ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

Allelopathic Effects of the Invasive *Prosopis juliflora* (Sw.) DC. on Selected Native Plant Species at Middle Awash, Southern Afar Rift of Ethiopia.

By

Samuel Getachew

samget12@yahoo.com

January 2010

Addis Ababa

Allelopathic effects of the invasive *Prosopis juliflora* (Sw.) DC. on selected native plant species at Middle Awash, Southern Afar Rift of Ethiopia

By

Samuel Getachew

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the degree of Master of Science in Biology (Botanical Science)

Addis Ababa University School of Graduate Studies

Allelopathic effects of the invasive *Prosopis juliflora* (Sw.) DC. on selected native plant species at Middle Awash, Southern Afar Rift of Ethiopia

By

Samuel Getachew

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement for the degree of Master of Science in Biology (Botanical Science)

Approved by examining board:

_____ (Examiner) _____

_____ (Examiner) _____

_____ (Advisor) _____

_____ (Advisor) _____

_____ (Chairman) _____

TABLE OF CONTENTS

List of Tables ..... **vi**

List of Figures ..... **vi**

List of Acronyms and Abbreviations ..... **viii**

ACKNOWLEDGEMENTS ..... **ix**

ABSTRACT ..... **x**

1. INTRODUCTION **1**

1.1. OBJECTIVES 4

1.1.1. General objective *4*

1.1.2. Specific Objectives *4*

2. LITRATURE REVIEW **5**

2.1. *PROSOPIS JULIFLORA*: A NOXIOUS INVASIVE WEED 5

2.1.1. Description and Taxonomic Hierarchy of Prosopis juliflora *5*

2.1.2. Biology *6*

2.1.3. World Distribution and Introduction to Ethiopia *8*

2.1.4. Impacts of Prosopis juliflora on humans, domestic animals and biodiversity *12*

2.1.4.1. Impacts on humans and domestic animals 12

2.1.4.2. Impacts on biodiversity 12

2.1.4.2.1 Shade impacts of *Prosopis juliflora* on native plant species 13

2.1.5. Allelopathic effects of Prosopis juliflora *13*

2.1.6. Different Prosopis controlling methods *15*

2.1.6.1. Mechanical Methods 15

2.1.6.2. Chemical Methods 16

2.1.6.3. Biological Control 16

2.1.6.4. Fire 17

3. MATERIALS AND METHODS **17**

3.1. THE STUDY AREA 17

3.1.1 Climate *18*

3.2 Selection of species for the study……..19

3.2.1 PLANT MATERIAL 19

3.3 VEGETATION DATA COLLECTION 20

3.4 VARIATION IN CANOPY CHARACTERSTICS.....20

3.4.1 canopy diameter.....*20*

3.4.2 Canopy closure *20*

3.4.3 Branching nature *20*

3.4.4 Branch angle.....*21*

3.5 ALLELOPATHIC EFFECTS OF *P. JULIFLORA* 21

3.5.1 Initial leachate bioassays.....*21*

3.5.1.1 Germination and growth record *21*

3.5.2 Amended soil with decaying plant parts and growth records *22*

3.5.3 Soil bioassay *22*

3.6 STATISTICAL ANALYSIS.....23

4. RESULTS AND DISCUSSIONS.....23

4.1. VEGETATION CHARACTERISTICS 23

4.2 CANOPY CHARACTERISTICS….....29

4.3. ALLELOPATHIC EFFECTS OF *P. JULIFLORA*.....30

4.3.1 Germination *30*

4.3.2 Germination rate.....*36*

4.3.3 Seedling growth.....*42*

4.3.4 Amended and under canopy soil *46*

5. CONCLUSIONS AND RECOMMENDATIONS…….. 47

6. REFERENCES 49

Appendices 57

APPENDIX 1 57

APPENDIX 2. 57

List of Tables

Table 1. Trees, shrubs and herbs recorded in the study areas…….25

Table 2. Density of trees, shrubs and herbs recorded in the study areas…….26

Table 3. Mean growth variables of trees and their effects on canopy closure……29

Table 4. Results from the germination experiment of *Acacia nilotica*, *Acacia tortilis, Cenchrus cillaris* and *Enteropogon rupestris* subjected to different treatments...…….....31

Table 5. Shoot length (cm) in aqueous extracts of leaf, bark and root of *Prosopis juliflora* of different concentrations ……..42

Table 6. Root length (cm) in aqueous extracts of leaf, bark and root of *P. juliflora* of different concentrations…….....43

Table 7. Results of germination percentage from residue amended and under canopy soil experiment ……..46

List of Figures

Figure 1a. Natural distribution of *Prosopis* showing especially the distribution of *Prosopis juliflora-Prosopis pallida* complex ……...9

Figure 1b. Present distribution of *Prosopis* showing especially the distribution of *Prosopis juliflora-Prosopis pallida* complex…….10

Figure 2. Map of the study area …….....18

Figure 3. Mean monthly rain fall and mean monthly maximum and minimum temperature for the last thirty years …….....19

Figure 4. Invasion of the different habitat types by *P. juliflora*: riverine, swamp, and open *Acacia* woodland vegetation…….……..28

Figure 5. The effects of different concentrations of aqueous extracts of *P. juliflora* obtained from leaf, bark, root and plant residues on seed germination of the study plants …….....35

Figure 6. Rate of seed germination of *Acacia nilotica* under different concentrations of aqueous extract of leaf, bark and root of *P. juliflora* ……..37

Figure 7. Rate of seed germination of *Acacia tortilis* under different concentrations of aqueous extracts of leaf, bark and root of *P. juliflora* 38

Figure 8. Rate of seed germination of *Cenchrus cillaris* under different concentrations of leaf, bark and root aqueous extract of *P. juliflora* …….39

Figure 9.Rate of seed germination of *Enteropogon rupestris* under different concentrations of leaf, bark and root aqueous extracts of *P. juliflora* …….40

List of Acronyms and Abbreviations

ANOVA	Analysis of Variance
ANRS	Afar National Regional State
CRD	Completely Randomized Design
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
FRC	Forestry Research Center
GEF	Global Environmental Facility
GISP	Global Invasive Species Program
IAS	Invasive Alien Species
LSD	Least Significant Difference
RBIPMA	Removing Barriers to Invasive Plant Management in Africa.
SPSS	Statistical Package for Social Sciences
UNEP	United Nations Environmental Program
WAS	Werer Agro-Metrological Station

ACKNOWLEDGEMENTS

I am very grateful to my advisors Prof. Sebsebe Demissew and Dr. Tadessse Wolde mariam for their invaluable advice and support, without which the study could not have been successfully completed.

I would like to thank the UNEP/GEF Project on Removing Barriers to Invasive Plant Management in Africa (RBIPMA), Ethiopian Institute of Agricultural Research (EIAR) for providing me the financial support and for Forestry Research Center (FRC) for availing me vehicles and laboratory facilities during the study. I thank also Werer Agricultural Research Center and colleagues working at the center for their invaluable support in seed and data collection. Special thanks also shall go to Demessew Negatu in supporting me in the data collection.

None of this would have been completed without the moral support and friendship of Shiferaw Alem, my brother Tadiwos Getachew and members of my family. Thanks for their loving support.

ABSTRACT

The allelopathic effect of aqueous extracts of leaf, bark and root of *Prosopis juliflora* was studied on germination percentage, germination rate and seedling growth of *Acacia nilotica*, *Acacia tortilis* (both members of the legume Family, Fabaceae), *Cenchrus cillaris* and *Enteropogon rupestris* (both members of the grass Family, Poaceae). Effects of soil amended with decaying plant parts of *P. juliflora* and it's under canopy soil were analyzed on germination percentage of the above selected plants to observe the field situation. Vegetation sampling in different habitat types in the area was made to identify the target plant species. Comparison of canopy characteristics among *P. juliflora*, *A. nilotica* and *A. tortilis* was also made to observe differences if any in canopy closure. *P. juliflora* was recorded in all habitat types in the study area: open *Acacia* woodland, riverine and swamp vegetation types. *P. juliflora* was observed invading the different habitats and affecting the plant diversity there in. Low plant diversity was recorded in *P. juliflora* dominated fields. Even if the canopy closure of *P. juliflora* was not significantly different from other trees, its growth characteristics and dense thickets formation restrict light to the ground flora and block winds. This results in the death of under canopy vegetation and hence low plant diversity. Leaf, bark and root aqueous extract of *P. juliflora* at 0, 0.5, 0.8, 1, 2 and 6% were prepared and their effect studied on germination percent, germination rate and seedling growth of the selected plant species in the study. Germination of *A. nilotica* and *A. tortilis* was not affected by all treatment types. Leaf and root extracts at higher concentrations inhibited germination of *C. cillaris* and *E. rupestris*. Bark extract facilitated germination of *C. cillaris* at lower concentrations. In general all treatment types speeded up the germination rate for *A. nilotica* and *A. tortilis* at the beginning, while these slow down the germination rate of *C. cillaris* and *E. rupesteris*. Shoot and root growth of the study species was inhibited by leaf extracts. Bark

extracts were stimulatory to shoot and root growth of the species under study at lower concentrations except for *C. cillaris. C. cillaris* root growth was not affected by bark extracts at lower concentrations. Root extracts were stimulatory at lower concentrations while it was inhibitory at higher concentrations to shoot and root growth of the study species except for *C. cillaris. C. cillaris* shoot growth was not affected by root extracts at lower concentrations. Seed germination of all study species except *A. nilotica* was inhibited by the amended and under canopy soil. The effect was high on the grasses than on the tree species studied and root growth was more inhibited than shoot growth. Suppression of seed germination, facilitation or retardation of the germination speed and seedling growth of the study species suggests that these responses are attributed to an allelopathic effect of *P. juliflora* on the test species. These results indicate that the effect is species specific and leaf seems to contain greater number / amount of inhibitors than does bark and root. Bark seems to contain the least. Heavy accumulations of leaf litter under *P. juliflora* result in accumulation of toxic substances in soil layers, inhibiting growth of other species. This may be one of the main reasons for its invasiveness and low plant diversity seen under its canopy.

Keywords: Allelopathy, aqueous extract, canopy closure, germination percentage, germination rate, habitat, plant diversity, *P. juliflora*, seedling growth.

INTRODUCTION

Invasive alien species are those that become established in a new environment, and then proliferate and spread in ways that are destructive to biodiversity and /or human interests (GISP, 2004). The spread of invasive alien species (IAS) is now recognized as one of the greatest threats to the ecological and economic well-being of the planet.

These species are causing enormous damage to biodiversity and on agricultural systems we depend on. Health effects on human beings and animals are increasing and impacts on biodiversity irreversible. Introduced alien species outcompete, infect or transmit diseases, compete, attack, or hybridize with native ones (Wittenberg and Cock, 2001).

With increasing trade and globalization, movement of people and goods also increased. This facilitated the spread of IAS.

Prosopis juliflora is a noxious invasive weed that is native to America Ranging from Peru to Mexico (GISP, 2004). Currently, it occurs as invasive weed in 25 African countries including Ethiopia (GISP, 2004). The earliest introductions to Africa in the 19th century may have been through Senegal, South Africa and Egypt (Pacieezuick *et al*., 2001). In Ethiopia, *Prosopis juliflora* was introduced and cultivated for shade, timber, forage, food and medicine (Asfaw Hunde and Thulin, 1989). It escaped cultivation and spread to farmlands, irrigation areas and rangelands. *Prosopis juliflora* has now invaded most of the pastoral areas in Afar Regional State.

The success of *P. juliflora* is largely attributed to the high number of seeds produced and their efficient dispersal mechanisms (Hailu Shiferaw *et al*., 2004). Seeds of *P. juliflora* disperse by means of flowing water such as rivers and floods, livestock and wild animals. If the seeds fail to germinate at a particular point in time, they undergo to dormancy and remain in the seed bank. With the destruction of the vegetation cover, the soil will be exposed, that promotes the germination (GISP, 2004).

Currently, *P. juliflora* poses a threat to indigenous biodiversity whenever it is established in Ethiopia in general, in the Middle Awash area in particular because of its weedy and invasive nature, and its allelopathic effect. In this area, about 30,000 hectare of grass land, rangelands, water points and croplands are estimated to be occupied by *P. juliflora* (Zeray Mehari, 2008). Areas that are currently invaded by *P. juliflora* were important sources of forage for livestock in the Afar people. The invasion by *P. juliflora* reduces grass availability and stocking density by livestock. According to Ameha T. (2006; cited in Zeraye Mehari, 2007) the invasion is also affecting multipurpose indigenous trees and the plant species biodiversity. According to Ameha T. the plant biodiversity under the canopy of *P. juliflora* is less than under indigenous *Acacia* species. The invasion by *P. juliflora* leads to shrinkage of the rangelands and grasslands and will therefore threaten the existence of the community.

Allelopathy is the detrimental effect of chemicals or exudates produced by one living plant species on the germination, growth or development of another plant species or microorganisms sharing the same habitat (Akobundu, 1987). Phenols and other harmful products of plant metabolism that are temporarily stored in the vacuoles and later released into the soil by living plants are known to affect other plants.

Allelopathic materials inside a tree can produce major changes in the survival, growth, reproduction and behavior of other organisms if they escape into the environment. These effects can be positive or negative. Allelo-chemicals can be produced by plants and affect seed germination, root growth, shoot growth, stem growth, symbiotic effectiveness, microorganism-based soil transformation, pathological infection, insect injury scope and scale, and environmental stress impacts on other plant species (Coder, 1999).

