed bed. Gentle and Duggin (1997a) and Duggin and Gentle (1998) demonstrated that physical soil disturbance associated with cattle grazing might also increase resource availability due to the removal of competitive biomass. *Lantana camara* itself benefits from the destructive foraging activities of vertebrates, such as pigs, cattle, goats, horses, sheep, and deer, through enhanced vegetative propagation (Thaman, 1974; Fensham *et al.*, 1994). Some bird species have also facilitated seed dispersal by construction of their nests using broken *L. camara* leading to its spread (Loyn and French, 1991).

2.3.3 Geographical range

Lantana camara has a widespread distribution (35°N – 35°S) beyond its native range, becoming naturalized in over 60 countries (Day *et al.*, 2003). The distribution of *L. camara* using the CLIMAX model (Day *et al.*, 2003) and Myers biodiversity hot spots (Myers *et al.*, 2000), shows substantial overlap with each other, which could indicate a severe threat for the ecosystems in hot-spot areas. *Lantana camara* covers an altitudinal range of up to 2000 m in the Pulnis hills in southern India, but Mathews (1972) could not determine the genotypic and the phenotypic differences in the individuals occurring at different altitudes. The distribution of *L. camara* is still expanding, with many countries and islands that were listed in 1974 (Thaman, 1974) as not having *L. camara* (e.g. Galapagos Islands, Solomon Islands, Palau, Saipan, Tinian, Yap, and Futuna Islands) being infested with *L. camara* more recentl (Waterhouse and Norris, 1987). The density of *L. camara* infestations within its native rang is also increasing, which has been recognized as an additional threat to ecosystems.

2.3.4 Vegetative reproduction

Once established, the rapid vegetative growth of *L. camara* facilitates the formation of large, impenetrable clumps (Van Oosterhout *et al.*, 2004) and high seed production. The more common means of vegetative spread is through layering, where horizontal stems produce roots when they come in contact with soil (Swarbrick *et al.*, 1995). In addition, suckering also can occur. Prostrate stems can root at the nodes if covered by moist soil, fallen leaves or other debris. In Australia, it is commonly well-spread by land owners dumping vegetative material in the bushland (Day *et al.*, 2003). *Lantana camara* stems or leaves could develop roots and grow into plants and eventually flower.

2.3.5 Fire tolerance

Although *L. camara* burns readily during hot, dry conditions, even when green (Gujral and Vasudevan, 1983), moderate and low intensity fires can promote the persistence and spread of *L. camara* thickets, rather than reducing them. Moreover, the removal of competing neighborhood plant species and increases in soil nutrients following burning can increase its germination (Gentle and Duggin, 1997a; Duggin and Gentle, 1998). Under conditions o increased soil fertility (Duggin and Gentle, 1998), its re-establishment is encouraged following mechanical or chemical control of mature plants.

2.3.6 Competitive ability

Under conditions of high light, soil moisture, and soil nutrients, the mortality rate of mature *L. camara* plants in its naturalized range is very low (Sahu and Panda, 1998). *Lantana camara* infestations are very persistent and, in forest communities, have the potential to block succession and displace native species, resulting in a reduction in biodiversity (Loyn and French, 1991; Duggin and Gentle, 1998). At some sites, *L. camara* infestations have been so persistent that they impede the regeneration of the rainforest (Lamb, 1988). *Lantana camara* is a very effective competitor with native colonizers (Duggin and Gentle, 1998) and is capable of interrupting the regeneration processes of other indigenous species by decreasing germination, reducing early growth rates, and increasing mortality. This results in marked changes in the structural and floristic composition of natural communities. Therefore, as the density of *L. camara* in forests increases, species richness decreases (Fensham *et al.*, 1994). However, *L. camara* does not invade intact forests, but is found on its margins (Humphries and Stunton, 1992).

2.3.7 Allelopathy

Lantana camara is thought to be allelopathic, i.e. able to inhibit or suppress by chemical means the germination and/or growth of some competing plant species. Rice (1974) defines allelopathy as any direct or indirect effect by one plant, including micro-organisms, on another through the production of chemical compounds that escape into the environment and subsequently influence the growth and development of neighboring plants. Aldrich (1984) describes two types of allelopathy, namely the true allelopathy and the functional allelopathy. True allelopathy is the release into the environment of compounds that are toxic in the form in which they are produced in the plant while the functional allelopathy is the release into the environment of a substance that is toxic as the result of transformation by micro-organisms. There are numerous chemical compounds in plants that can function as allelochemicals and these allelochemicals are found in leaves, roots, stems, flowers and fruits. Leaves are the major source in most species. The roots generally produce smaller quantities and less toxic compounds compared to the leaves (William, 1999). The allelopathic interactions are undoubtedly an important factor in determining species distribution and abundance within some plant communities (Rizvi *et al.*, 1992).

The allelopathic effect of *L. camara* results in severe reductions in seedling recruitment of nearly all species under its cover (Anonymous, 1962). No growth or only stunted growth have been observed for other species growing close to *L. camara* due to allelopathic effects, as shown by the fern *Cyclosorus dentatus* Forsk., (Pteridophyta), milkweed vine (*Morrenia odorata* Lindl.; Asclepiadaceae), rye (*Lolium multiflorum* Lam.; Poaceae) and many crops, such as wheat, corn, and soybean (Achhireddy and Singh, 1984; Achhireddy *et al.*, 1985). Jain *et al* (1989) observed that about 14 phenolic compounds are present in *Lantana* that can reduce the seed germination and growth of young plants. A series of aromatic alkaloids and phenolics can be extracted from the various plant parts of *L. camara* (Khan *et al.*, 2003). Allelochemicals promote or inhibit crop growth based on their concentration (Ambika *et al.*, 2003), and the concentration increases from root to stem and leaf (Chaudhary and Bhansali, 2002), making the leaf toxic to grazing animals (Ambika *et al.*, 2003).

A substantive Australian field trial (Gentle and Duggin, 1997a), observed that *L .camara* due to its strong allelopathic properties has the potential to interrupt the regeneration process of other species by decreasing germination, reducing early growth rates and selectively increasing mortality of other plant species. These result in a reduction of seedling diversity (Loyn and French, 1991; Gentle and Duggin, 1998) and subsequently in marked changes in the structural and floristic composition of natural communities. Therefore, as the density of *L. camara* in forests increases, species richness decreases (Fensham *et al.,* 1994).

Glasshouse studies (Swarbrick *et al*., 1995) have also suggested that *L. camara'*s allelopathy inhibits or suppress by chemical means the germination and/or growth of some competing plant species. Furthermore, an experimental study in Uganda (Matsebula and Richard, 2005) revealed that *L .camara* had a negative effect on shoot elongation of millet and this indicated some toxicity from *L. camara.*

2.4 Impacts of *Lantana camara on* native biodiversity

The generally suppressive effect of *L. camara* on a wide range of native species is attested by several studies (Gentle and Duggin, 1998; Day *et al*., 2003). Field observations by Driscoll and Quinlan (1985) were that "eucalypt seedlings generally fail to establish under *L. camara* ", perhaps through inhibition of germination through lack of light but Fensham *et al*. (1994) noted the persistence of at least some regenerant dry rainforest tree species beneath *L. camara* thickets.

*Lantana camara'*s dominance may adversely affect the richness of some soil faunal assemblages. Cummings (2004) reported a reduced presence in *Lantana*-dominated vegetation of several functional groups of ant species, compared to the adjacent 'non *Lantana'* (rainforest and sclerophyll) communities, and concluded that this probably related both to initial disturbance events and to the structure of *Lantana*-dominated vegetation that followed.

Research by Fernandes *et al.* (2001) pointed to a progressive loss of diversity among mycorrhizal arbuscular fungi in rainforest systems of Madagascar and this correlated with a loss of vascular plant diversity.

Swarbrick *et al.* (1995) presented summary data from Alcova (1987) that showed a large, at least 70 per cent decline in inferred recruitment number of native tree and shrub saplings present in *Lantana*-infested areas of eucalypt woodland compared to *Lantana*-free areas. In Queensland, *L. camara* has been identified as a potential threat to more than 60 plant and animal species of conservation significance (ARMC-ANZ, 2001).

2.5 Impacts of *Lantana camara* on ecosystem processes

Studies have also shown that *L. camara* may change soil microhabitat through shading, self-mulching, and alter water and nutrient balances. Lamb (1988) identified an increase in soil nitrate in a eucalypt woodland following *L. camara* invasion, to the benefit of the *Lantana* and other weeds, and to the detriment of low-nitrogen native species, and a decline in other nutrients. Gentle and Duggin (1998) pointed to *L. camara*'s ability to aggressively compete for and sequester surface-soil nutrients, such as are made available by disturbance episodes, and verified experimentally *Lantana*'s ability to out-compete and suppress an analogous native coloniser of mesic forests *Choricarpia leptopetala* (Myrtaceae).

Lantana camara is not established as a causal mechanism but the ability of *Lantana* to arrest vegetation succession for decades (Lamb, 1991) and to inhibit growth of at least some micro-organisms (Parsons and Cuthbertson, 2001), suggests that it may also inhibit mycorrhizal recolonisation.

Fensham *et al.* (1994) documented declines in plant species richness with increasing levels of *L. camara* infestation of dry rainforest, and accumulation of heavy fuel loads along boundaries between savanna woodland and dry rainforest, leading to significant canopy tree loss and edge erosion in the latter, with *Lantana* dominating the area of lost dry rainforest and rendering it prone to further fires.

SECTION TWO: FIELD SURVEY

CHAPTER 3: DESCRIPTION OF THE STUDY AREA

3.1 Location

The field survey was done at Lilayi Game Ranch about 20 km south of Lusaka city in central Zambia and lies between latitudes 15° 32' 26" S and 15° 32' 29" S and longitudes 28°20' 13" E and 28°20' 18" E and the extent of this ranch is shown in Figure 3.1.1. The actual size of Lilayi Game Ranch is 500 ha and the two *L. camara* study groves are within 430 m of each other.

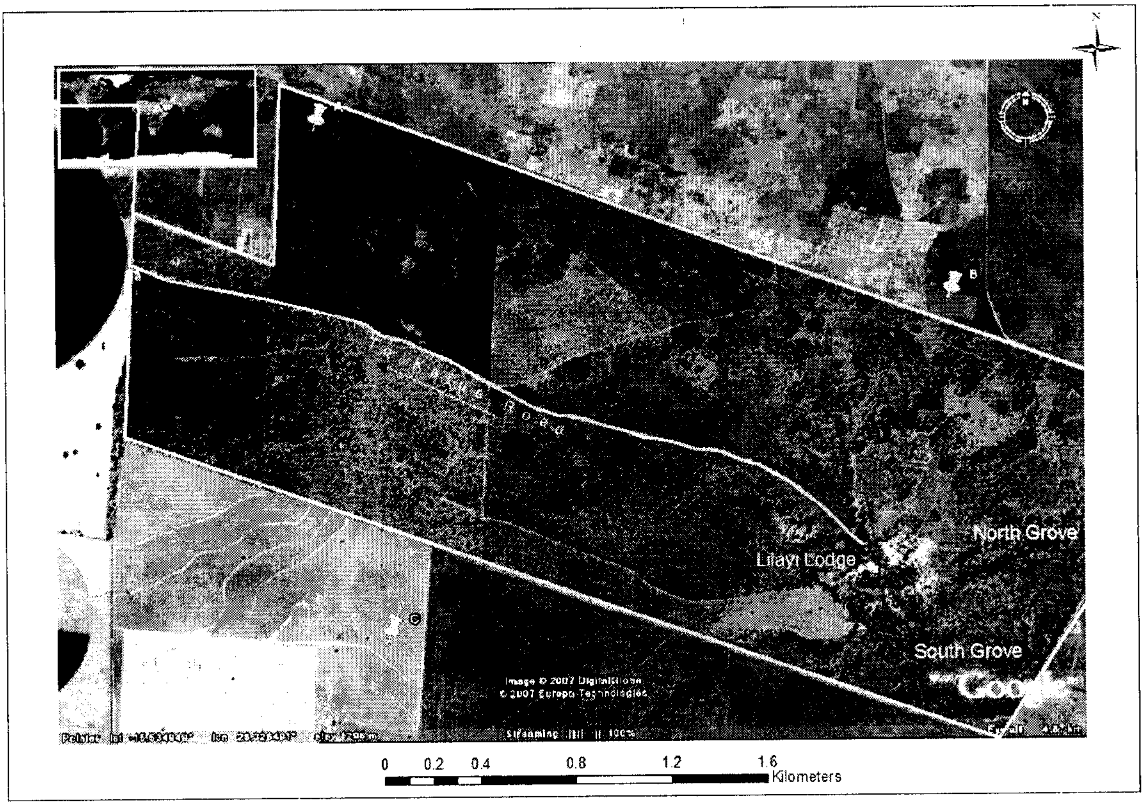

Figure 3.1.1: Map of Lilayi Game Ranch and location of the two *L. camara* study Groves, south of Lusaka, Zambia

3.2 Abiotic Environment

The climate of central Zambia is characterized by the alternation of dry and wet seasons. The dry season can be divided into two parts: The cool season from April to mid-August and the hot season from mid-August to October. The rainy season lasts from November to March with an annual mean rainfall of 787 mm at Mt Makulu, 15°33' S, 28°15' E, 1,220 m above sea level, 9 km north-west of Lilayi Game Ranch. The field survey was done in April 2007 following the 2006/2007 wet season that experienced a total of 550 mm of rainfall. The rainy season has moderate temperatures. Monthly daily minimum and maximum mean temperatures are 15.7° C and 30.1° C, respectively, at Mt Makulu weather station.

The soils at Lilayi Game Ranch have been classified by the Soil Survey Unit in the Department of Agriculture as an association of Lixisols and Leptosols. Lixisols have clay deposition from surface to lower subsurface horizons in the soil profile, abruptly overlying a slowly permeable horizon and characterized by strong weathering with high base saturation (>50%) ; medium cation retention capacity with low clay activity. Leptosols are weakly developed shallow soils characteristic of hilly surfaces often with steep slopes and these soils are limited in depth by a continuous cemented layer within 30 cm of the surface (Soil Survey Unit, 1991). In spite of these soil subdivisions, generally, the area can be categorized as having a relatively uniform sandy clay loam soil.

3.3 Biotic Environment

The vegetation type found at Lilayi Game Ranch is miombo and munga woodlands. Miombo woodland is dominated by trees of the family Fabaceae and the genera *Brachystegia, Julbernadia* and *Isoberlinia* (Fanshawe, 1971). Co-dominants in the miombo woodland include *Erythrophleum africana, Syzygium guineense, Uapaca* spp, *Parinari curatellifolia* and *Pterocarpus angolensis*. Smaller trees and shrubs are also widespread like *Anisophyllea boehmii, Bysocarpus orientalis, Ochna pulchra* and *Strychnos* spp. The most widespread miombo woodland grasses include those in the genera *Andropogon, Brachiaria, Digitaria, Eragrostis, Loudetia, Tristachya* and *Themeda* (Fanshawe, 1971). Munga woodland is a 1 – 2 storeyed deciduous woodland with scattered emergents and is characterized particularly by *Acacia, Combretum* and *Terminalia* species. Other characteristic genera include *Adansonia, Afzelia, Albizia, Amblygonocarpus, Dalbergia, Erythrophleum* and *Lannea.* A dense stand of tall grass is the characteristic feature of munga woodland. Common genera are *Brachiaria, Echinochloa, Eragrostis, Hyparrhenia* and *Urochloa.* Munga woodland is usually associated with a flat topography (Fanshawe, 1971).

3.4 Land Use

Lilayi Game Ranch contains animals such as giraffe, porcupine, pangolin, zebra, waterbuck and other antelopes. The Ranch has two large dams that support a prolific bird community with over 300 bird species. According to Allan Miller (personal communication), before the current land use, the area was used for cattle grazing and some parts were used for crop production and was turned into a game ranch in 1989. Fire management in the Ranch involves burning once in two years.

CHAPTER 4: METHODS

In order to assess the effects of *L. camara* on indigenous flora, a field survey was conducted to determine whether there was a spatial gradient in indigenous woody plant diversity caused by the presence of *L. camara* patches and to identify species that appeared to be suppressed by *L. camara*.

4.1 Survey of Plants

The field survey was done over a period of two weeks from 31st March to 14th April 2007. Although the wet season ends in March, the study period experienced some rains. A grove is a distinct vegetation patch that is surrounded by other vegetation type(s). *Lantana camara* often forms distinct thickets, patches or groves within the invaded landscape. The density of the groves in the Ranch is about 4 groves per hectare and the study area had eighteen groves with diameters ranging from 1.0 m to 5.3 m. The two largest groves were selected for this study because these were assumed to be the oldest. The study groves were located in a North to South direction with one grove in the north (hereafter North Grove) and another one in the South (hereafter South Grove) (see Figure 3.1.1). The North Grove had a diameter of 5.3 m and the South Grove had a diameter of 4.9 m. The diameters of the groves were based on mean diameter calculated from two different diameters measured from east to west and north to south for each of the two groves. The distance between the two groves was 430 m.

If indeed *L. camara* negatively affects other plant species, species diversity and/or abundance should increase with distance away from *L. camara* groves. In order to investigate this gradient in species diversity and abundance, transects were established radiating away from each *L. camara* grove.

Four transects per grove were established around each of the two sample groves that radiated from the center of each grove following compass directions (Figure 4.2.1) which is a normal tradition in forestry survey. Each transect was 48 m long. The beginning and end of each transect was geo - referenced using a Global Positioning System (GPS) and the coordinates recorded. Ant hills were avoided as much as possible during the establishment of the transects.

A total of ten quadrats (3.0 m x 3.0 m) with an inter-quadrat distance of 2.0 m were established along each transect with the assumption that this level of sampling along each transect was sufficient enough to capture any gradient in species diversity and/or abundance of indigenous species in relation to *L. camara* groves.

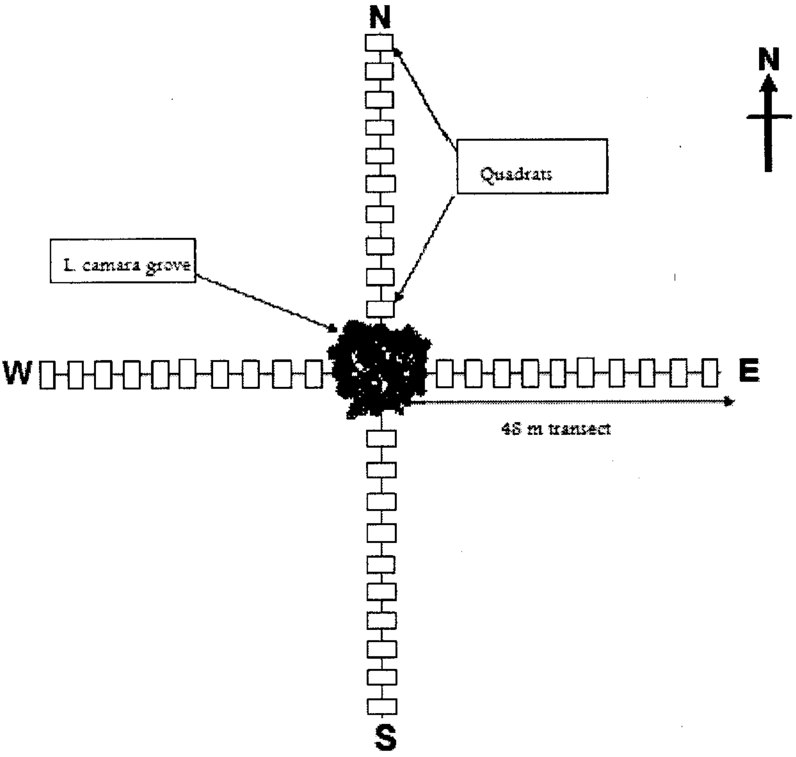

Figure 4.2.1: Layout of transects and quadrats radiating from a *L. camara* grove into the surrounding vegetation.

Woody plant species including seedlings, saplings and trees in each quadrat were identified and recorded and for unidentified plants, specimens were collected for identification using material at the University of Zambia Herbarium. Although the woody plant species were counted regardless of size, they were later classified as shrubs and trees using information from literature. Nomenclature of plants follows Fanshawe (1971).