The leaves of *P. juliflora* contain various chemicals including tannins, flavinoids, steroids, hydrocarbons, waxes and alkaloids (Pasiecznik, 2001). These are known to affect palatability to livestock but also have effects on the germination and growth of other trees, shrubs etc. As a result of this, the plant diversity both the number of individual plants of a species and the number of species around *P. juliflora* will be affected by the allele-chemicals. These allele-chemicals change the microenvironment around. The chemicals will remain in the soil even after *P. juliflora* is removed and hinder the growth of native species from reestablishing again (Pasiecznik, 2001).

Tree canopy cover is the land area covered by a tree crown or crowns, as measured in square meter and branch angle of a plant is the angle formed by the branch of a plant with the stem. Canopy cover is the proportion of the forest floor covered by the vertical projection of the tree crowns while canopy closure is the proportion of the sky hemisphere obscured by vegetation when viewed from a single point (Jennings *et al*., 1999). If the branch angle and crown diameter of a plant is large and with much branches and dense crown, there will be low sunlight reaching the ground floor. *P juliflora* forms a dense canopy cover that prevents passage of sunlight. This will make

it difficult for the plant species under the canopy to have enough light that is very crucial for photosynthesis. Microclimate adjustment created under canopy of exotic species will result in displacement of native species. Thus the purpose of this study is to evaluate the allelopathic effects and canopy characteristics of *P. juliflora* in selected native and legume species in Middle Awash.

1.1. Objectives

1.1.1. General Objective

The overall objective of the study is to evaluate the allelopathic effects of *Prosopis juliflora* on four native plant species found at Melka-Werer (Middle Awash): *Acacia nilotica* and *Acacia tortilis* (members of the Family Fabaceae), and *Cenchrus cillaris* and *Enteropogon rupestris* (members of the Family Poaceae) and to compare canopy characteristics of *P. juliflora* with other common tree species in the study area, *Acacia nilotica* and *Acacia tortilis.*

1.1.2. Specific Objectives

- To evaluate aqueous extracts of leaves, bark and root of *Prosopis juliflora* on seed germination, germination rate and seedling growth of the plants selected for the study.
- To assess effects of soil amended with decaying plant parts of *Prosopis juliflora* on seed germination of the test plants.
- To asses effects of under canopy soil on seed germination of the selected species.
- To evaluate the variation in canopy characteristics of *Prosopis juliflora* with other common tree species (*A. nilotica* and *A. tortilis)* in the study area.

2. LITRATURE REVIEW

2.1. *Prosopis juliflora*: *A noxious invasive weed*

Invasive alien species are found in nearly all major taxonomic groups of organisms. Invasive species include viruses, fungi, algae, mosses, ferns, higher plants, invertebrates, fish, amphibians, reptiles, birds and mammals.

P. juliflora is one of the invasive alien plant species that are on threatening the native plant species. It grows in very hot, dry climates, with the temperature up to 48 ^{o}C and annual precipitation from 150 to 750 mm. It is found from sea level to 1500m. The root penetrates to great depth in the soil searching for the required water. It can grow in the variety of soil types including saline and alkaline areas in sandy and rocky soils. The tissue of *P. juliflora* is photosynthetically active throughout the year, presenting a wide spread root system through which the tree fully exploits the available water resources. Its low nutritional requirements and resistance to water deficit give *P. juliflora* a great plasticity of response, which allows its wide distribution in arid and semiarid zones in the tropics (Pacieezuick *et al*., 2001).

2.1.1. Description and Taxonomic hierarchy of *Prosopis juliflora*

P. juliflora is a spreading shrub or a tree that reaches 3 to 8 m tall. The bark is fissured and brown in color. Spines 0.5 to 5 cm in length, axillary and paired, sometimes solitary and do not occur on all branches. Leaves have one to four pairs of pinnae and with 10 to 16 pairs of leaflets. Petiole reaches 0.5 to 7.5 cm long. Leaflets are elliptical oblong, 6 to 23 mm long, 1.6 to 5.5 mm wide, and most often glabrous. Inflorescence: racemes, greenish white flowers turn to light yellow when mature. Calyx: 0.8 to 1 mm long with minute ciliated teeth. Petals are 2 to 3 mm long and

hairy within but glabrous on the outer part. Stamens 4 and are up to 5 mm long. Pods incurves at apex may be sickle shaped in some trees. The endocarp may have up to 25 rounded, rectangular segments. Seeds are oval and brown (Lowe *et al*., 2004, Pacieezuick *et al*., 2001).

According to www.plants.usda.gov the taxonomical hierarchy of *P. juliflora* is:

Kingdom - Plantae

Subkingdom – Trachobionta

Superdivision- Spermatophyta

Division- Magnoliophyta

Class- Magnoliopsida

Subclass- Rosidae

Order- Fabales

Family- Fabaceae

Subfamily- Mimosidaeae

Genus- *Prosopis* L.

Species- *Prosopis juliflora* (SW.) DC.

Prosopis is better known as Mesquite but like many trees, it has many local names in different countries i.e. Weyane in Ethiopia.

2.1.2. Biology

Pollination in *P. juliflora* is effected by insects. The seeds are dispersed mostly by water around wetlands and rivers (Solbrig and Cantino, 1975). Pods have high sugar content, are low in anti- feedants and are widely sought after by a variety of animals. Birds, bats, reptiles and ants also feed on the fruits and are potential agents of dispersal (Pasiecznik *et al*., 2001). Livestock are now the primary dispersal agents.

Wild animals also disperse the seeds of *P. juliflora* by consuming the fruit. After the seed passes through the gut of animals and excreted along with feces, it will germinate. The passage of the seeds through the gut facilitates the germination of the hard coated seeds of *P. juliflora*. (Hailu Shiferaw *et al*., 2004). After falling, the seed will become a component of the seed bank and remain viable for many years. Seedlings are rarely observed under the canopy of *P. juliflora*. This is because of shading (Singh *et al.,* 2008) and allelopathic effects of *Prosopis* (Noor *et al*., 2005) and insect attacks.

The seeds of *P. juliflora* are orthodox seeds, that posses an inherently high level of dormancy (Hailu Shiferaw *et al*., 2003). The hard seed coat must be broken or weakened to facilitate germination to occur. Seed germination of *P. juliflora* is usually about 21% and after scarification of the seed coat shows about 100% germination (Hailu *et al*., 2004). Other factors that affect the germination of seeds include salinity (that decrease germination with its increase) (Khan *et al*., 1987); alkalinity (that affect germination when above pH 9.0) (Srinviasu and Toky, 1996) and temperature with optimum condition for germination at about 30°C, the decrease below 20°C or above 40°C results in reduced germination (Sundararaj *et al*., 1996).

In general, a number of characteristics foster the invasion of *P. juliflora*. These are the production of many small seeds, attractive and rewarding pods, accumulation of long lived seeds in the soil, production of mixture of seeds, some of which germinate immediately after dispersal and others remain dormant for spreading germination over time and incredible ability of re-sprouting and fast coppice growth from stumped or damaged trees (Hailu Shiferaw *et al*, 2004).

2.1.3. World Distribution and Introduction to Ethiopia

Prosopis juliflora is indigenous from Mexico and Cuba in the north (at 22-25°N), to southern Peru in the south (18-20°S) and from eastern Venezuela and the eastern Caribbean (62°E) to Mexico in the west (112°W). The countries included in the above in latitudinal and longitudinal ranges include Mexico, Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Colombia, Venezuela, Ecuador and Peru (Pasiecznik *et al.*, 2001).

Prosopis juliflora has a very wide soil and site adaptability ranging from sand dunes to clay soils; from saline to alkaline soils; from areas below 200 to more than 1500 m above sea level; and from 50 to 1500 mm mean annual rain fall (Pasiecznik *et al*., 2004; Zeila *et al.*, 2004). It also can withstand and survive temperatures from as high as 50°C (air temperature) and 70°C (soil temperature) (Pasiecznik *et al*., 2004). It is one of the most common trees in semi-arid and arid parts of the sub-tropical and tropical zones (Pasiecznik *et al*., 2001; Pasiecznik *et al.*, 2004). Nowadays, it is very common in Africa, Asia and Australia (Figure 1)

According to LeHouerou (1980; cited in Hailu Shiferaw, 2004), and Asfaw Hunde and Thulin (1989), *Prosopis juliflora* (Sw.) DC. has been introduced to and become naturalized in the tropics including Ethiopia, where it was cultivated for shade, timber, forage, food and medicine. But currently *P. juliflora* escaped cultivation and invaded farmlands, irrigation schemes, rangelands, etc. in different countries including Ethiopia. Now *Prosopis juliflora* has invaded the rangelands in the Afar Regional State.

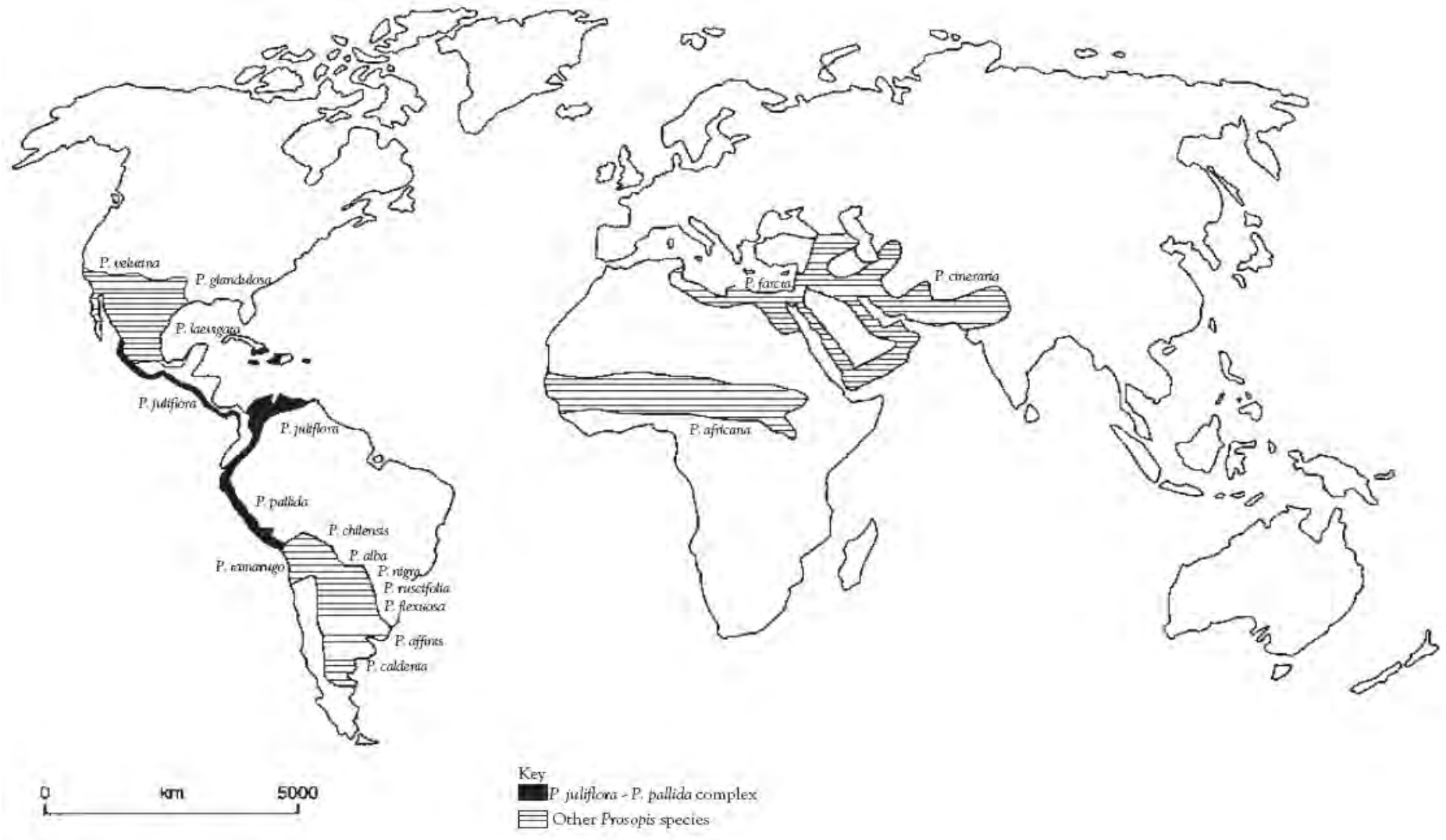


Figure 1a. Natural distribution of *Prosopis* showing especially the distribution of *Prosopis juliflora-Prosopis pallida* complex (Source: Pasiecznik *et al*., 2001).