The data recorded during the field survey included transect (i.e. South, North, East or West), quadrat number (i.e. 1 to 10), plant species encountered and abundance.

4.2 Data Analysis

The existence of spatial autocorrelation was assessed by variogram and fractal analyses using Geo-statistics 7.0 (Gamma Design Software, 2004) to determine spatial gradients in the distribution and abundance of indigenous woody plants around the two *L. camara* Groves. Spatial autocorrelation is a statistical technique that examines the degree of similarity between variables across a geographic space (Legendre, 1998). Variogram analysis generates models that can be used to estimate the period over which spatial dependence in the distribution data is apparent. Fractal analysis generates a fractal dimension D, which is a function of the slope of a log-log variogram plot (Burrough, 1981) and can be used to assess the strength of autocorrelation. The data for species showing significant levels of autocorrelation were further subjected to linear regression analysis to corroborate the existence of autocorrelation.

P–CORD which generates the Shannon-Weiner Diversity Index was used to analyze plant diversity data that was obtained from quadrats in order to determine species diversity which can be defined as the number of different species in a particular area.

P-CORD calculates the Shannon-Weiner Diversity Index (H′) using the formula:

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

Where S is the number of species and pi is the proportion of individuals belonging to species i,

CHAPTER 5: FIELD SURVEY RESULTS

5.1 Overall Floristic Diversity

Before considering spatial distribution of species in relation to *L. camara* groves, this section gives an overview of floristic diversity on the sample quadrats ordered by transects. Floristic diversity will be presented as species diversity and density. The idea of species diversity contains two concepts, namely species richness and evenness. Species density is used as the simplest measure of species diversity while species richness refers to the number of species in a community.

There were a total of thirty eight (38) species of woody plants belonging to twenty eight (28) genera and eighteen (18) families recorded on all quadrats of which 58% were shrub species and 42% were tree species. The family of Fabaceae was the most diverse with 26% of the recorded species (Table 5.1.1). The North Grove had the highest plant diversity with an average Shannon-Weiner Diversity Index of 1.23 while the south Grove had an average index of 1.08 (see Appendix E for details).

Table 5.1.1: Woody plants observed on sample quadrats in April, 2007 at Lilayi Ranch, central Zambia

Family	**Genera**	**Species**		**Total**
		Tree	**Shrub**	
Solanaceae	*Withania*		1	1
Malvaceae	*Azanza*	1		1
Fabaceae	*Bauhinia*	1		1
	Pericopsis	1		1
	Burkea	1		1
	Dalbergia	1		1
	Brachystegia	1		1
	Albizia	4		4
	Acacia	1		1
	Erythrina	1		1
	Dichrostachys		1	1
Ochnaceae	*Ochna*		1	1
Anacardiaceae	*Lannea*	1		1
Orchidaceae	*Eulophia*		1	1
Combretaceae	*Combretum*	3		3
Tiliceae	*Zahna*	1		1
Rhamnaceae	*Maesopsis*	2		2
	Ziziphus		1	1
Annonaceae	*Uvariastrum*	2		2
	Hexalobus		1	1
Apocynaceae	*Diplorhyncus*	1		1
Clusiaceae	*Harungana*		1	1
Apiaceae	*Steganotaenia*		1	
Flacourticeae	*Flacourtia*		1	1
Ixonanthaceae	*Phyllocosmus*	1		1
Rubiaceae	*Rothmania*		1	1
Loganiaceae	*Strychnos*		1	1
Ebenaceae	*Diospyros*	1		1
Total 18	**28**	**27**	**11**	**38**

Dominance of species was determined by the frequency occurrence of species in the quadrats and on this basis the most dominant species with frequency occurrence in quadrats given in brackets, were *Bauhinia petersiana* (79%), *Brachystegia spiciformis* (76%), *Pericopsis angolensis* (73%), *Combretum molle* (71%), *Brysorcapus orientalis* (68%), *Withania somnifera* (63%) and *Phyllocosmus lemaireanus* (59%).

.2 Species Distribution on Transects

he mean species density for the two groves was different with the North Grove having the ighest mean species density of 4.6 per quadrat whilst the mean species density for the South rove was 4.1 per quadrat. The t - test indicated that there was a significant difference in the nean species density between the two groves ($t = 2.0$, $df = 78$, $p < 0.05$).

nalysis of the data by grove and transect revealed that the mean species density per quadrat n the northern transect of the North Grove was the highest at 5.7 followed by the eastern ransect at 5.0. The western and southern transects had the least average species density at 3.8. Analysis of Variance (ANOVA) showed that there were significant differences in the mean species density between transects on the North Grove ($F = 3.62$, $p < 0.05$). The Bonferroni all - pairwise comparisons revealed that the North and the South transects had significantly different species densities while the mean species density for the East and West transects were not significantly different.

For the South Grove, the mean species density per quadrat on the western transect was the highest at 4.6 followed by the northern and eastern transects at 4.1 with the southern transect having the least density at 3.6. The ANOVA results showed that there were no significant differences in the mean species density among transects on the South Grove.

Species-area curves were also used to compare the species diversity among the eight transects. The species-area curve is one of the foundations of modern ecological science (Connor and McCoy, 1979). It is a method of presenting species diversity in a graphical form and the curve shows the rate at which new species are encountered as the sample size increases. The curve is constructed by plotting cumulative species on the y – axis against cumulative sample area or size on the x – axis (Krebs, 1989). Sampling is sufficient when no or very few species are added with each successive quadrat resulting in the flattening of the species-area curve. Minimum number of sample quadrats for inventorying biodiversity may be estimated at the point when the species-area curve starts to flatten.

The northern transect on the North Grove had the highest species richness (Figure 5.2.1) followed by the eastern transect on the same grove. Out of the total of eight transects, four had their species-area curves flattening indicating that the sampling effort was adequate in recording the woody flora on these transects.

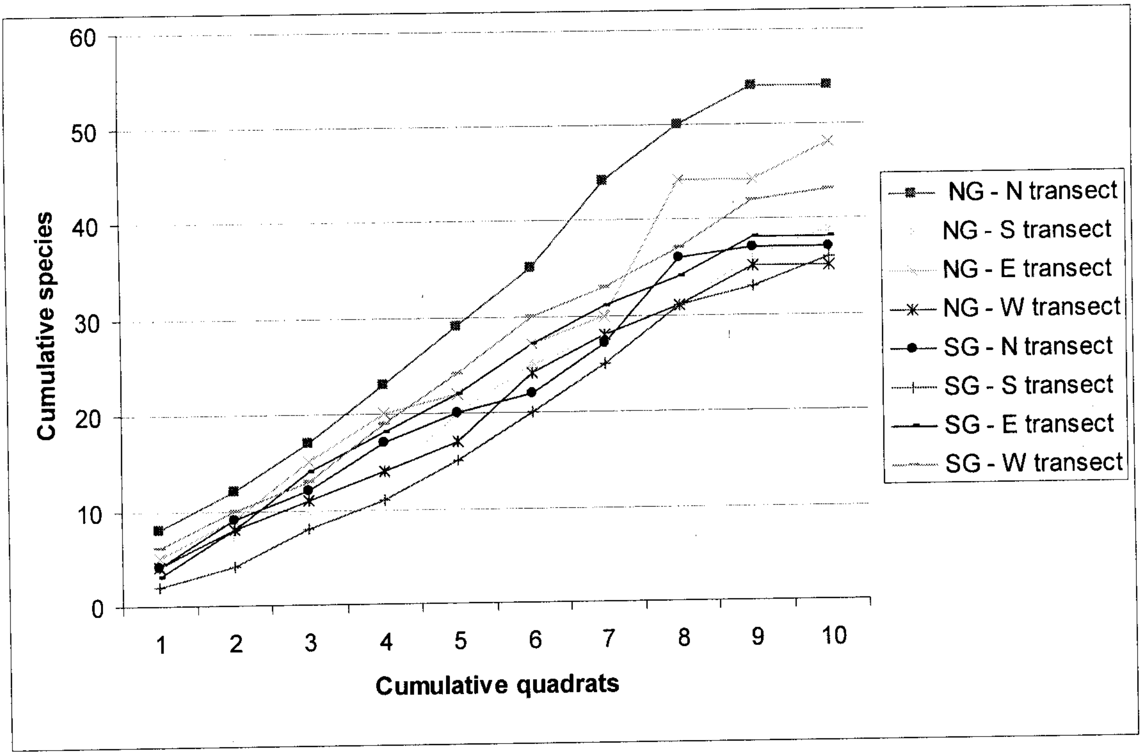

Figure 5.2.1: Relationship between cumulative sample quadrats (3 x 3m each) and cumulative woody plant species along eight sample transects centered on two *L. camara* groves at Lilayi Game Ranch.

.3 Influence of *L. camara* on Population Abundance

There was no relationship between quadrat distance from *L. camara* groves and woody plant bundance, implying that no spatial autocorrelation existed in the abundance of plants in relation to distance from *L. camara* groves as the coefficient of determination (R – squared) anged from 0.129 to 0.282 with $p > 0.05$. Analysis of data by tree and shrub species gave imilar results. However when the results were analyzed by individual species, the abundance f seven species indicated the presence of spatial autocorrelation (Table 5.3.1).

Table 5.3.1: Results of autocorrelation analysis using fractal dimension of individual species bundance on quadrat distance from *L. camara* Groves at Lilayi Ranch, central Zambia

Species	**R^2**
Bauhinia petersiana	0.916
Lannea discolor	0.787
Flacourtia indica	0.787
Eulophia aurantiaca	0.768
Combretum amara	0.762
Dalbegia nitidula	0.760
Erythrina abyssinica	0.624

However, linear regression and scatter plot analysis revealed that, for six out of the seven species in Table 5.3.1, correlation was unduly influenced by a single outlier observation as exemplified by *Lannea discolor* (Figure 5.3.1).

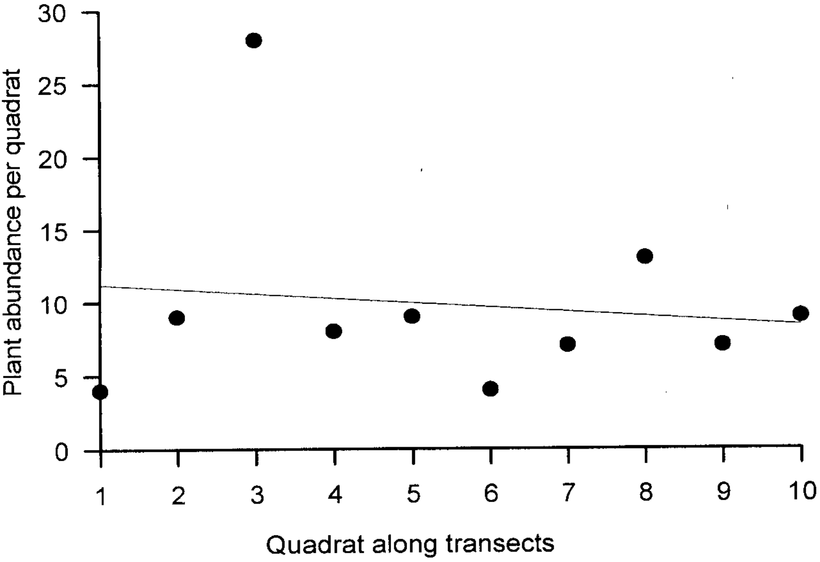

Figure 5.3.1: Scatter plot and linear regression line for *Lannea discolor* abundance in quadrats along transects radiating from *L. camara* groves.

The species that was not influenced by outliers was *Bauhinia petersiana* (Figure 5.4.1). This species presents evidence of a possible spatial gradient in abundance that was related to distance from *L. camara* groves. In this case, the abundance of *B. petersiana* increased with distance away from *L. camara* groves.

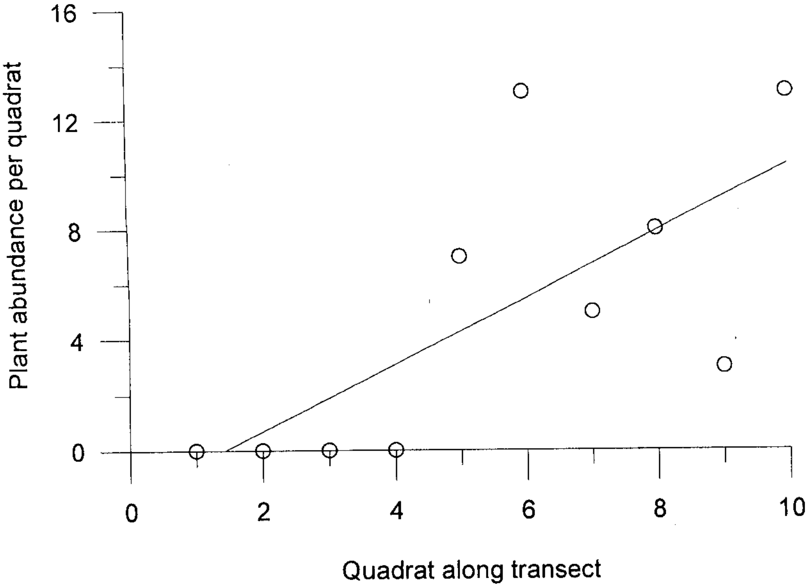

Figure 5.4.1: Scatter plot and linear regression line for *Bauhinia petersiana* abundance in quadrats along transects radiating from *L. camara* groves.

CHAPTER 6: DISCUSSION

Several studies have shown that the ecological impacts of invasive plants include displacement of indigenous species and declines in species diversity. For example, Matsebula and Richard (2005) who assessed the production of allelopathic substances by *L. camara* in the Kibale Forest National Park in Uganda concluded that *L. camara* had a negative effect on the floristic diversity within its neighborhood. However, the results in this study showed that *L. camara* did not necessarily influence plant diversity in its neighborhood. The reasons for *L. camara* not influencing plant diversity could be that its influence significantly depends on its density and age. It can be assumed that the influence of *L. camara* occurs at very high density beyond the observed density of 4 groves per ha at Lilayi Ranch. It can also be noted that may be the size of the *L. camara* groves need to be quite large, beyond the diameter of 4.9 m and 5.3 m, in order to have an influence on the floristic diversity at Lilayi Game Ranch. However, there is no available literature and data that indicate the specific age and density at which *L. camara* starts to influence plant diversity. According to Allan Miller (personal communication) of Lilayi Ranch, the age of the *L. camara* at Lilayi Ranch is not known.

At grove level, direction seemed to have an effect on the mean species density of the *L .camara* groves as the differences in the mean species density per quadrat were significant with the North Grove having the highest mean species density.

SECTION THREE: LABORATORY EXPERIMENTS

CHAPTER 7: METHODS

In order to determine the existence of allelopathy caused by *L. camara* on selected indigenous plant species and mechanisms by which *L. camara* negatively affects the selected indigenous plant species, laboratory experiments were done and this section presents methods, data analysis, results and discussion related to the laboratory experiments that were carried out at the Department of Biological Sciences of the University of Zambia at the Great East Road Campus in Lusaka.

7.1 Selection of Experimental Species

The experimental species selected for the laboratory experiments was *Bauhinia petersiana.* The selection of the experimental species was based on results of spatial autocorrelation analysis that showed that this species might be negatively influenced by the presence of *L. camara* groves (see Section Two, chapter 6).

7.2 Collection and Preparation of Laboratory Experiment Materials

According to William (1999), there are different plant materials known to produce allelopathic chemicals and these chemicals are found in leaves, roots, stems and fruits.

Therefore *L. camara* fresh leaves and roots were collected and used in the laboratory experiments. Other materials collected included seeds and soil.

Lantana camara fresh leaves and roots were collected at Lilayi Game Ranch from the two *L. camara* Groves used in the field survey (see Section Two). Fresh *L. camara* leaves were collected from twig branches while roots were collected by digging out some *L. camara* plants and cutting off roots. The leaves and roots were air dried for a period of seven days in the laboratory in order to remove excess moisture and later ground separately using the traditional wooden mortar and pestle before use in seed germination studies.

Seeds of *B. petersiana* and soil used as germination medium were collected from 5th August to 11th August, 2007 at Lilayi Game Ranch. Seeds were stored in manila envelopes which were kept under uncontrolled room conditions to stimulate post-dispersal natural conditions until required for planting. Soil was collected 70 m away from the two *L. camara* Groves to avoid allelopathic contamination in soil from under or near the Groves. The collection of soil involved the removal of the top vegetation in order to dig out the soil. Once the vegetation was removed, enough soil weighing 200 kg was dug up to a depth of 35 cm using a hoe and collected for seed germination studies.

7.3 Seed Germination

The laboratory seed germination experiments involved the preparation of *L. camara* leaf and root material for addition in seed germination soil in clay pots with a depth of 20 cm and a volume of 3 litres.

In order to assess the effect of leaf and root material on the germination and early growth of *B. petersiana* seedlings, seeds were sown under four different treatments as follows:

(i) Treatment # 1: Soil mixed with *L. camara* dried and pounded leaf material prepared from fresh leaves

(ii) Treatment # 2: Soil mixed with *L. camara* dried and pounded roots prepared from fresh roots

(iii) Treatment # 3: Soil mixed with both dried and pounded leaf and root material

(iv) Treatment # 4: Control (no additions)

For treatments (i) and (ii) the soil was thoroughly mixed with a 100 g each of dried and pounded leaves and roots, respectively. For treatment (iii) that involved a combination of leaf material and roots, the soil was mixed with 50 g of dried and pounded leaf material and 50 g of dried and pounded root material. Each treatment was replicated 10 times.

Twenty seeds of *Bauhinia petersiana* were sown in each pot under natural light conditions with a total of ten pots per treatment (Figure 7.2.1). Seeds of *Bauhinia petersiana* have no dormancy (Msanga *et al.*, 1998) and therefore did not require pre-sowing treatment.

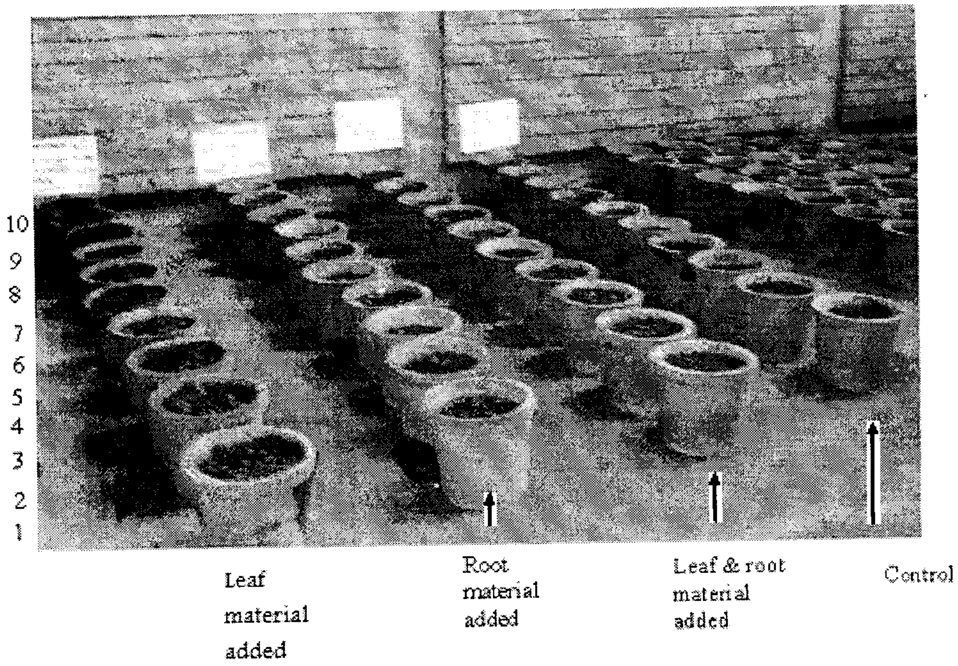

Figure 7.2.1: Layout of the seed germination experiments in an open space between laboratory blocks in the Department of Biological Sciences building at the University of Zambia, Great East Road campus, in Lusaka.