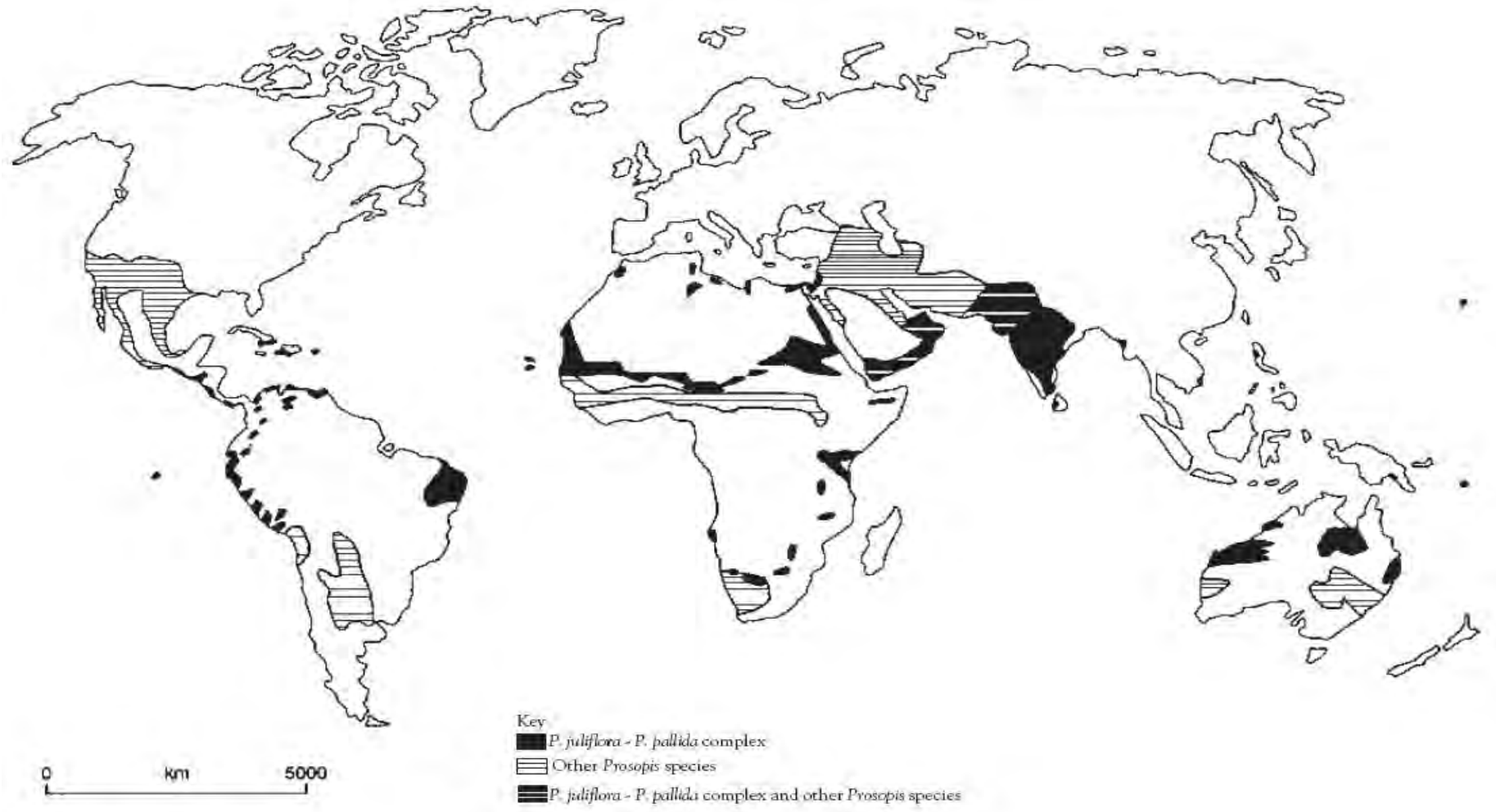


Figure 1 b. Present distribution of *Prosopis* showing especially the distribution of *Prosopis juliflora- Prosopis pallida* complex (Source: Pasiecznik *et al*., 2001).

In northern India, *P. juliflora* is a pioneer species that rapidly colonizes denuded / abandoned ravines and is damaging local biodiversity. Grasslands and indigenous trees and wildlife go on extinct (Raghubanshi *et al.,* 2005). *P. juliflora* also invaded farmlands in north eastern Sudan. In Kenya arid and semi arid parts are facing invasion by this invasive plant (Pasiecznik *et al*., 2001).

In Ethiopia, *Prosopis juliflora* was initially observed in the eastern part of the country in the late 1970s at Goro nursery site in Dire-Dawa probably introduced from India (EARO and HADRA, 2005). It was first introduced to Awash area of the Afar Regional State some 30 years ago (Zeray Mehari, 2008). *P. juliflora* was planted in the area for its feed for livestock, fuelwood sources, reclaiming salty areas, etc. Expecting the advantage, it was planted over large areas in the Region by programs like food for work program until 1988 (EARO and HADRA, 2005). The plant then started competing with grasses and indigenous trees and invaded farmlands and rangelands in the area and with great damage on biodiversity, livestock and food production.

In addition to this deliberate introduction of the species for the above mentioned uses, its inherent characteristics of fast growth, production of many seeds, seeds maintaining its viability in the droppings of livestock's and wild animals, dormant seeds in the soil seed bank and its resistance to browsing greatly contributed to the current invasion status. Now *P. juliflora* becomes the national no.1 invasive alien plant species (EARO and HADRA, 2005).

2.1.4. Impacts of *Prosopis juliflora* on humans, domestic animals and biodiversity

2.1.4.1. Impacts on humans and domestic animals

The thorn of *P. juliflora* causes inflammation when injuries occur. The injury does not heal easily despite intensive medical treatment (Abiyot Birhanu and Getachew Tesfaye, 2006). The local people are also complaining about its effects on health and its rapid colonization of the area. According to Duck (1983; cited in Abiyot Birhanu and Getachew Tesfaye, 2006), the wood is also known to cause dermatitis when it burns. The local people are also complaining a death of cattle by feeding on leaves for a long time.

2.1.4.2. Impacts on biodiversity

Prosopis juliflora has negative impacts on local farmlands and pasturelands. It creates a physical barrier against seedlings of other plant species and make establishment very difficult. Since its branches are many, dense, and have evergreen leaves, sunlight will not reach the ground and plants under canopy of *P. juliflora* will not have enough sunlight that is very crucial for photosynthesis. This may results in the death of plants under canopy of *Prosopis juliflora* (Pasiecznik, 2001).

Chaturvedi *et al* (1988) indicated the water use efficiency of *P. juliflora* to be 710 kg H_2O/ kg dry matter. With other species, 345 kg H_2O/ kg dry matter was estimated for *P. chilensis* (Felker *et al.,* 1983). This high level of water use efficiency is related to high evaporation rate of their leaves. This makes the water table to lower and unable to be reached by the roots of native plant species and results in displacement of the native species with *P. juliflora* takes place.

Prosopis juliflora also release allelochemical substances into the soil which may disrupt the physiology and mutalistic relations present in the native species (Pasiecznik, 2001; Noor *et al*., 1995). This may help *Prosopis juliflora* to out-compete the local plant species.

2.1.4.2.1 Shade impacts of *Prosopis juliflora* on native plant species

Reduced numbers of seedlings of native species have been recorded under canopy of non- indigenous invaders (Gordon, 1998). This is due to the conversion of more open stands to closed-canopy systems accompanied by low-light, higher humidity, lower temperatures, and other environmental and biological changes (Hobbs and Mooney, 1986). This microclimate adjustment leads to decrease in population number and species composition of the area.

2.1.5. Allelopathic effects of *Prosopis juliflora*

Allelopathic effects can be positive and negative, depending upon the dose and the organism affected. Allelopathy is the active or passive effects of chemicals released into the environment which influences other organisms. It is the biochemical modification of the environment to enhance the donor (*P. juliflora*) survival and reproduction (Coder and Warnell, 1999). The chemicals released inhibit (rarely stimulate) the germination and growth of associated plants. Apart from this, they inhibit nutrient absorption and dry matter accumulation in shoots and roots of target species (Wacker *et al,*. 1990).

Allelochemicals affect many different cellular processes in target organisms, including disruption of membrane permeability (Galindo *et al.*, 1999), ion uptake (Lehman and Blum, 1999), inhibition of photosynthesis and the respiratory chain

(Calera *et al*., 1995), alteration of some enzymatic activities (Politycka, 1998), and inhibition of cell division (Anaya and Pelayo- Benavides, 1997).

The leaves of *P. juliflora* contain various chemicals including tannins, flavinoids, steroids, hydrocarbons, waxes and alkaloids (Pasiecznik, 2001). These are known to affect palatability to livestock but also have effects on the germination and growth of *P. juliflora*, crops, weeds and other trees (Pasiecznik, 2001). The effects of these chemicals are direct on the germination and growth of plants. Plant growth inhibitory alkaloids: 3`-oxo-juliprosopine and secojuliprosopine were isolated from the extract of *P. juliflora* leaves (Nakano *et al.,* 2004).

As a general rule, the longer species lived together, the less allelopathy affects their interference. New species compositions, rapid successional changes, and introduced exotic species can generate a large allelopathic effect (Coder and Warnell, 1999).

Allelopathic chemicals can be released or escaped from a tree by several means: evaporating into the air or from the soil surface; erosion or leaching from the tree surface; exudates from roots; and release by decaying dead organic materials. Seeds, fruits, buds and pollen all can have significant concentration or allelochemical within. These defense materials can prevent damage and decay of reproductive materials. Leaves, buds and phloem tissues can generate and concentrate allelopathic chemicals to minimize injury and consumption. Allelopathic materials can lengthen survival times in a hostile environment (Coder and Warnell, 1999).

Species with large allelopathic components of interference usually modify the surrounding soils enough to act as a shield from other allelopathic species. A number

of allelopathic species can be found growing together because each are successfully controlling their own interfere with the environment while protecting themselves from the allelopathic materials of others. Environments with large components of interference due to allelopathy are stressful areas to grow for both the conveyors (allelopathic plants) and receivers (native plants) (Coder and Warnell, 1999). Allelopathic chemical production may have been significantly increased in trees because of water stress, and the chemical exudation increase due to increased root surface area. In trees, it is one portion of the total stress that must be overcome to survive.

2.1.6. Different *Prosopis juliflora* controlling methods

Prosopis species are recognized as problem woody weeds in many countries world-wide. But control programs have been implemented for only temperate species while intervention programs for the tropical species (*P. juliflora*) has not yet been implemented. There are four kinds of controlling mechanism: mechanical, chemical, fire and biological (Pasiecznik *et al*., 2001).

2.1.6.1. Mechanical Methods

In this method, all the trees will be cut and all the seedlings and stumps uprooted. The operation is too labor intensive and expensive. Hand clearing remains practical only for small landholdings of high value such as for agriculture, or where labor is relatively cheap. Mechanical controlling can be carried out with tractors operated machines, but effectiveness is limited by tree size, and it is more cost effective in lighter infestation.

2.1.6.2. Chemical Methods

Chemical control has supremacy over other control methods due to its quick action and time saving. In India, ammonium sulphamate was successful in killing *P. juliflora* trees and as a stump treatment (Panchal and Prabhakar'Shetty, 1977). 2, 4-D i.e. 2,4 - Dichlorophenoxy acetic acid provided excellent suppression of top growth, few trees were actually killed and such chemical treatments had to be applied periodically to ensure that forage yields were maintained. Infested sites often needed spraying over 5-7 years.

The most effective chemical for high tree kill of *P. glandulosa* in the USA is clopyralid, but dicamba, picloram and triclopyr have also been successfully used either alone or in combination (Jacoby and Anseley, 1991). However method of control using chemicals is very expensive and largely unsuccessful in the long term.
It has been accepted that using herbicides, eradication of vegetations are possible but the potential environmental damage (non-Glycophosphate based herbicides) from widespread use of some herbicide must also be taken into consideration.

2.1.6.3. Biological Control

Several biological control mechanisms have been developed and implemented. These use species of *Prosopis juliflora* seed feed by bruchid beetles. In the native range, bruchid beetles can destroy substantial amounts of seed produced, thus severely limiting the potential for invasion. For example, according to Lima (1994; cited in Pasiecznik *et al*., 2001) the twig girdler *Oncideres limpida* attack *P. juliflora* in Brazil.

Biological control also involves animals besides insects to eat and kill seeds. *Prosopis* species seeds when passed through the gut of cattle, they would germinate better. So replacing these livestock with others such as sheep and pigs can prevent the expansion of *Prosopis* (Pasiecznik *et al.,* 2001). This is because of the seeds lose their viability during passing through the gut of these animals.

2.1.6.4. Fire

Fire is another controlling method and original management tool of invasive species. Young seedlings are sensitive to fire but older trees become increasingly protected by thick bark as they mature and will re-sprout rapidly after fire. Fire can, however, be used successfully as a management tool for preventing the re-establishment of young *Prosopis* species seedlings while also improving forage production.

3. MATERIALS AND METHODS

3.1. The Study Area

The study area is located at Middle Awash, particularly, Melka-Worer in Amibara Wereda, Afar National Regional State (ANRS). It is located at about 09°28'09.4" N - 09°17'18.8" N and 40°18'53.8" E - 40°10'08.1" E, about 285 km north-east of Addis Ababa at an altitude of 740 m (Fig 2).

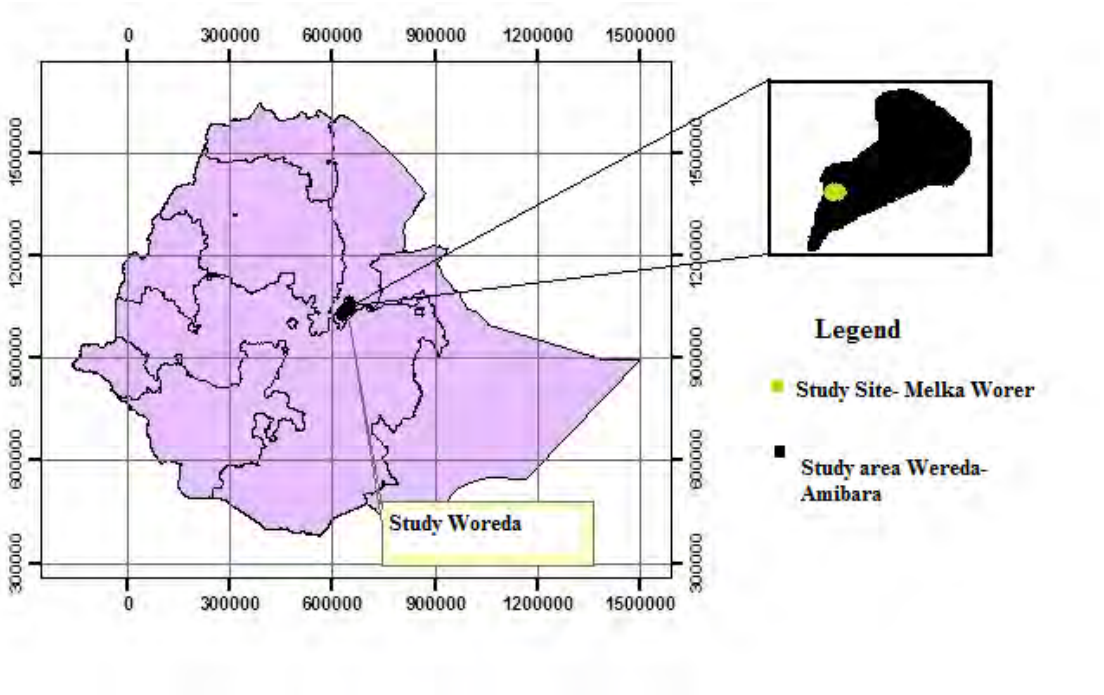


Figure 2. Map of Ethiopia showing the Study area.