Seeds were watered three times per week on Mondays, Wednesdays and Fridays with

500 ml of tap water per pot per watering occasion. Seed germination was based on seedling emergence and was monitored weekly on Mondays.

7.4 Assessment of Seedling Growth

In order to determine the rate of seedling growth, one seedling in each pot was marked immediately after emergence and the number of leaves counted and recorded on a weekly basis as a measure of seedling growth under the various treatments.

After nine weeks from the date of sowing, the number of seedlings per pot and the status of each seedling was recorded (i.e. live or dead). Each seedling was carefully uprooted and cleaned in tap water and the root and shoot (main axis) length measured and the number of leaves and shoots counted and recorded. Each of the seedling samples was then placed in an envelope (roots and shoots in separate envelopes) of the same size (9 x 6 cm) that had been weighed earlier on. The seedling samples were then oven dried at 80° C for 48 hours and the roots and shoots weighed separately in order to determine the above and below ground biomass. The weight of each envelope was subtracted from the total weight of the envelope and the seedling sample in order to determine the weight of the seedling sample.

7.5 Data Analysis

Analysis of Variance (ANOVA) was used to determine the effect of *L. camara* pounded leaves and roots on seed germination and seedling growth using Statistix 8.0 (Analytical Software, 2003). Percentage seed germination data were arcsine square – root transformed to improve normality in data distribution and tested for normality using the Shapiro-Wilk (W) test (Analytical Software, 2003) before carrying out ANOVA. Significance of difference was based on $p = 0.05$.

CHAPTER 8: RESULTS OF LABORATORY EXPERIMENTS

This section presents results of the laboratory experiments on the effect of *Lantana camara* on *Bauhinia petersiana* seedling emergence and growth under the different treatments. The treatments are described in chapter 7 and are abbreviated in this chapter as follows:

Leaf material treatment (LMT)
Root material treatment (RMT)
Leaf and root material treatment (LRMT)

8.1 Seed Germination

Seedling emergence was used as a measure of seed germination. *Bauhinia petersiana* seedling emergence occurred during a period of 1 to 5 weeks after seed sowing with the majority (> 75%) of seedlings having emerged by the third week. The germination pattern also showed that the seedling emergence rate was slower and lower under the LMT (Figure 8.1.1).

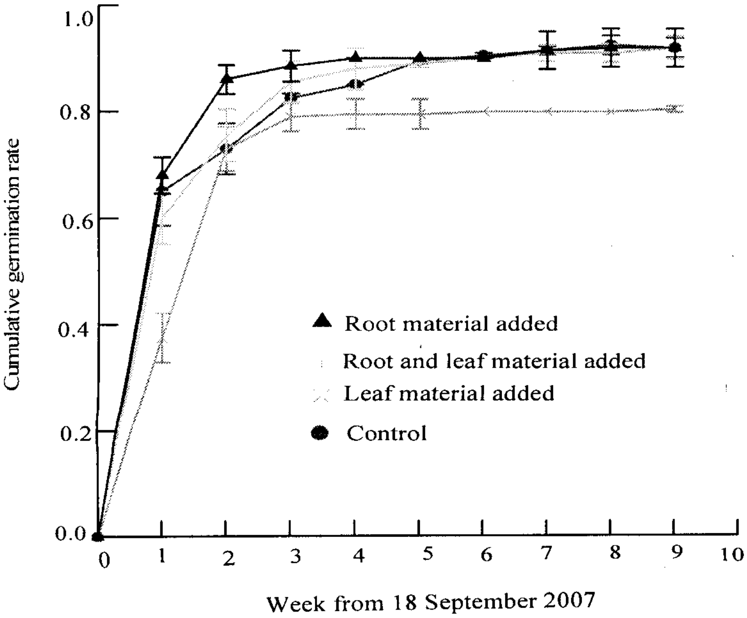

Figure 8.1.1: Cumulative seedling emergence rate over a period of nine weeks under four treatments. Vertical lines represent standard error.

with the LMT and control. The results revealed that leaf production in the marked seedlings was lowest under the LRMT and RMT (Figure 8.2.1).

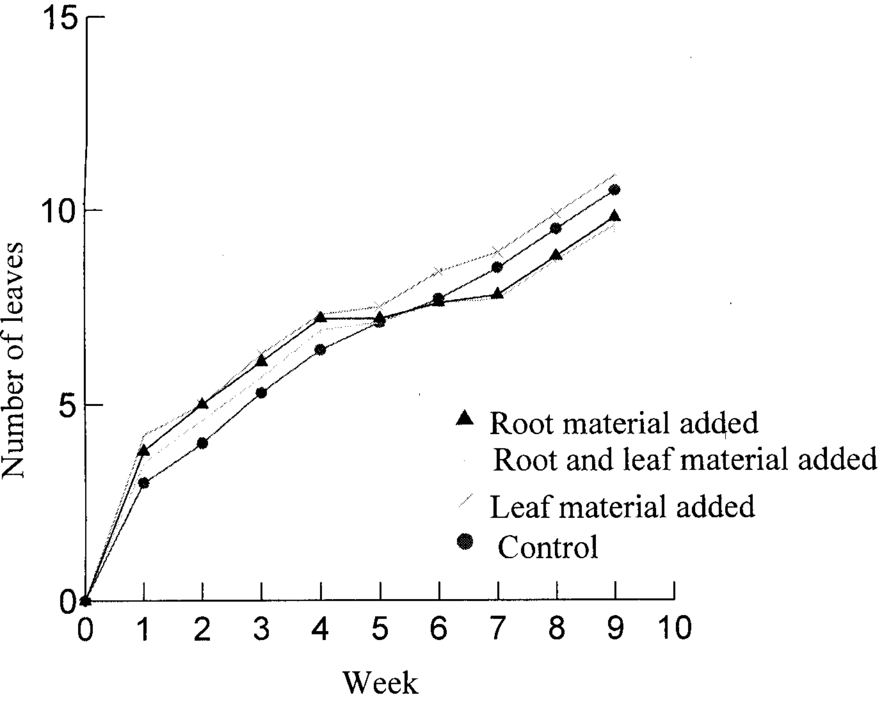

Figure 8.2.1: Leaf production pattern over a period of nine weeks under four treatments

Total leaf production ranged from 9.6 ± 0.37 under the LRMT to 9.8 ± 0.39 under RMT and 10.5 ± 0.43 under LMT and 10.9 ± 0.53 under control. The differences in leaf production by the seedlings among the treatments were significantly different (*F* = 9.90, $p < 0.05$) with the Bonferroni all – pairwise comparison test revealing that seedlings in the control treatment had significantly more leaves while seedlings in the rest of the treatments produced leaves that were not significantly different . This shows that the addition of *L. camara* root material reduced leaf production in the *B. petersiana* seedlings.

8.2.2 Size of seedlings at nine weeks

Seedling size was determined by the number of leaves, root length and biomass and shoot length and biomass. There were significant differences in mean root length, shoot length and root biomass at the end of nine weeks of observations (Figure 8. 2.2).

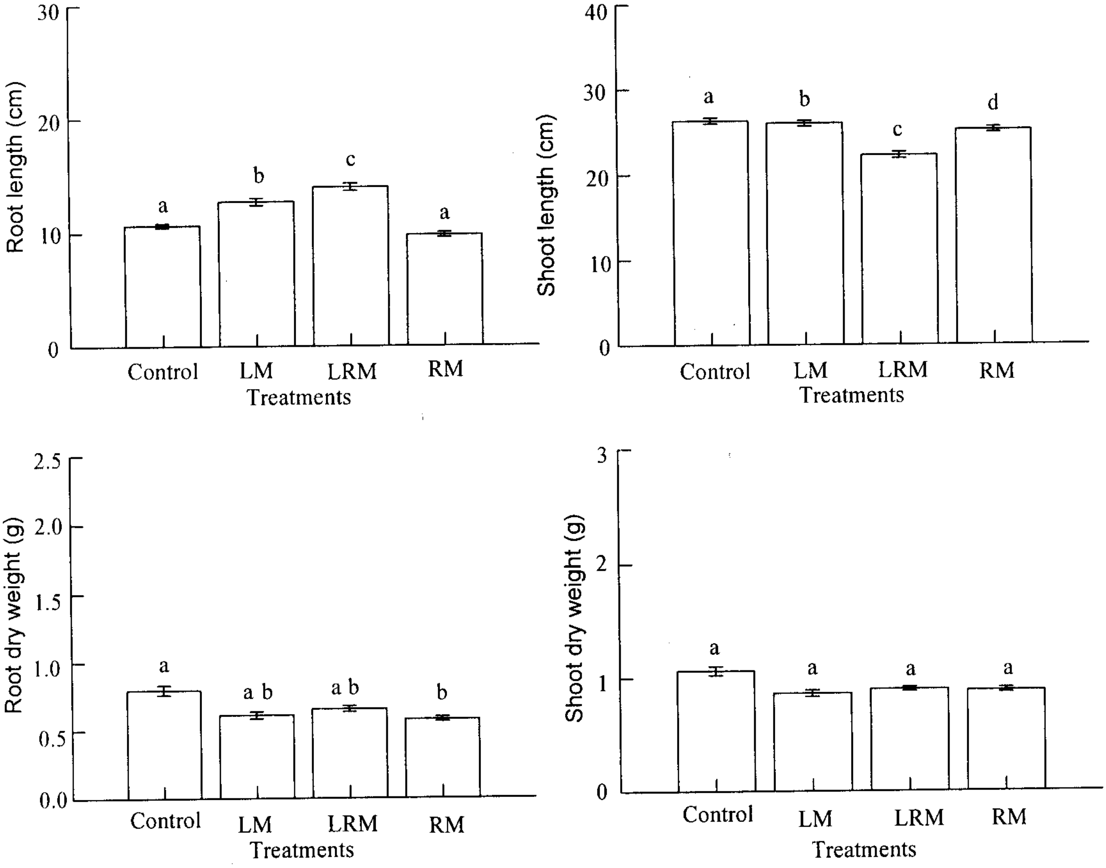

Figure 8.2.2: *Bauhinia petersiana* seedling size at the end of nine weeks of observation. Treatments include leaf material (LM), leaf and root material (LRM) and root material (RM) added to soil. Vertical lines on bars indicate standard error. Treatments with different letters on bars are significantly different at p = 0.05 based on analysis of variance.

The addition of leaf and leaf plus root material resulted in seedlings with significantly longer root length of 12.7 ± 0.33 cm and 14.0 ± 0.33 cm, respectively. The differences in the root length of seedlings among the various treatments were significant *(F* = 52.7, $p < 0.05$). The Bonferroni all – pairwise comparison test revealed that the root length of seedlings under the LMT and LRMT was significantly longer while the root length of seedlings under the RMT and control were not significantly different (see Figure 8.2.2). This shows that the addition of *L. camara* leaves increased root length growth of *B. petersiana* seedlings.

Shoot length was shortest among seedlings under the LRMT (22.25 ± 0.39 cm) and increased to 25.22 ± 0.33 cm under RMT, 26.01 ± 0.34 cm under LMT and 26.3 ± 0.37 under control. The differences in shoot growth of seedlings under the various treatments were significant (*F* = 27.0, $p < 0.05$). The Bonferroni all – pairwise comparison test revealed that the shoot length of seedlings under the LRMT was significantly shorter than that observed in the rest of the other treatments (Figure 8.2.2). This shows that the addition of a combination of leaves and roots of *L. camara* were responsible for the shorter shoot length growth in *B. petersiana* seedlings.

Significant differences in root biomass were observed between seedlings under the control treatment (0.75 ± 0.03 g) and RMT (0.56 ± 0.04 g) but these biomasses were not significantly different from those of seedlings under the LMT and LRMT (see Figure 8.2.2). The Analysis of Variance (ANOVA) results indicated that there were significant differences in the root biomass among treatments (*F* = 9.91, $p < 0.05$) with the Bonferroni all – pairwise comparison test revealing that seedlings under the control treatment had significantly higher root biomass than the rest of the seedlings. This shows that the addition of *L. camara* leaf and root material reduced the root biomass of the *B. petersiana* seedlings.

8.2.3 Effect of seedling density

Seedling density per pot significantly affected both shoot length ($F = 23.71$, $p < 0.0001$) and shoot biomass ($F = 2.28$, $p < 0.05$) (Table 8.2.3). The Bonferroni all – pairwise comparison test revealed that the shoot length of seedlings under the LRMT was significantly shorter (22.25 ± 0.357 cm) than that observed in the rest of the other treatments which were not *significantly different among themselves.*

e 8.2.1: Effect of density on mean shoot length and shoot biomass. Mean values are given with lard error.

t	Shoot length by treatment				Shoot biomass by treatment			
	Control	**LMT**	**LRMT**	**RMT**	**Control**	**LMT**	**LRMT**	**RMT**
				18.7±4.00				0.9±0
				23.4±2.35				0.8±0.
		17.3±1.50	17.7±1.00	21.1±0.91		0.7±0.12	0.8±0.03	0.6±0.
		22.36±1.10	20.7±0.42	23.2±0.55		0.6±0.1	0.9±0.03	0.9±0.
		23.7±0.46	22.5±0.68	26.7±0.40		0.9±0.1	0.9±0.03	0.9±0.
	22.9±0.88	26.4±0.53	24.6±0.66	27.8±0.62	0.81±0.09	0.8±0.05	1.0±0.04	0.9±0.
	25.5±0.73	29.0±0.54	28.1±1.76	26.7±1.4	1.00±0.08	1.0±0.07	0.8±0.06	0.9±0.
	26.8±0.58	30.0±0.65	31.5±2.90	34.6±1.7	1.0±0.06	0.7±0.1	1.0±0.05	1.1±0.
	27.7±0.67	28.3±1.44			1.2±0.10	0.8±0.30		
	26.5±1.01				1.1±0.10			
	$F = 27$ P < 0.0001				$F = 9.97$ P < 0.0001			

The Bonferroni all – pairwise comparison test also revealed that the mean shoot biomass of seedlings under control treatment was significantly heavier (1.056 ± 0.027 g) than the rest of the seedlings in the other treatments which were not significantly different. This shows that the addition of *L. camara* leaf and root material reduced shoot length and shoot biomass in *B. petersiana* seedlings.

8.2.4 Isolation of effects of treatment from density effects on shoot length and shoot biomass

There is a possibility of confounding the effects of treatment and density on shoot length and shoot biomass and in order to separate the effect of density from that of treatment, ANOVA was run for seedlings with similar density per pot to determine whether it was density or treatment that had a significant effect on shoot length and biomass. Seedlings that were in pots with densities of 9, 10 and 11 were used as these had complete data on mean shoot length and shoot biomass for all the treatments. The results revealed that there were significant differences in shoot length of all the three different densities ($F = 26.7$, $p < 0.0001$ for the density of 9, $F = 5.41$, $p < 0.005$ for the density of 10 and $F = 6.19$, $p < 0.005$ for the density of 11) and shoot biomass ($F = 8.87$, $p < 0.0001$ for the density of 9, $F = 5.15$, $p < 0.005$ for the density of 10 and $F = 9.91$, $p < 0.005$ for the density of 11). The Bonferroni all – pairwise comparison test revealed that the mean shoot length of seedlings under LRMT was significantly shorter in all the three densities (22.15 ± 0.346 cm, 21.27 ± 1.279 cm, 20.78 ± 0.819 cm) than that observed in the rest of the other treatments which were not significantly different among themselves. The Bonferroni all – pairwise comparison test also revealed that the mean shoot biomass of seedlings under control treatment were significantly heavier for all the three densities (1.07 ± 0.028 g, 1.39 ± 0.164 g, 1.21 ± 0.131 g) than the rest of the seedlings in the other treatments. This shows that the addition of *L. camara* leaf and root material, regardless of the seedling density, reduced seedling shoot length and shoot biomass.

CHAPTER 9:DISCUSSION

The experimental results have revealed that germination and seedling growth in terms of leaf production, root biomass, shoot length and shoot biomass of *B. petersiana* was reduced by *L. camara* leaf and/or root material and this is consistent with results of other studies (Anonymous, 1962) that have shown that the allelopathic effect of *L. camara* results in severe reductions in seedling recruitment of nearly all species under its influence. Other studies have also revealed that no growth or only stunted growth have been observed for other species growing close to *L. camara* due to allelopathic effects, as shown by the fern *Cyclosorus dentatus* Forsk. (Pteridophyta), milkweed vine (*Morrenia odorata* Lindl.; Asclepiadaceae), rye (*Lolium multiflorum* Lam.; Poaceae) and many crops, such as wheat, corn, and soybean (Achhireddy and Singh, 1984; Achhireddy *et al.*, 1985). As many as 14 phenolic compounds are present in *L. camara* that can reduce the seed germination and growth of young plants (Jain *et al.*, 1989).

According to William (1999) there are numerous chemical compounds in plants that can function as allelochemicals and these allelochemicals are found in leaves, roots, stems, flowers and fruits. Leaves are the major source in most species. The experimental results showed that the germination pattern of the seeds in soil to which *L. camara* leaf material was added had the least germination rate and this is in conformity with what was observed by William (1999) that leaves are the major source of allelochemicals in most species besides roots and other plant parts. Furthermore, a bioassay set up in Uganda (Matsebula and Richard, 2005) with different concentrations of *L. camara* leaf extracts in soil to determine potential allelochemicals effects on germination and shoot elongation of millet revealed that *L .camara* reduced shoot elongation ($X^2 = 34.92$, $p < 0.001$) of millet seedlings and this was attributed to its allelopathic properties. The results obtained by Matsebula and Richard (2005) are similar to the results in this study which revealed that *L. camara* reduced seed germination, leaf production, root biomass, shoot length and shoot biomass of *B. petersiana* seedlings. However, the results have also revealed that *L .camara* leaves and roots increased the root growth of the *B. petersiana* seedlings.

In addition, a substantive Australian study (Gentle and Duggin, 1997a) also observed that *L . camara* due to its strong allelopathic properties has the potential to interrupt the regeneration process of other species by decreasing germination, reducing early growth rates and selectively increasing mortality of other plant species.

Since the effect of density on shoot length and shoot biomass was controlled and the results still showed significant differences of shoot length and shoot biomass of seedlings under the various treatments, it shows that the treatments to which *L. camara* extracts were added were responsible for the significant differences in shoot length and shoot biomass and not density.

Gentle and Duggin, (1997a) observed that *L .camara* due to its strong allelopathic properties has the potential to interrupt the regeneration process of other species by decreasing germination, reducing early growth rates and selectively increasing mortality of other plant species.

Although literature on *L. camara*'s allelopathy is scarce, there is literature on other invasive alien species. For instance, Rebecca *et al.* (2007) who examined the effects of *Ceratiola ericoides* leaf, litter and root leachates on the germination and early seedling survival of six

Florida scrub species reported that leachates reduced germination percentages which ranged between 7.4 and 10 % among treatments compared to 12 % in the control. Rebecca *et al.* (2007) further reported that leaf leachates reduced germination more effectively than root and litter leachates. Tanrisever *et al.* (1987) as quoted by Rebecca *et al.* (2007) reported that allelochemicals from Florida rosemary reduced germination of pyrogenic sandhill grasses.

In addition, a water soluble extract from different parts of *Prosopis juliflora* (an invasive alien species) including litter had been shown to inhibit seed germination of many species. For example, aqueous extracts from under canopy soil and from different parts of *Prosopis juliflora* inhibited germination and early seedling growth of various cultivars of *Zea mays, Triticum aestivum* and *Albizia lebbeck* as observed by Noor *et al.* (1995). Furthermore, Al – Humaid and Warrag (1998) concluded that *Prosopis juliflora* leaves contain water soluble allelopathins which could inhibit seed germination and retard rate of germination and seedling growth in *Cynodon dactylon.* Chellamuthu *et al.* (1997) as quoted by Ali El – Keblawy (2006) indicated that germination of black gram (*Vigna mungo*) and *Sorghum bicolor* was significantly reduced by *Prosopis juliflora* with maximum reduction occurring at 2 % and attributed to leaf litter.

The results of all these studies cited above are in one way or another consistent with the findings of the present study.