3.1.1 Climate

Thirty years meteorological data from Werer Agricultural Research Center shows bimodal type of rain fall type in Middle Awash Rift valley area (Fig. 3). July and August are the wettest months with mean monthly rain fall greater than 100 mm. The second rainy season is from February to April. The rainfall reaches around 70 mm. The area is characterized by high moisture deficit because of high evapo-transpiration. Mean annual evapo-transpiration is 2702 mm which much exceeds mean annual rainfall of the area which is about 562 mm. The mean maximum temperature is 34.1^{o}C and the minimum mean temperature is 19^{o}C (Fig 4). The maximum and the minimum temperatures are 38^{o}C and 14.2^{o}C in June and November respectively.

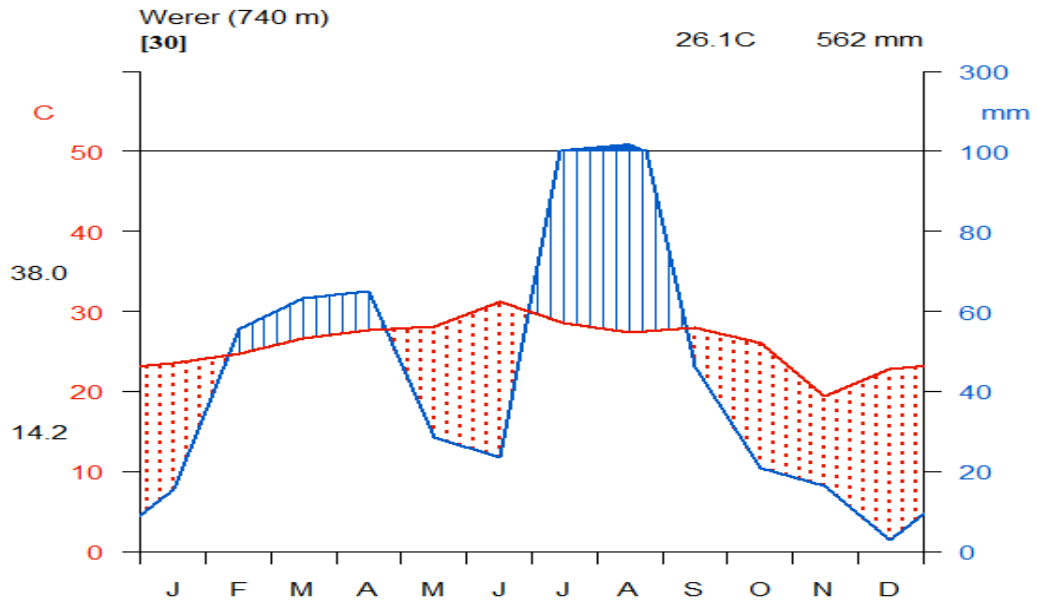


Figure 3. Mean monthly rain fall and maximum and minimum temperature for the last thirty years. (Source: Werer Agro-meteorological Station (WAS)).

3.2 Selection of species for the study

A preliminary survey was carried out to select the dominant tree and forage grass species in the study area that would be particularly affected by the allelopathic effects of *P. juliflora*. Two dominant tree species: *A. nilotica* and *A. tortilis* and two dominant highly valuable forage grass species: *C. cillaris* and *E. rupestris* were selected among the many that occur in the area based on from field observations and information from Werer Agricultural Research Center.

3.2.1 Plant material

Leaves, barks, roots and residues of *P. juliflora* were collected from an area infested by *P. juliflora* in Melka-Werer. These were air-dried, powdered and stored in polythene bags. Seeds of *A. nilotica* and *A. tortilis* (legumes), *C. cilaris* and *E. rupestris* (grasses) were also collected for the allelopathy trial.

3.3 Vegetation data collection

Three habitat types (*Acacia* woodland, riverine and marsh) were identified. Four plots with 400 m^2 were laid out in each of these habitats, two in open *Acacia* woodland (in flat and open slopes), one in riverine and one in swamp vegetation to know the target plant species. Vegetation counting for trees, shrubs and herbs was made in the study area to know their density (individuals no / ha). Plant specimens were collected and identified at the National Herbarium (ETH), Addis Ababa University.

3.4 Variation in Canopy Characteristics

3.4.1 Canopy diameter

Once the two dominant native species, *A. nilotica* and *A. tortilis* were identified canopy diameter of *P. juliflora*, *A. nilotica* and *A. tortilis* were measured and compared by taking 50 individuals from each species within and out of the plots using a measuring tape.

3.4.2 Canopy Closure

Comparison of variation in canopy closure among the dominant tree species: *P. juliflora*, *A. nilotica* and *A. tortilis* were made by selecting 50 mature trees of each species from within and out of the plots. Measurements were taken by using a spherical densiometer.

3.4.3 Branching nature

Fifty individual mature trees from each species: *P. juliflora*, *A. nilotica* and *A. tortilis* were selected and height was measured from the ground up to the first branch by using a measuring tape and compared.

3.4.4 Branch Angle

Branch angle of three branches of a tree were taken and averaged from 50 individual trees of *P. juliflora, A. nilotica* and *A. tortilis.*

3.5 Allelopathic effects of *P. juliflora*

3.5.1 Initial Leachate Bioassays

An aqueous extract was prepared by adding 0, 0.5, 0.8, 1, 2 and 6 g of leaves, barks and roots of *P. juliflora* (powder) in 100 ml of distilled water. Then the solution was shaked for 10 seconds and kept for 24 hours in the dark. It was filtered using a filter paper and designated as 0%, 0.5%, 0.8%, 1%, 2% and 6% and stored for seed treatment experiment (Rafiqul Hoque, 2003). The following treatments were used:

T_o = Seeds of receptor plants grown in distill water only (Control),

T1= Seeds of receptor plants grown in extracts of 0.5% concentration.

T2= Seeds of receptor plants grown in extracts of 0.8% concentration.

T3= Seeds of receptor plants grown in extracts of 1% concentration.

T4= Seeds of receptor plants grown in extracts of 2% concentration.

T5= Seeds of receptor plants grown in extracts of 6% concentration.

3.5.1.1 Germination and Growth Record

The germination test was carried out in sterile Petri dishes using a filter paper. Four ml of each concentration of leaf, bark and root was added to each Petri dish of respective treatments shown above and moisture was maintained with distilled water. The control was treated with 4 ml distill water only. Four replications with 25 seeds each of receptor plants (*A. nilotica, A. tortilis, C. cillaris* and *E. rupestris*) was used

for each treatment. Germination count was made at two days interval until no new seed germination was observed for two consecutive counts and radicle and plumule length was recorded at the end of the experiment. The seed was considered as germinated when the radicle emerge visibly.

3.5.2 Amended soil with decaying plant parts and growth records

To simulate a natural condition 5, 8, 10, 20 and 60 gm of *P. juliflora* decaying plant parts (powder) was added into 1 kg soil collected from fields outside *P. juliflora* to get 0.5, 0.8, 1, 2 and 6% concentrations of *P. juliflora* respectively. Then 500 ml of distilled water was added and left for 16 hours. Then 160 g of the respective amended soil was taken for growth experiments (Singh *et al.*, 2005).

Twenty-five seeds of the native species (*A. nilotica, A. tortilis, C. cillaris* and *E. rupestris*) with four replications were sawn in each amended soil type in Petri dishes. Each Petri dish was sprayed with distilled water to maintain the moisture. Germination count was done at two days interval until no new seed germination observed for two consecutive counts and root and shoot length was recorded at the end of the experiment.

3.5.3 Soil Bioassay

Soil at a depth of about one inch was collected under *P. juliflora* canopy soil. Soil was also collected from some distance outside the *P. juliflora* canopy. This second sample served as a control. All soil samples were sieved through a 5 mm sieve to remove large clods of dirt, roots and other vegetative materials. Each petri-dish was filled with 40 g of soil and 25 seeds of specified native species (*A. nilotica, A. tortilis, C. cillaris* and *E. rupestris*). Each treatment was replicated four times. Fourteen ml of

distilled water was added in each petri-dish. Distilled water was used to maintain moisture in the petri-dish. After germination occured the germination percentage was recorded (Hillman, 1997).

3.6 Statistical Analysis

Data was subjected to analysis of variance using SPSS 18.0 software program. Excel 2007, one way ANOVA and Dunkan's multiple range test were used for the data analysis. All data were tested at $p<0.05$ level. Germination rate and mean germination capacity were shown using chart and bar graphs respectively.

4. Results and Discussions

4.1. Vegetation characteristics

Twenty seven species were recorded in the sampling plots (Table 1). Out of this thirteen are trees and shrubs and the rest fourteen are herbs. 9 species were observed in the riverine plot, where as 8 in swamp, 12 species in *Acacia* woodland respectively. Among these species *P. juliflora* was recorded in all plots. Its density was also the highest in the area (Table 2). That is *P. juliflora* invaded the whole habitat types in the area (Table 1). The number of species recorded in open *Acacia* woodlands was few (Table1). This is due to the relatively high density of *P. juliflora* is associated with fewer number of other plant species (El-Keblawy and Al- Rawai, 2007). *P. juliflora* has a negative impact on plant diversity (Singh *et al.,* 2008). Along with *P. juliflora, A. tortilis* was common in Open *Acacia* woodlands, *A. nilotica* in riverine, *Typha domingenesis* and *Sporobulus spicatus* in swamp areas.

Grasses were recorded only in swamps. No grass species and only a small number of herb species were recorded in *P. juliflora* invaded lands (Table 1). *P. juliflora* was invading all the habitat types observed in the area and affecting the *Acacia* woodlands more than the others, and changing to *P. juliflora* dominated shrub lands (Table 1). Information obtained from the elderly members of the community shows that the *Acacia* woodlands had been covered with forage grasses before invasion by the exotic *P. juliflora.* Now, these valuable forage grass species have not been observed at *P. juliflora* dominated lands (Table 1). These forage grasses were very important feed for their livestock and goats for pastoralist community in the area. Due to lack of sufficient grass species to their animals (cattle, goats and camels), the community is experiencing serious food shortage. As a result the pastoralist people in the area are forced to evacuate their original land in search of forage grasses (Shetie Gatew, 2008).

According to Sebsebe Demissew and Friis (2009) the area is categorized under *Acacia-Commiphora* woodland vegetation type. This vegetation type in the area is being changed into *P. juliflora* dominated shrub land. From field observation and information from the elderly indicated that open areas that were range and farm lands previously are now being invaded by *P. juliflora* much higher than areas alreadycovered with vegetation. This may possibly be due to the fact that open areas are highly prone for invasion by alien species (Ruijven *et al.,* 2003). The area coverage of *P. juliflora* was increasing from 5.45% in 1986 to 6.75% in 2001 with an average of 0.08% per year (Shetie Gatew, 2008). Since its invasion 20 years ago, *P. juliflora* has been invading almost the whole land use types in the study areas (Shetie Gatew, 2008). However the extent and severity of invasion differ from one land use

Table 1. Trees, shrubs and herbs recorded in the study areas.

No	Species Name	Family Name	Vernacular Name	Vegetation Types			
				Riv	Ma	Ac-f	Ac- sl
1	*Acacia mellifera* (Vahl) Benth.	FABACEAE	Mekearto				x
2	*Acacia nilotica* (L.) Willd.ex Del.	FABACEAE	Keselto	x			
3	*Acacia senegal* (L.) Willd.	FABACEAE	Adadoita			x	x
4	*Acacia tortilis* (Forssk.) Hayne	FABACEAE	Eebto			x	
5	*Aerva javanica* (Burm.f.) Schultes	AMARANTHACEAE	Oliya				x
6	*Argemone mexicana* L.	PAPAERACEAE	NF	x			
7	*Cadaba rotundifolia* Forssk.	CAPARIDACEAE	Erengele			x	
8	*Cenchrus cillaris* L.	POACEAE	Serdo		x		
9	*Crotalaria albicaulis* Franch	FABACEAE	Oklina				x
10	*Cryptostegia gradiflorar* Roxb. ex R. Br.	ASCLEPIADACEAE	Halimero	x			
11	*Dactyloctenium aegypticum* (L.) Willd.	POACEAE	Derema		x		
12	*Dactyloctenium scindicum* Boiss.	POACEAE	Afaramole		x		
13	*Discopodium penninervium* Hochst.	SOLONEACE	Gerbado				x
14	*Glinus lotoides* L.	MORAGINACEAE	Eludibi	x			
15	*Grewia tenax* (Forssk.) Fiori	MOLLUGINACEAE	Hidayito			x	
16	*Hildebrandtia africana* Vatke	CONVOLVULACEAE	Boboa				x
17	*Ipomoea aquatica* Forssk.	CONVOLVULACEAE	Hanterba		x		
18	*Nicotina glauca* Graham	SOLONEACE	Yorik	x			
19	*Parthenium hysterophorous* L.	ASTERACEAE	NF	x			
20	*Persicaria glabra* (Willd.) Gomez de la Maza	POLYGONACEAE	NF	x			
21	*Persicaria senegalensis* (Meisn.) Sojak	POLYGONACEAE	Weima	x			
22	*Prosopis juliflora* (Sw.) DC.	FABACEAE	Weyane	x	x	x	x
23	*Salvadora persica* L.	SALVADERACEA	Idayito				x
24	*Seddera bagshawei* Rendle	CONVOLVULACEAE	Riba				x
25	*Sporobolus pyramidallis* P.Beauv.	POACEAE	Hamilto		x		
26	*Sprobolus spicatus* (Vahl) Kunth	POACEAE	Hamhem		x		
27	*Typha domingenesis* Pers.	TYPHACEAE	Fila		x		

Riv = Riverine, Ma = Marshy, Ac- f.= Flat *Acacia* woodland, Ac- sl = Sloppy *Acacia* woodland .