CHAPTER 10: CONCLUSION AND RECOMMENDATIONS

10.1 Overall Conclusion

This study showed that *L. camara* did not necessarily influence plant diversity in its neighborhood. The reasons for *L. camara* not influencing plant diversity could be that its influence significantly depends on its density and age. It can be assumed that the influence of *L. camara* occurs at very high density beyond the observed density of 4 groves per ha at Lilayi Ranch. It is worth mentioning that the effect of *L. camara* exists on other biodiversity such as, herbaceous plants although these were not considered in the present study.

This study has shown that L. camara has allelopathic properties that reduced seed germination and seedling growth with respect to leaf production, root biomass, shoot length and shoot biomass of *B. petersiana* seedlings but not root length that actually was higher under the different treatments involving addition of *L. camara* leaf and root material.

This study set out to test the hypotheses that (i) *Lantana camara* has allelopathic properties that reduce seed germination of indigenous plants in Zambia and (ii) *Lantana camara* has allelopathic properties that reduce seedling growth in terms of leaf production, root length, root biomass, shoot length and shoot biomass of indigenous plants of Zambia. The findings of the study support these hypotheses that *L. camara* has allelopathic properties that reduce seed germination and seedling growth in terms of leaf production, root length, shoot length and shoot biomass of *B. petersiana.*

The study has therefore generated new information about *L. camara* impacts on native plant diversity and has demonstrated possible mechanisms through which these impacts are brought about. In this sense, the study has significance to Zambia and other countries in which *L. camara* is a serious invasive species.

10.2 Recommendations

Since *L. camara* appears to have allelopathic properties that reduce seed germination and seedling growth of some native woody plants, such as *B. petersiana,* the following recommendations are made to improve biodiversity conservation:

i. There is need for prevention of its spread into uninfested areas as this will be the most cost – effective way of conserving indigenous biodiversity

ii. Banning the sale and use of *L. camara* in gardens as these are potential sources of new infestations

iii. There is need to use an integrated approach to biodiversity conservation that uses a variety of control methods with a range of methods including herbicides, mechanical removal, fire and biological control. Biological control may not eradicate *L. camara* but could reduce the plant from a weed to a non-weed status which is then maintained in a steady dynamic equilibrium with the control agent species. In this way, biodiversity may be maintained

iv. There is need for community awareness about the effects of *L. camara* on plant diversity, ecosystems, spread prevention and invasive weed management

v. There is need for future studies to consider the effect of *L. camara* on herbaceous plants and ecosystem functions since these were not considered by the present study.

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APPENDICES

Appendix A: Data recording sheet of plants for the field survey

THE UNIVERSITY OF ZAMBIA

SCHOOL OF NATURAL SCIENCES

Inventory of flora on *Lantana* centred transects

Data collection sheet for the field survey

Site:………………………………………………

Lantana grove:…………………………

Transect: East, West, North, South

Sampling Date:…………………………

Transect origin: Lat……………. Long:…………

Transect end: Lat………Long……………

Quadrat #:…………………………………………

Quadrat size (m): L………
W…………

Quadrat distance (m) from previous quadrat:……

Species	**# of plants**	**Voucher specimen**	**Plant photo specimen**

ppendix B: Questionnaire to Lilayi Management about Lilayi Game ranch

THE UNIVERSIY OF ZAMBIA

DEPARTMENT OF BIOLOGICAL SCIENCES

MSc TROPICAL ECOLOGY & BIODIVERSITY

THESIS TITLE: AN INVESTIGATION INTO THE ROLE OF ALLELOPATHY IN INFLUENCING PLANT DIVERSITY AROUND *LANTANA CAMARA* GROVES: A CASE OF LILAYI RANCH

Question # 1

How big is the Lilayi ranch (ha)?

Question # 2

Has the area always been used as a game ranch? If not, what was it used before it became a game ranch and when did it become a game ranch?

Question # 3

How was *Lantana camara* introduced at the Lilayi ranch

Appendix C: Number of tree and shrub species recorded during the field survey and their abundances. Distance from origin refers to the distance from the origin of the transect to the start of the quadrat

at	**Distance from origin (m)**	**Shrub species**	**Tree species**	**Total species**	**Abundance shrubs**	**Abundance trees**	**Total abundance**
a camara North Grove							
	0	4	4	8	27	15	42
	5	1	3	4	6	13	19
	10	2	3	5	20	13	33
	15	4	2	6	21	9	30
	20	2	4	6	11	15	26
	25	3	2	6	18	13	31
	30	3	6	9	16	18	34
	35	1	5	6	2	36	38
	40	1	3	4	3	42	45
	45	1	3	4	5	18	23
	0	0	4	4	0	4	4
	5	2	3	3	2	1	3
	10	4	3	3	2	1	3
	15	6	3	3	1	2	3
	20	8	7	7	1	6	7
	25	10	5	5	3	2	5
	30	12	3	3	3	0	3
	35	14	3	3	2	1	3
	40	16	5	5	3	2	5
	45	18	3	3	0	3	3
	0	2	3	5	9	20	29
	5	1	3	4	3	5	8
	10	1	5	6	1	76	77
	15	1	4	5	2	25	27
	20	0	2	2	0	23	23
	25	1	4	5	1	30	31
	30	0	3	3	0	25	25
	35	1	6	7	4	37	41
	40	4	3	7	9	9	18
	45	1	5	6	2	36	38
	0	1	3	4	12	18	30
	5	0	4	4	0	22	22
	10	1	2	3	1	10	11
	15	1	2	3	4	5	9
	20	1	2	3	1	18	19
	25	3	4	7	5	13	18

	30	1	3	4	5	15	20
	35	1	2	3	6	21	27
	40	4	0	4	14	0	14
	45	5	0	5	17	0	17
a camara South Grove							
	0	1	3	4	15	7	22
	5	2	3	5	16	9	25
	10	1	2	3	17	27	44
	15	1	4	5	18	14	32
	20	1	2	3	12	21	33
	25	1	1	2	49	1	50
	30	3	2	5	12	9	21
	35	2	3	5	35	15	50
	40	2	1	3	16	10	26
	45	2	4	6	16	23	39
	0	2	1	2	18	3	21
	5	2	1	2	4	5	9
	10	3	1	4	28	9	37
	15	2	1	3	28	2	30
	20	2	2	4	17	9	26
	25	2	3	5	17	9	26
	30	4	1	5	9	5	14
	35	4	2	6	12	3	15
	40	2	0	2	9	0	9
	45	2	1	3	4	4	8
	0	1	2	3	35	10	45
	5	3	2	5	35	7	42
	10	3	3	6	9	27	36
	15	2	2	4	4	32	36
	20	1	3	4	1	15	16
	25	3	2	5	9	8	17
	30	4	0	4	14	0	14
	35	2	1	3	13	5	18
	40	2	2	4	24	5	29
	45	2	1	3	6	9	15
	0	4	2	6	12	10	22
	5	2	2	4	21	14	35
	10	2	1	3	6	28	34
	15	5	1	6	18	8	26
	20	2	3	5	5	15	20
	25	4	2	6	10	7	17
	30	2	1	3	10	7	17
	35	3	1	4	14	13	27
	40	3	2	5	7	14	21
	45	2	2	4	6	12	18

Appendix D: Names of species and their percentage abundances recorded during the field survey

Species	**% Abundance**
Bauhinia petersiana	79
Erythrina abysinica	1
Ziziphus abysinica	1
Combretum molle	71
Pericopsis angolensis	73
Dicrostachys cinerea	53
Combretum zeyheri	10
Azanza gackeana	15
Albizia harveyi	12
Phylocosmus candidus	37
Rothmania aenglirana	58
Dalbergia nitidula	50
Bisocarpus orientalis	68
Albizia versicolor	20
Eulophia aurantiaca	12
Combretum amara	24
Flacourtia indica	13
Hexalobus monopetalus	20
Withania somnifera	63
Maesopsis eminii	19

Phyllocosmus lemaireanus	59
Albizia antunesiana	16
Ochna pucra	10
Lannea discolor	24
Burkea Africana	13
Zahna Africana	24
Brachystegia spiciformis	76
Strychnos inocua	10
Diospyros batocana	12
Uvariastrum hexaloboides	13
Diplorhyncus condylocarpon	16
Harungana madagascariensis	15
Steganotaenia araliacea	14
Acacia sieberana	10

ppendix E: Results of P – CORD used in the analysis of plant diversity

```
antana North Grove

                 Summary of    40 plots
--------------------------------------------------------------------------------
Num.  Name             Mean   Stand.Dev.               S      E      H      D`
-----------------------------------------------------------------------------
   1 QN1              1.448      3.888                 8  0.796  1.655 0.7256
   2 QN2              0.655      1.778                 4  0.950  1.316 0.7202
   3 QN3              1.138      3.102                 5  0.864  1.390 0.7181
   4 QN4              1.034      2.129                 6  0.984  1.763 0.8244
   5 QN5              0.897      1.934                 6  0.964  1.727 0.8107
   6 QN6              1.034      2.471                 5  0.959  1.543 0.7756
   7 QN7              1.172      2.156                 9  0.921  2.025 0.8529
   8 QN8              1.310      4.036                 6  0.738  1.322 0.6496
   9 QN9              1.552      4.634                 4  0.869  1.204 0.6686
  10 QN10             0.793      2.455                 4  0.867  1.203 0.6465
  11 QS1              0.621      1.635                 4  0.977  1.355 0.7346
  12 QS2              0.345      1.111                 3  0.937  1.030 0.6200
  13 QS3              0.379      1.474                 2  0.946  0.655 0.4628
  14 QS4              0.483      1.902                 3  0.725  0.796 0.4490
  15 QS5              0.793      1.820                 7  0.887  1.726 0.7902
  16 QS6              0.931      2.329                 5  0.939  1.512 0.7572
  17 QS7              0.931      3.217                 3  0.853  0.937 0.5679
  18 QS8              0.552      2.114                 3  0.757  0.831 0.4766
  19 QS9              1.241      5.383                 5  0.460  0.741 0.3395
  20 QS10             1.172      4.351                 3  0.713  0.783 0.5069
  21 QE1              1.000      2.686                 5  0.870  1.400 0.7253
  22 QE2              0.276      0.797                 4  0.906  1.255 0.6875
  23 QE3              2.655     12.219                 6  0.350  0.627 0.2604
  24 QE4              0.931      2.520                 5  0.879  1.415 0.7215
  25 QE5              0.793      3.200                 2  0.887  0.615 0.4234
  26 QE6              1.069      2.939                 5  0.859  1.383 0.7138
  27 QE7              0.862      2.863                 3  0.889  0.977 0.5984
  28 QE8              1.414      2.706                 7  0.974  1.896 0.8435
  29 QE9              0.621      1.208                 7  0.966  1.879 0.8395
  30 QE10             1.310      4.335                 6  0.640  1.147 0.6011
  31 QW1              1.034      2.822                 4  0.957  1.327 0.7178
  32 QW2              0.759      2.340                 4  0.859  1.191 0.6488
  33 QW3              0.379      1.293                 3  0.851  0.935 0.5785
  34 QW4              0.310      0.967                 3  0.966  1.061 0.6420
  35 QW5              0.655      2.553                 3  0.697  0.766 0.4598
  36 QW6              0.552      1.352                 6  0.889  1.593 0.7656
  37 QW7              0.690      1.892                 4  0.952  1.320 0.7150
  38 QW8              0.931      3.504                 3  0.773  0.849 0.4938
  39 QW9              0.483      1.883                 4  0.646  0.895 0.4592
  40 QW10             0.552      1.785                 4  0.835  1.157 0.6172
-----------------------------------------------------------------------------
  AVERAGES:           0.894      2.745               4.6  0.844  1.230 0.6402
```

```
                   Skewness  Kurtosis
---------------------------------------
   1 QN1          4.207    20.066
   2 QN2          2.611     5.835
   3 QN3          2.984     8.873
   4 QN4          1.739     1.714
   5 QN5          2.130     4.068
   6 QN6          2.276     4.235
   7 QN7          1.805     2.529
   8 QN8          4.055    17.946
   9 QN9          3.165     9.595
  10 QN10         3.865    16.671
  11 QS1          2.509     5.499
  12 QS2          3.444    12.324
  13 QS3          4.028    16.637
  14 QS4          4.832    24.817
  15 QS5          2.811     8.872
  16 QS6          2.804     8.493
  17 QS7          3.798    14.947
  18 QS8          4.683    23.488
  19 QS9          5.251    28.304
  20 QS10         3.858    14.937
  21 QE1          2.874     8.112
  22 QE2          3.079     9.148
  23 QE3          5.335    28.970
  24 QE4          3.045     9.131
  25 QE5          4.380    20.198
  26 QE6          3.155    10.593
  27 QE7          3.396    10.948
  28 QE8          1.640     1.527
  29 QE9          1.722     1.935
  30 QE10         3.802    14.639
  31 QW1          2.881     8.593
  32 QW2          3.654    14.409
  33 QW3          3.479    11.438
  34 QW4          3.124     9.432
  35 QW5          4.507    21.559
  36 QW6          2.770     7.523
  37 QW7          2.896     8.595
  38 QW8          4.538    22.116
  39 QW9          4.961    25.931
  40 QW10         4.182    19.436
---------------------------------------
   Averages:      3.407    12.852
-----------------------------------------------
Number of cells in main matrix =     1160
Percent of cells empty =   84.224
Matrix total =   0.1037E+04
Matrix mean  =   0.8940E+00
Variance of totals of plots    =   0.1617E+03
CV of totals of plots    =      49.05%
-----------------------------------------------
S = Richness  = number of non-zero elements in row
E = Evenness  = H / ln (Richness)
H = Diversity = - sum (Pi*ln(Pi)) = Shannon`s diversity index
D = Simpson`s diversity index for infinite population = 1 - sum (Pi*Pi)
       where Pi = importance probability in element i
```

Lantana South Grove

```
                Summary of    40 plots
----------------------------------------------------------------------------
Num.  Name           Mean    Stand.Dev.           S      E      H      D`
----------------------------------------------------------------------------
   1 QN1            1.048       3.383             4  0.634   0.879 0.4793
   2 QN2            1.190       3.386             5  0.715   1.150 0.5856
   3 QN3            2.095       5.804             3  0.903   0.992 0.6043
   4 QN4            1.524       4.203             5  0.729   1.174 0.6074
   5 QN5            1.571       4.611             3  0.834   0.916 0.5620
   6 QN6            2.381      10.684             2  0.141   0.098 0.0392
   7 QN7            1.000       2.280             5  0.873   1.406 0.7166
   8 QN8            2.381       7.039             5  0.709   1.141 0.5560
   9 QN9            1.238       3.659             3  0.818   0.898 0.5562
  10 QN10           1.857       3.890             6  0.863   1.547 0.7535
  11 QS1            1.000       3.950             2  0.592   0.410 0.2449
  12 QS2            0.429       1.363             2  0.991   0.687 0.4938
  13 QS3            1.762       4.774             4  0.814   1.129 0.6194
  14 QS4            1.429       5.662             3  0.442   0.485 0.2400
  15 QS5            1.238       3.727             4  0.703   0.975 0.5414
  16 QS6            1.571       3.155             5  0.948   1.526 0.7695
  17 QS7            0.667       1.461             5  0.890   1.433 0.7347
  18 QS8            0.619       1.465             5  0.856   1.378 0.6982
  19 QS9            0.429       1.748             2  0.503   0.349 0.1975
  20 QS10           0.381       1.071             3  0.887   0.974 0.5938
  21 QE1            2.143       7.735             3  0.583   0.641 0.3615
  22 QE2            2.000       4.950             5  0.802   1.291 0.6746
  23 QE3            1.714       3.730             6  0.843   1.511 0.7377
  24 QE4            1.714       6.520             4  0.457   0.634 0.2963
  25 QE5            0.762       1.972             4  0.839   1.163 0.6484
  26 QE6            0.810       1.632             5  0.940   1.514 0.7682
  27 QE7            0.667       1.623             4  0.894   1.240 0.6837
  28 QE8            0.857       2.175             3  0.992   1.089 0.6605
  29 QE9            1.381       4.260             4  0.699   0.969 0.5208
  30 QE10           0.714       2.194             3  0.777   0.853 0.5244
  31 QW1            1.048       1.936             6  0.932   1.669 0.7975
  32 QW2            1.667       4.736             4  0.756   1.049 0.5861
  33 QW3            1.619       6.119             3  0.526   0.578 0.3045
  34 QW4            1.238       2.343             6  0.928   1.662 0.7899
  35 QW5            0.952       2.247             5  0.852   1.371 0.7000
  36 QW6            0.810       1.401             6  0.966   1.732 0.8166
  37 QW7            0.810       2.089             3  0.977   1.073 0.6505
  38 QW8            1.286       3.165             4  0.908   1.259 0.6776
  39 QW9            1.000       2.236             5  0.876   1.410 0.7256
  40 QW10           0.857       2.175             4  0.883   1.224 0.6605
-------------------------------------------------------------------------
  AVERAGES:         1.246       3.564           4.1  0.782   1.087 0.5795
-------------------------------------------------------------------------

                 Skewness  Kurtosis
----------------------------------
   1 QN1            3.936    16.668
   2 QN2            3.775    15.778
   3 QN3            2.815     7.572
   4 QN4            3.492    13.357
   5 QN5            3.102     9.674
   6 QN6            4.579    21.489
   7 QN7            2.545     6.282
```

```
    8 QN8          4.094    18.195
    9 QN9          3.065     9.228
   10 QN10         2.277     5.006
   11 QS1          4.397    20.191
   12 QS2          3.048     8.751
   13 QS3          3.265    11.808
   14 QS4          4.501    20.963
   15 QS5          3.604    14.023
   16 QS6          1.830     2.406
   17 QS7          2.243     4.553
   18 QS8          2.954     9.836
   19 QS9          4.474    20.756
   20 QS10         2.904     8.238
   21 QE1          4.239    19.023
   22 QE2          2.734     7.050
   23 QE3          2.542     6.680
   24 QE4          4.495    20.927
   25 QE5          2.743     7.153
   26 QE6          1.789     2.200
   27 QE7          2.540     6.405
   28 QE8          2.298     4.334
   29 QE9          3.924    16.822
   30 QE10         3.354    11.732
   31 QW1          1.663     1.888
   32 QW2          3.388    12.585
   33 QW3          4.412    20.337
   34 QW4          1.926     3.387
   35 QW5          2.843     8.916
   36 QW6          1.339     0.547
   37 QW7          2.426     5.185
   38 QW8          2.954    10.007
   39 QW9          2.373     5.440
   40 QW10         3.072    10.672
-----------------------------------
   Averages:       3.099    10.652
---------------------------------------------
Number of cells in main matrix =      840
Percent of cells empty =   80.595
Matrix total =   0.1047E+04
Matrix mean  =   0.1246E+01
Variance of totals of plots    =   0.1277E+03
CV of totals of plots    =      43.18%
---------------------------------------------
S = Richness  = number of non-zero elements in row
E = Evenness  = H / ln (Richness)
H = Diversity = - sum (Pi*ln(Pi)) = Shannon`s diversity index
D = Simpson`s diversity index for infinite population = 1 - sum (Pi*Pi)
where Pi = importance probability in element i (element i
                  relativized by row total)
```

Appendix F: Data recording sheet for the laboratory experiment for seed germination

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DEPARTMENT OF BIOLOGICAL SCIENCES

Data sheet for seed germination

Date.............................. Week...............................

# of seeds sown/pot:................ Date seeds sown:...................

	Treatments							
Pot #	**# of s/lings in leaf litter**	**# of leaves of marked seedling in leaf litter**	**# of s/lings in roots**	**# of leaves of marked seedling in roots**	**# of s/lings in leaf litter & roots**	**# of leaves of marked seedling in leaf litter & roots**	**# of s/lings in control**	**# of leav of mar see in con**
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Comments:...
....
....

ppendix G: Data sheet for growth of seedlings at the end of the experiment (9th week)

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ate of harvest…………………………..

reatment	Pot #	Status of seedling	# of shoots	# of leaves	Wt of envelope	Root length	Shoot length	Fresh wt of roots	Dry wt of roots	Fresh wt of shoot	Dry wt sho