Table 2. Density of trees, shrubs and herbs recorded in the study area.

No	Species Name	Density (ind. / ha)
1	*Acacia mellifera*	6
2	*Acacia nilotica*	6
3	*Acacia senegal*	263
4	*Acacia tortilis*	75
5	*Aerva javanica*	13
6	*Argemone mexicana*	281
7	*Cadaba rotundifolia*	63
8	*Crotalaria albicaulis*	38
9	*Cryptostegia gradiflora*	106
10	*Discopodium penninervium*	131
11	*Glinus lotoides*	625
12	*Grewia tenax*	6
13	*Hildebrandtia africana*	13
14	*Ipomoea aquatica*	38
15	*Nicotina glauca*	113
16	*Parthenium hysterophorus*	19
17	*Persicaria glabra*	69
18	*Persicaria senegalensis*	69
19	*Prosopis juliflora*	2231
20	*Salvadora persica*	200
21	*Seddera bagshawei*	375

type to another. The plant highly encroached to the *Acacia* woodland (Shetie Gatew, 2008). This may be due to the fact that it is highly coppicing (Hailu Shiferaw *et al*., 2004). When the local people cut the plant for fire wood and charcoal, a number of coppices arise from a single shoot. Thus cutting down of the tree might lead to its expansion.

When *P. juliflora* grows together with *Acacia* species, it out-competes and replaces the native *Acacia* species from the area. Livestock, camels and goats also played a significant role in spreading of *P. juliflora* via their feaces (Hailu Shiferaw *et al*., 2004) by carrying seeds to different areas.

Areas covered by swamp vegetation were also invaded by *P. juliflora*. Since root of this tree species can reach up to the water table, it can use all of the water and out compete and replace other surrounding species (Hailu Shiferaw *et al*., 2004). When the density of *P. juliflora* is increasing in the swamps, these areas will dry out and also with reduced plant diversity.

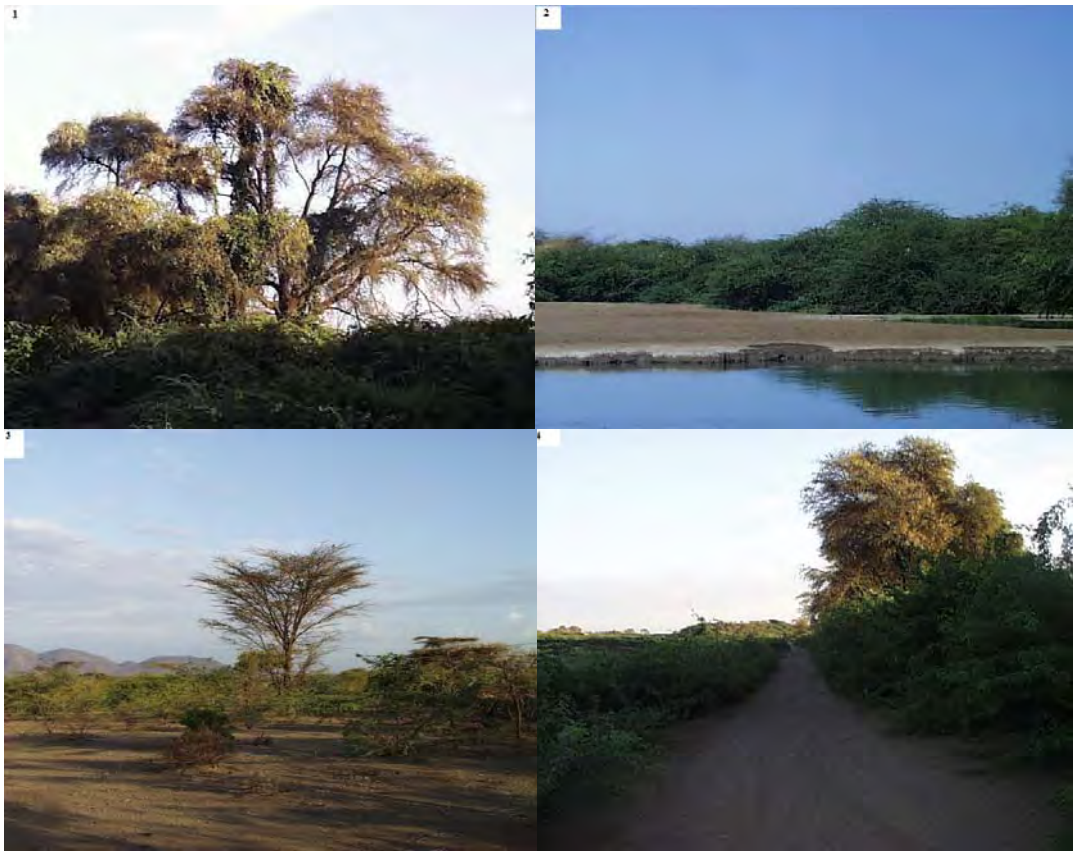


Figure 4. Invasion of the different habitat types of the area by *P. juliflora*: riverine (1), swamp (2) and open *Acacia* woodland (3 and 4) respectively. *Photo Samuel Getachew.*

4.2. Canopy characteristics

P. juliflora starts branching close to the ground than the other two tree species. While the branches of *A. nilotica* start further away from the ground than *A. tortilis* and *P. juliflora*. This made under canopy seedlings establishment difficult as a result of a physical barrier created by lower branches. Sunlight that may reach the ground is low as a result of interference with light from above and side directions. This results in the death of under story vegetations.

The branch angle of *P. juliflora* is not different from *A. nilotica´s* while it is less than *A. tortilis´s*. Rather than rising up of each branch to form a dense crown at the top like many Acacia species do, *P. juliflora* branches stretch out to side ways. This make branches of adjacent trees of *P. juliflora* intercept each other and hence its patch formation nature.

Canopy diameter of *P. juliflora* is less than the others. While its canopy closure is not significantly different from *A. tortilis* and *A. nilotica* but it is still greater than both (Table 3). This relatively high canopy closure resulted in dense canopy under *P. juliflora* and hence fewer light reaching to the ground.

Table 3. Mean growth variables of trees and their effects on canopy closure.

Parameters	Species			F values	ANOVA result
	P. juliflora	*A. tortilis*	*A.nilotica*		
Height to the first branch (m)	0.0532 [c]	0.0948[b]	2.5412 [a]	68.2	0.001
	± 0.12469	± 0.81590	± 1.68377		
Canopy diameter (m)	4.6400[c]	7.9020[b]	20.8900[a]	261.596	0.000
	± 1.01499	± 2.89274	± 5.74243		
Branch angle	53.9340[b]	62.0360[a]	54.7340[b]	9.393	0.000
	± 8.96289	±10.91265	± 10.90451		
Canopy closure (%)	58.2760[a]	55.5620 [a]	55.6250[a]	0.39	0.680
	± 17.25066	± 14.64148	± 20.55040		

The same letters are not significantly differ (P<0.05) from each other (Duncan's multiple range test).

P juliflora forms a microclimate with low temperature, low-light and high humidity that resulted in the death of under canopy vegetations (Hobbs and Mooney, 1986). This may be one of the reasons for few plant diversity observed under the *P. juliflora* fields (Singh *et al.*, 2008).

There is evidence that limited crown spread and height might allow high photosynthetically active radiation to reach the ground (Singh *et al,*. 2008). Thus although the crown diameter and height of *P. juliflora* are smaller than the other dominant study tree species (*A. nilotica* and *A. tortilis*), *P. juliflora* forms patches of vegetation and its dense evergreen leaves throughout the year resuling in a dense canopy that limits the amount of sunlight reaching the ground (Singh *et al*., 2008). The other dominant trees (*A. nilotica* and *A. tortilis*) form high crown diameter with high canopy closure. But since they are scattered in the area, light may reach the ground from above and from the side. The depressive effect of *P. juliflora* canopy in the abundance of annuals is more than perennials (EL-Keblawy and Al-Rawai, 2007). The seedlings of most annuals and perennials had not been seen except its own in the field. This may be attributed to the allelopathic nature of *P. juliflora* that hinder other species seedlings from emergence and its' shade effects (EL-Keblawy and Al-Rawai 2007). The ability of seeds of *P. juliflra* to tolerate the allelopathic substances and grow underneath their canopies increase poses more challenges due to the invasive ability of the species. EL-Keblawy and Al-Rawai (2007) also reached the same conclusion in that large and medium sized individuals of *P. juliflora* significantly reduced the number of species and density under canopy compared to outside canopy.

4.3. Allelopathic effects of *P. juliflora*

4.3.1 Germination

As compared to the control seed germination of *A. nilotica* was not affected by all treatment types of leaf, bark and root extracts (Table 4). *A. tortilis* seeds were not inhibited by all concentrations of the different treatment types. Aqueous extracts of

Table 4. Results from the germination experiment of *A. nilotica, A. tortilis, C. cillaris* and *E. rupestris* subjected to different treatments.

Species	Treatments	Concentrations (%)						
		0	0.5	0.8	1	2	6	LSD (0.05)
A. nilotica	Leaf	23.5 ± 1.732	23 ± 1.633 [a]	24.25 ± 0.500[a]	23.75 ± 0.957 [a]	23.5 ± 1.000[a]	22 ± 2.646[a]	0.211
	Bark	23.5 ± 1.732	23.5 ± 1.291[a]	23.5 ± 1.291[a]	24 ± 1.414[a]	22 ± 0.816[a]	23.75 ± 0.957[a]	0.351
	Root	23.5 ± 1.732	22.25 ± 2.062 [a]	18.5 ± 4.123[a]	21.25 ± 2.754 [a]	20 ± 1.414[a]	20.5 ± 1.000[a]	0.099
A. tortilis	Leaf	23 ± 1.414	24.5 ± 0.577[a]	21.75 ± 2.500[a]	24 ± 1.414[a]	23 ± 0.816 [a]	23.25 ± 0.500[a]	0.148
	Bark	23 ± 1.414	23 ± 0.816[a]	24.25± 0.500[a]	24 ± 0.816 [a]	24.25± 0.957[a]	24 ± 0.816[a]	0.024
	Root	23 ± 1.414	23.5 ± 1.000[a]	24.25 ± 0.500[a]	23 ± 1.414[a]	24 ± 1.414[a]	21.75 ± 1.258[a]	0.686
C. cillaris	Leaf	10 ± 2.449	6.75± 0.957[b]	6.25 ± 1.893[b]	6 ± 1.826[b]	2 ± 2.160[b]	0[b]	0.000
	Bark	10 ± 2.449	11.75 ± 4.193[a]	13.25 ± 2.630[a]	13 ± 3.742 [a]	14.75 ± 1.893[b]	6.5 ± 3.416[a]	0.023
	Root	10 ± 2.449	6.75 ± 3.594[a]	7.75 ± 3.500[a]	9.5 ± 3.317[a]	7.25 ± 0.500[a]	3.75 ± 3.096[b]	0.087
E. rupesteris	Leaf	17.75 ± 1.708	14.5 ± 1.000[b]	11.75 ± 1.708[b]	10.5 ± 1.915[b]	8.25 ± 2.500[b]	0[b]	0.000
	Bark	17.75 ±1.708	15.75 ± 4.787[a]	22.25 ± 3.202[a]	18 ± 4.830[a]	15.75 ± 3.096[a]	13.25 ± 3.096[b]	0.047
	Root	17.75 ± 1.708	13.25 ± 3.304[b]	9.75 ± 1.258[b]	9.25 ± 3.304[b]	7.75 ± 3.403[b]	7.5 ± 4.041[b]	0.001

a, not significantly different; b, significantly different ($P<0.05$) from controls (Duncan's multiple range test).

leaf of *P. juliflora* exhibited a significant inhibition on seed germination of *C. cillaris* at all concentrations (Table 4). Bark facilitate seed germination of *C. cillaris* at small concentrations and significantly facilitate germination at 2% as compared to the control while when the concentration increased above 2%, germination declined but not significantly. Root extract exhibited significant inhibition at 6% on *C. cillaris* seed germination (Table 4). Leaf and root extracts significantly inhibited seed germination of *E. rupestris* at all concentrations. But bark treatment at all concentrations did not affect seed germination of *E. rupesteris*.

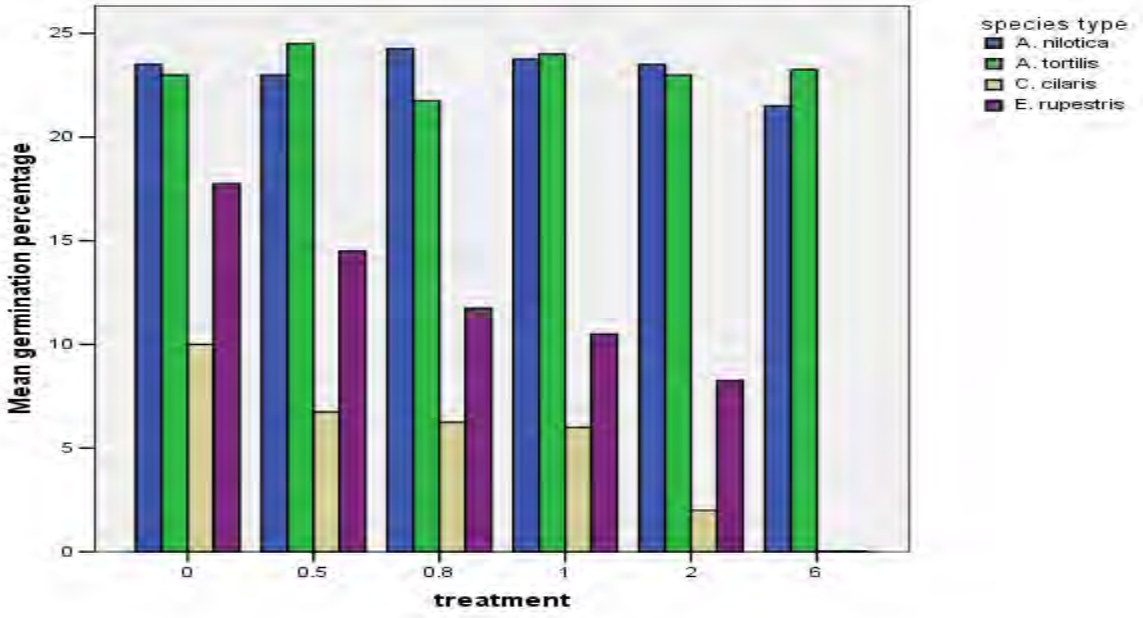
Inhibitions of seed germination especially the grasses and seedling growth of all study species by leaf and root extracts at higher concentrations indicate *P. juliflora* release growth retarding substances. Leaves seem to have the highest amount of inhibitory compounds than roots. It was also observed that germination of seeds of the dominant tree species not affected more by the allelochemical compounds of *P. juliflora* while grasses were highly affected. This result also supports results found from other allelopathic studies of *P. juliflora* and information from local people. Information from elderly indicated that the areas that are now invaded by the invasive *P. juliflora* had been covered with grasses. After invasion of the areas by *P. juliflora,* these valuable grass species which are very important for the pastoralist as a forage species for their cattle, goats and camels have disappeared.

There are also other evidences about allelopathic nature of *P. juliflora*. Seed germination of Bermuda grass (*Cynodon dactylon)* was greatly reduced by aqueous extracts of leaf of *P. juliflora* (Al- Humaid and Warrag, 1998). Autotoxicity of *P. juliflora* was also investigated and self-inhibition of seed germination observed except

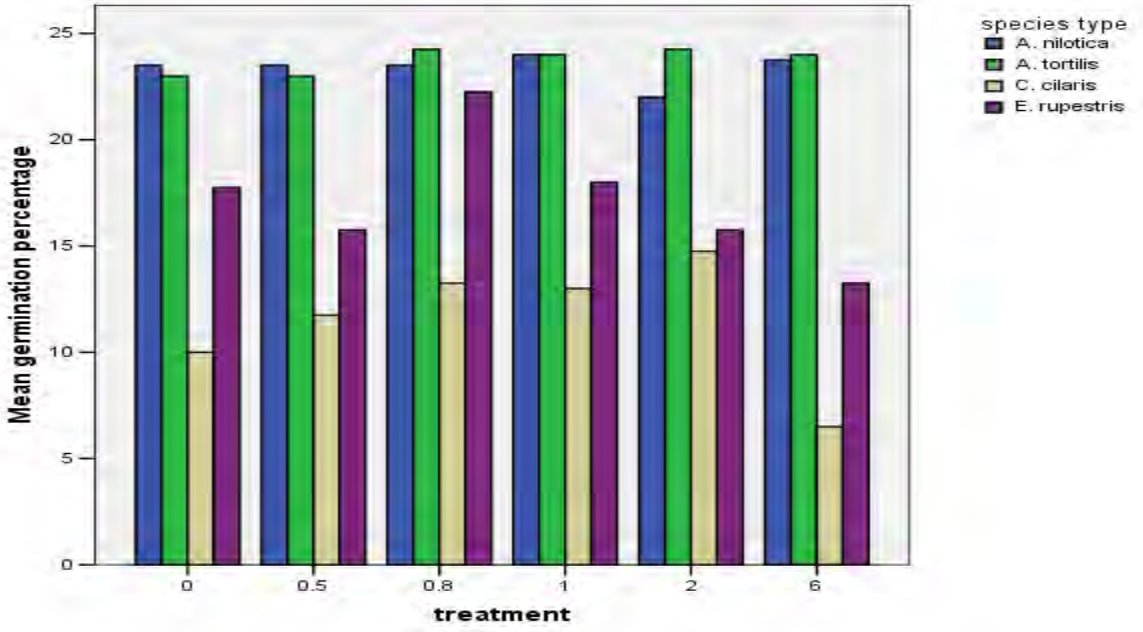
at least leaf concentration (Warrag, 1994). Aqueous extracts from under canopy soil and from different parts of *P. juliflora* inhibited germination and early seedling growth of various cultivars of *Zea mays, Triticum aestivum* and *Albizia lebbeck* (Noor *et al.,* 1995). In pot studies examining the allelopathic effect of *P. juliflora* leaf litter, (Chellamuthu *et al.,* 1997) indicated that germination of black gram (*Vigna mungo*), sorgum (*Sorghum bicolar*) and *P. juliflora* was significantly reduced with the maximum reduction occurring at 2% incorporation of *P. juliflora* leaf litter. Therefore *P. juliflora* affects the vegetation found in the invaded lands especially annuals.

The allelopathic effect of *P. juliflora* leaf litter is due to the presence of some phenolic compounds (Chellamuthu *et al.,* 1997). Nakano *et al.* (2001) suggested that L-tryptophan may play an important role in the allelopathy of *P. juliflora* leaves. Plant growth inhibitory alkaloids were also isolated from the extract of *P. juliflora* leaves (Nakano *et al.,* 2004).

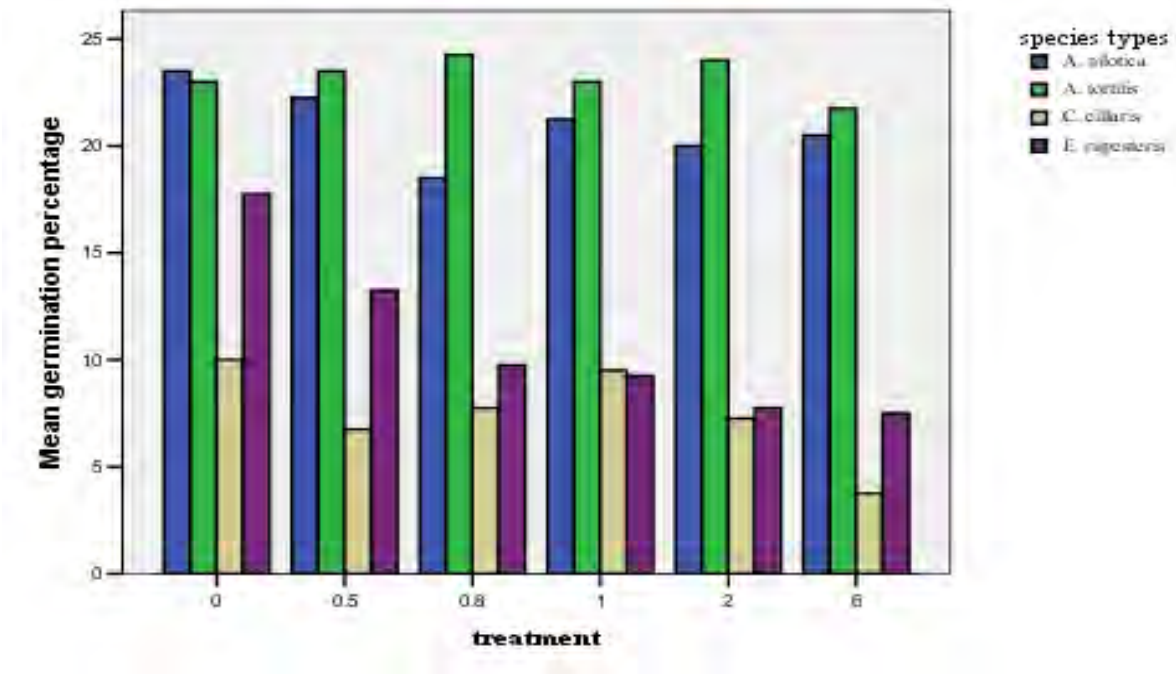
(a)


Mean germination percentage
25
20
15
10
5
0
0
0.5
0.8
1
2
6
treatment
species type
A. nilotica
A. tortilis
C. cilaris
E. rupestris

(b)


Mean germination percentage
25
20
15
10
5
0
0
0.5
0.8
1
2
6
treatment
species type
A. nilotica
A. tortilis
C. cilaris
E. rupestris

(c)



(d)

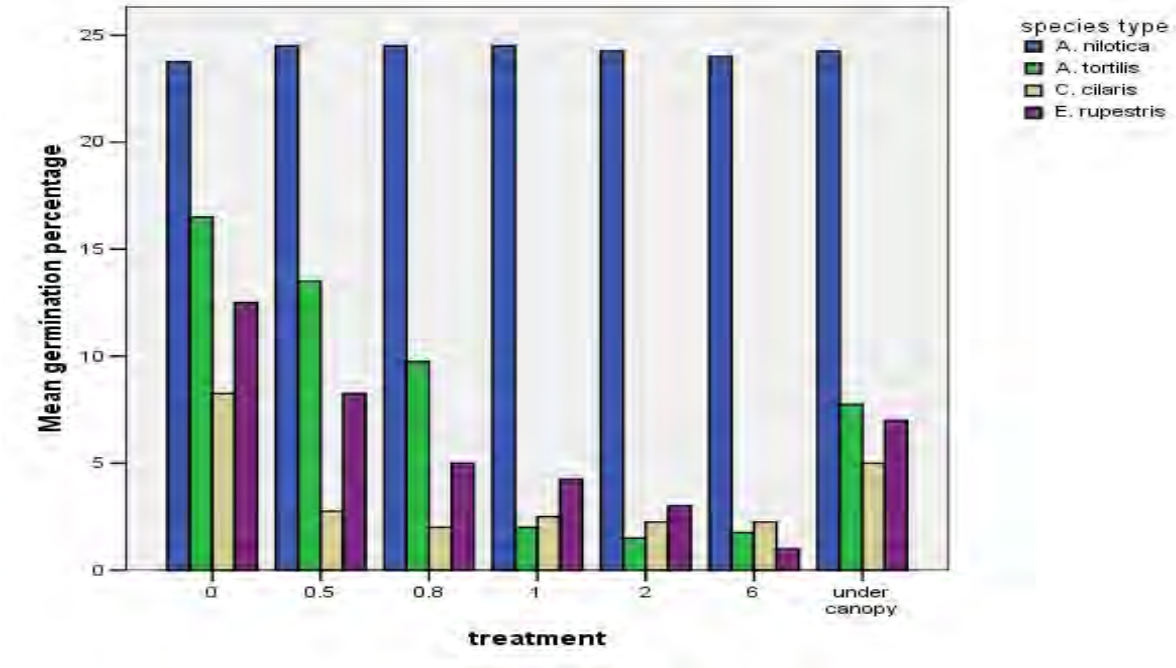


Figure 5. The effects of different concentrations of aqueous extracts of *P. juliflora* obtained from leaf (a), bark (b), root (c) and residues (d) on seed germination of the studied plant species.

4.3.2 Germination Rate

All aqueous extract treatments (leaf, bark and root) speeded up the amount of seed germinated each day for *A. nilotica* and *A. tortilis* when compared to the control in the first few days while the rate of germination was retarded for the grasses: *C. cillaris* and *E. rupesteris* by all treatments and concentrations levels.

It was observed that all leaf treatment lower the germination speed of *C. cillaris*. Bark and root treatments also delayed germination of *C. cillaris* initially. All of the treatments at all concentration levels slow down the germination speed of *E. rupestris*.

The effect of leaf aqueous extract of *P. juliflora* on germination rate of *Cynodon dactylon* (Al- Humaid and Warrag, 1998) had been studied. The germination rate of *Cynodon dactylon* was reduced by *P. juliflora* leaf extract when compared to the control.

In general, all aqueous extract treatments (leaf, bark and root) facilitated the amount of seed germination each day for the two tree species examined for the first few days. While it seemed that germination rate of both grass species examined was reduced by treatments at all concentrations.

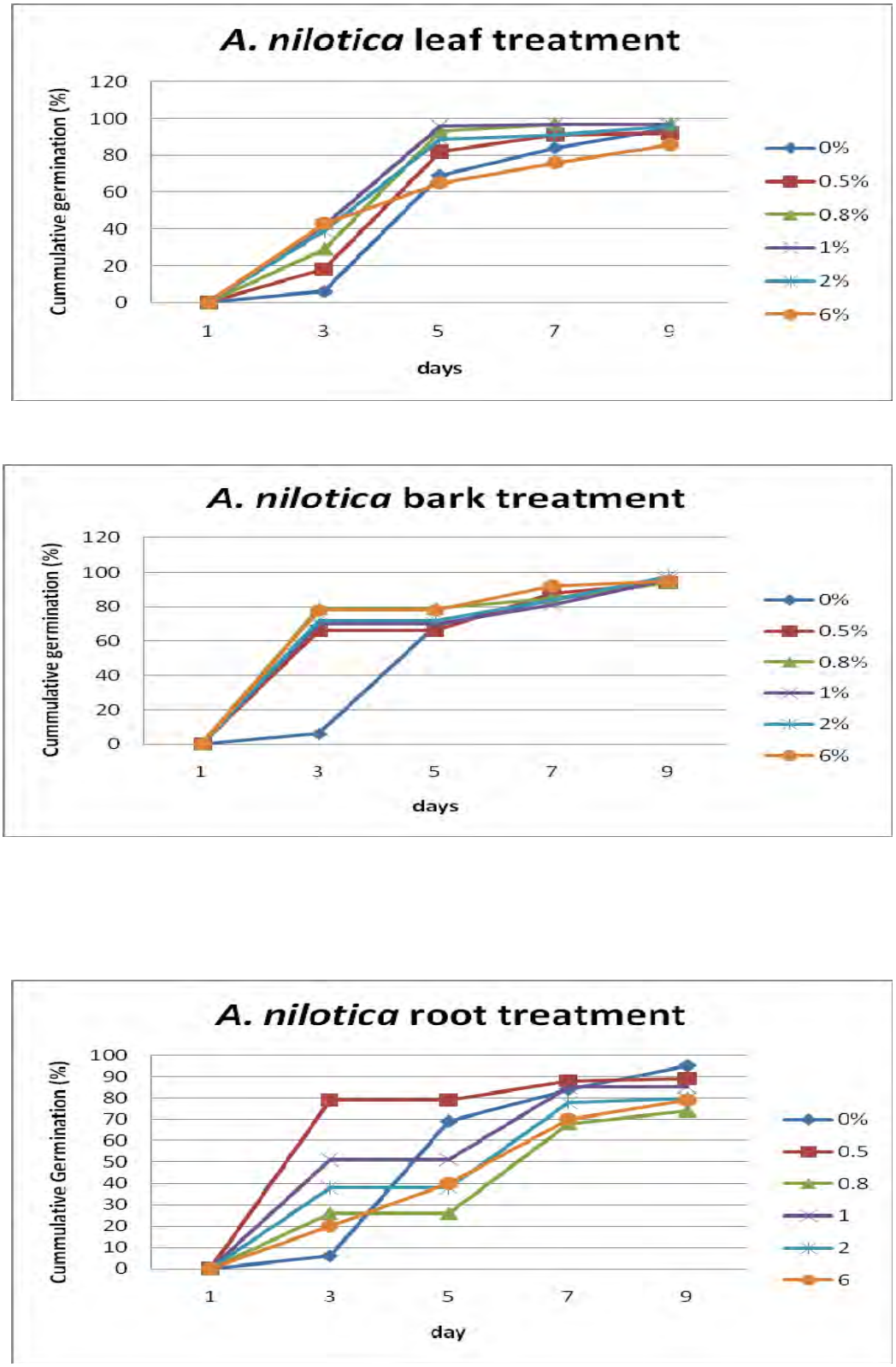
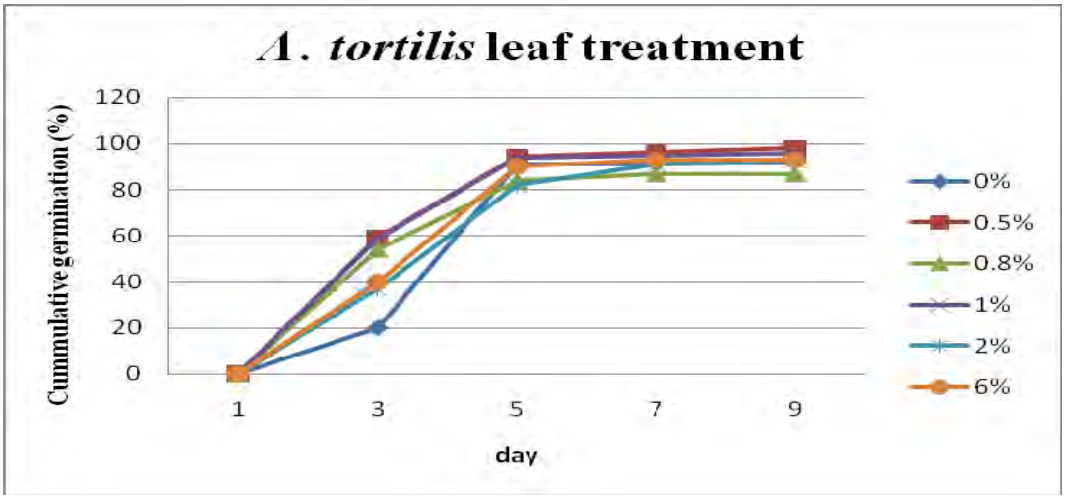
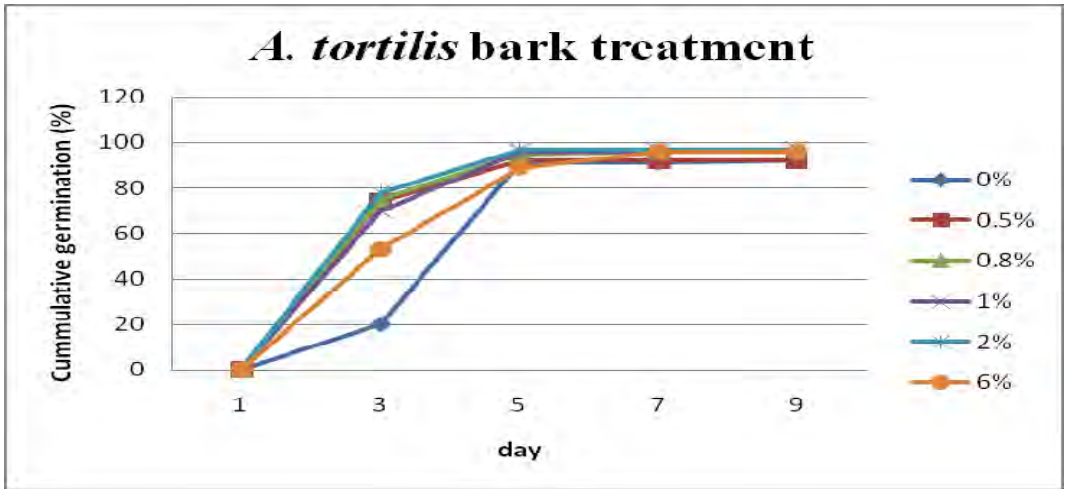


Figure 6. Rate of seed germination of *A. nilotica* under different concentrations of leaf, bark and root aqueous extract of *P. juliflora.*





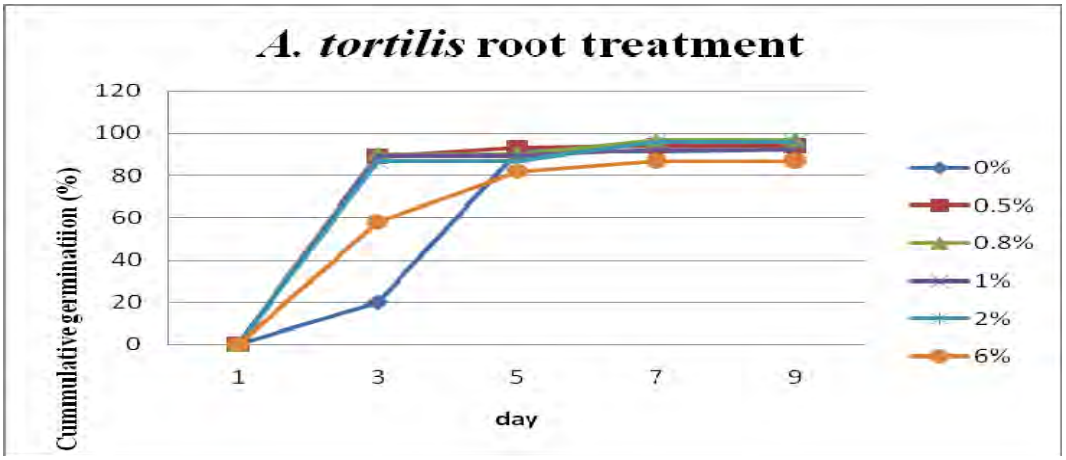


Figure 7. Rate of seed germination of *A. tortilis* under different concentrations of leaf, bark and root aqueous extract of *P. juliflora.*

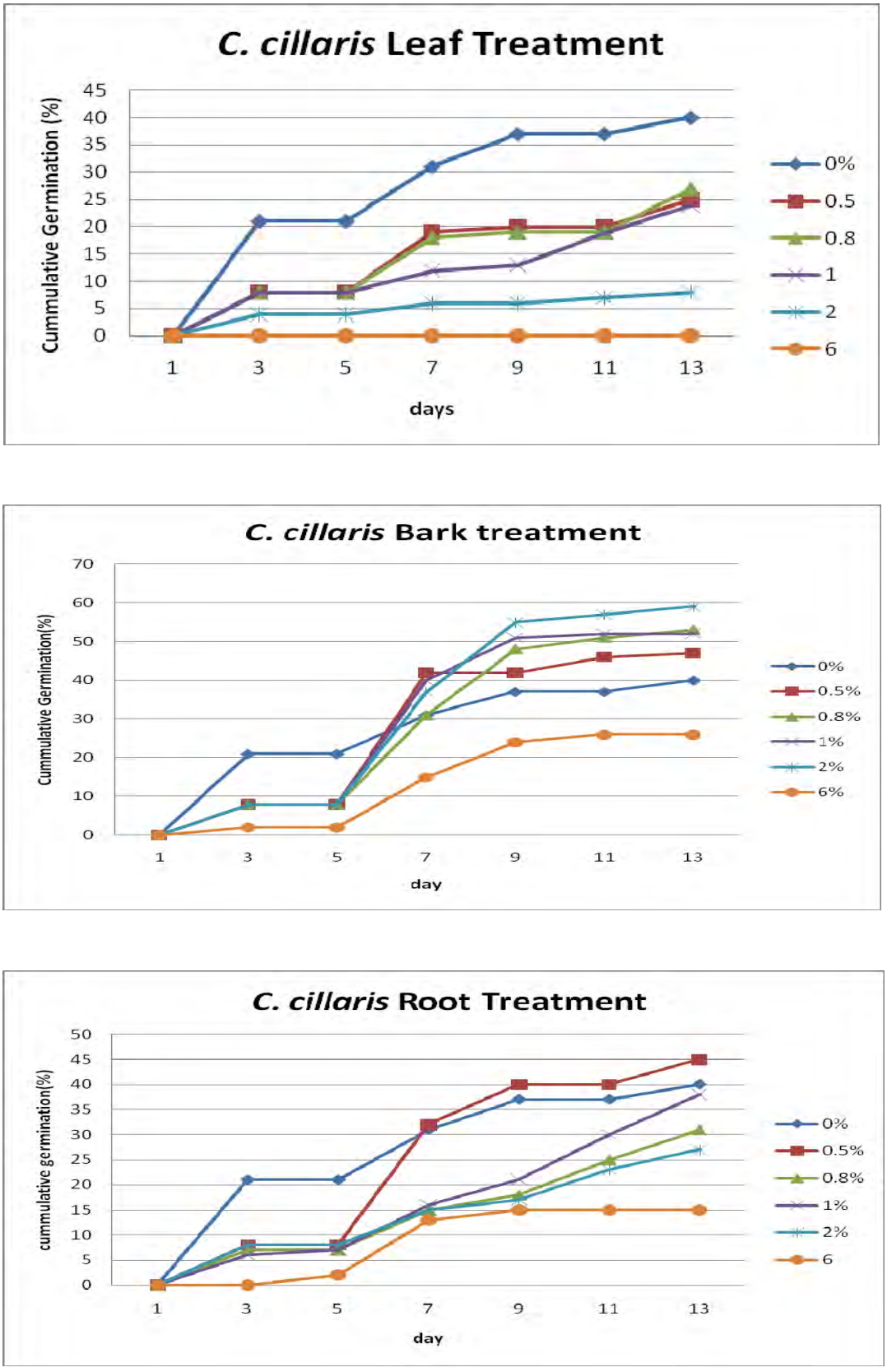


Figure 8. Rate of seed germination of *C. cillaris* under different concentrations of leaf, bark and root aqueous extract of *P. juliflora*.

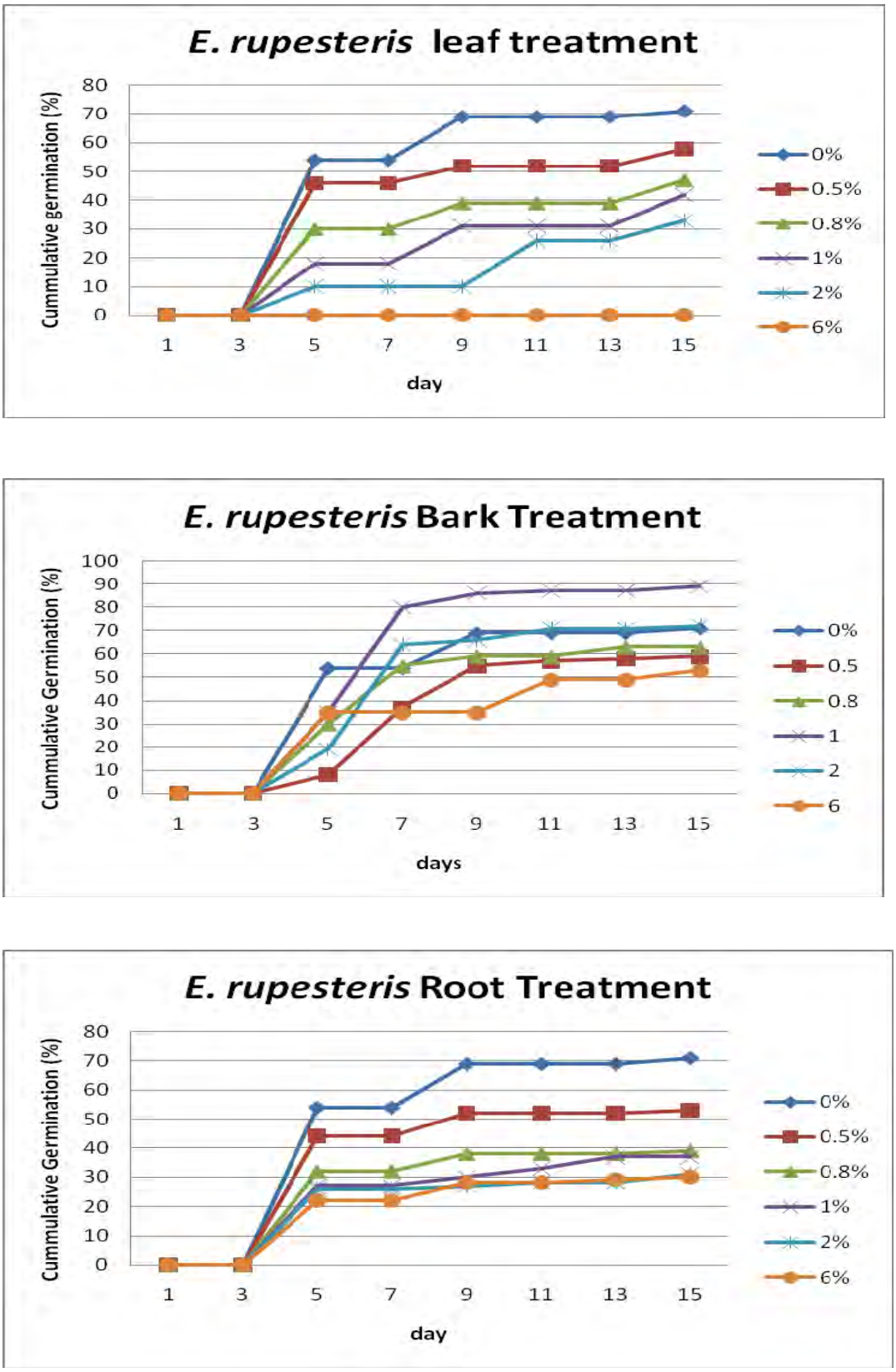


Figure 9. Rate of seed germination of *E. rupesteris* under different concentrations of leaf, bark and root aqueous extracts of *P. juliflora.*

4.3.3 Seedling Growth

There was a significant difference ($P < 0.05$) among treatment levels of *P. juliflora* extracts in influencing shoot and root length of *A. nilotica*. When compared with the control, except the aqueous extracts from leaves which had a deleterious effect on shoot length at high concentration, those extracts from bark at high concentration and root at all concentrations stimulated shoot growth of *A. nilotica*. Shoot growth was retarded by leaf extracts at 2 and 6% concentrations, while it was stimulated by bark at 6% and by all root extract concentrations (Table 5). Root growth was retarded in all concentrations of leaf aqueous extracts and in all concentrations of root extracts except at 0.5% while it was stimulated by bark extracts at higher concentration levels for *A. nilotica* (Table 6). Inhibition of shoot growth was at higher concentrations while root growth was by all concentrations of leaf and bark extracts. This shows inhibitory effect was high on root growth than shoot growth.

Shoot growth of *A. tortilis* was inhibited by leaf extracts at higher concentrations but not significantly while it was stimulated by bark extracts except at 0.5% and by root extracts at small concentrations (0.8 and 1%). However it was inhibited by root extracts at high concentrations (2% and 6%) for *A. tortilis* (Table 5). Leaf extracts had been inhibited root length of *A. tortilis* but not significantly while root length of *A. tortilis* was stimulated by bark and root aqueous extracts at low concentration (1%) and inhibited at high concentration but not significantly when compared to the control (Table 6). Inhibition was high on root growth than shoot growth by bark and root extracts.

Table 5. Shoot length (cm) for aqueous extracts of leaf, bark and root of *P. juliflora* of different concentrations

.

Species	Treatment type	Concentrations (%)						LSD (0.05)
		0	0.5	0.8	1	2	6	
A. nilotica	leaf	1.992 ± 1.1576	1.548 ± 0.8222[a]	1.944 ± 1.0038[a]	1.616 ± 1.6962[a]	1.416 ± 0.8764[b]	0.872 ± 0.5405[b]	0.004
	bark	1.992 ± 1.1576	2.000 ± 0.9695[a]	1.704 ± 0.9044[a]	2.015 ± 0.7956[a]	2.015 ± 0.9115[a]	2.744 ± 1.0532[b]	0.010
	root	1.992 ± 1.1576	2.996 ± 0.7508[b]	2.668 ± 0.5460[b]	2.736 ± 0.8036[b]	2.904 ± 1.0593[b]	2.594 ± 0.6786[b]	0.001
A. tortilis	leaf	2.080 ± 0.4958	2.092 ± 0.4242[a]	2.092 ± 0.7675[a]	2.212 ± 0.4576[a]	2.312 ± 0.5819[a]	1.948 ± 0.6179[a]	0.310
	bark	2.080 ± 0.4958	1.872 ± 0.5504[a]	2.523 ± 0.5984[b]	2.776 ± 0.5101[b]	3.052 ± 0.8501[b]	2.524 ± 0.4503[b]	0.000
	root	2.080 ± 0.4958	2.056 ± 0.6535[a]	2.196 ± 0.6535[b]	2.516 ± 0.5728[b]	1.728 ± 0.5899[b]	1.384 ± 0.5161[b]	0.000
C. cillaris	leaf	3.420 ± 0.9937	2.921 ± 0.1528[a]	3.175 ± 0.1712[a]	2.881 ± 0.6988[a]	2.800 ± 0.1414[a]	0[b]	0.000
	bark	3.420 ± 0.9937	3.764 ± 1.0563[a]	3.788 ± 0.5630[a]	3.800 ±0.9500[a]	4.084 ± 0.7883[b]	4.736 ± 1.0356[b]	0.000
	root	3.420 ± 0.9937	3.496 ± 1.1074[a]	2.059 ± 1.0350[b]	2.767 ± 1.2459[b]	2.453 ± 1.1463[b]	1.658 ± 0.6934[b]	0.000
E. rupesteris	leaf	3.152 ± 1.0092	2.084 ± 0.5669[b]	2.120 ± 0.7605[b]	1.975 ± 0.8188[b]	2.088 ± 0.6285[b]	0[b]	0.000
	bark	3.152 ± 1.0092	3.316 ± 0.1818[a]	3.440 ± 0.1607[a]	3.524 ± 1.5186[a]	4.808 ± 2.0646[b]	4.810 ± 1.0341[b]	0.000
	root	3.152 ± 1.0092	4.488 ± 1.3071[b]	4.172 ± 0.2132[b]	4.622 ± 1.2824[b]	3.963 ± 1.4655[b]	3.438 ± 0.1627[a]	0.000

a , not significantly different; b, significantly different (P<0.05) from controls (Duncan's multiple range test).

Table 6. Root length (cm) for aqueous extracts of leaf, bark and root of *P. juliflora* of different concentrations.

Species	Treatment type	Concentrations (%)						LSD (0.05)
		0	0.5	0.8	1	2	6	
A. nilotica	leaf	2.916 ± 1.4868	2.068 ± 0.8778[b]	2.056 ± 0.9337[b]	2.032 ± 0.8915[b]	2.052 ± 0.6092[b]	2.020 ± 0.8874[b]	0.008
	Bark	2.916 ± 1.4868	3.420 ± 1.6047[a]	3.764 ± 1.4680[b]	3.888 ± 1.4131[b]	3.775 ± 1.2460[b]	4.188 ± 1.7145[b]	0.066
	Root	2.916 ± 1.4868	3.148 ± 1.2774[a]	2.280 ± 0.6000[b]	2.080 ± 0.7176[b]	2.108 ± 1.0177[b]	1.194 ± 0.7900[b]	0.000
A. tortilis	leaf	2.292 ± 0.8020	2.064 ± 1.0148[a]	1.932 ± 0.8630[a]	1.964 ± 0.6645[a]	1.924 ± 0.5562[a]	1.872 ± 0.8018[a]	0.469
	Bark	2.292 ± 0.8020	2.760 ± 0.9760[a]	2.755 ± 1.0294[a]	3.756 ± 1.8819[b]	2.516 ± 1.0363[a]	2.244 ± 0.6468[a]	0.000
	root	2.292 ± 0.8020	2.760 ± 0.9760[a]	2.755 ± 1.0294[a]	3.756 ± 1.8819[b]	2.516 ± 1.0363[a]	2.244 ± 0.6468[a]	0.000
C. cillaris	leaf	2.692 ± 1.2281	1.950 ± 1.1621[b]	1.667 ± 0.1497[b]	1.869 ± 0.8905[b]	1.143 ± 0.6268[b]	0[b]	0.000
	bark	2.692 ± 1.2281	2.636 ± 1.4038[a]	2.672 ± 1.0964[a]	2.256 ± 0.9950[a]	2.656 ± 1.1196[a]	0.628 ± 0.1242[b]	0.000
	root	2.692 ± 1.2281	2.688 ± 1.3343[a]	2.076 ± 1.0912[b]	2.071 ± 1.1087[b]	1.893 ± 0.1981[b]	0.892 ± 0.3175[b]	0.000
E. rupesteris	leaf	3.836 ± 0.8693	3.628 ± 0.1061[a]	3.764 ± 1.0099[a]	3.510 ± 0.0912[a]	3.504 ± 0.7926[a]	0[b]	0.000
	bark	3.836 ± 0.8693	4.064 ± 1.2086[a]	4.140 ± 1.6378[a]	3.400 ± 0.1384[b]	3.520 ± 1 .2865[b]	3.4 ± 0.1340[b]	0.000
	root	3.836 ± 0.8693	5.756 ± 1.7676[b]	5.056 ± 1.5484[b]	5.126 ± 1.2899[b]	3.063 ± 0.1610[b]	0.929 ± 0.5041[b]	0.000

a, not significantly different; b, significantly different (P<0.05) from controls (Duncan's multiple range test).

C. cillaris shoot growth was inhibited by leaf extracts but not significantly when compared with the control except at 6% leaf concentration. Shoot growth was stimulated by bark aqueous extracts at high concentrations (2 and 6%) but inhibited by root extracts at all concentration levels except at 0.5% concentration level. Root growth of *C. cillaris* was retarded by: leaf aqueous extracts, 6% bark and 0.8, 1, 2 and 6% root extracts.

Shoot growth of *E. rupestris* was retarded by leaf extracts. All bark concentrations facilitated shoot growth of *E. rupestris* but significantly at 6%. Shoot growth was also stimulated by root extracts at small concentrations and not affected at 6% concentration level. Root growth of *E. rupestris* was inhibited by leaf extracts at higher concentrations (6%) while it was not affected by bark extracts and stimulated by root extracts at small concentrations (≤ 2%) but inhibited at higher concentrations (6%).

Leaf aqueous extracts of *P. juliflora* retarded root and shoot growth of *Cynodon dactylon* (Al- Humaid and Warrag, 1998), *P. juliflora* (Warrag, 1994) and *Lepidium sativum* (Nakano *et al*., 2004). In this study, it was observed that leaf extracts had an inhibitory effect on shoot-root length of the study species while bark and root had stimulatory effects at small concentrations, but root extracts had inhibitory effects at higher concentrations. Leaf seems to have high allelopathic compounds than root and bark and bark seems to have the least. This may be due to leaf being containing more allelo-compounds in number / amount. The effects are concentration dependent and species specific.

4.3.4 Residue amended and under canopy soil

Seed germination of *A. nilotica* was not affected by both residue amended with decaying plant parts and under canopy soil (Table 7). *A. nilotica* is also highly allelopathic (Al-Wakeel, 2007). This might be the reason why its germination was not been affected by allelopathy of *P. juliflora*. Seed of *A. tortilis* was inhibited from germination by 1, 2 and 6% plant residues of *P. juliflora* collected concentration and by under canopy soil (Table 7). This may be due to plant residues and under canopy soil contain much allelo-compounds than does each organ parts (leaves, stems and barks). All concentrations of residue amended soil and under canopy soil inhibited germination of *C. cillaris* seeds. *E. rupestris* seed germination was also inhibited by all concentration of residue amended soil except at 0.5% and by under canopy soil (Table 7). Percent of inhibition was concentration related, i.e. inhibition increased as concentration increased. From this it was observed that under canopy soil had inhibitory compounds when compared to the control (soil from outside fields). The amended and under canopy soil experiment revealed the field situation. Slow decomposition and heavy accumulation of leaf litter below *P. juliflora* resulted in accumulation of toxic substances in the soil layers, inhibiting the growth of other species. That is the reason why little vegetation is usually observed under *P. juliflora* canopy.

Table 7. Results of germination percentage from residue amended and under canopy soil experiment.

Species	Concentration (%)							LSD (0.05)
	0	0.5	0.8	1	2	6	under canopy soil	
A. nilotica	23.75 ± 1.5	24.5 ± 1.000 [a]	24.5 ± 1.000 [a]	24.5 ± 0.577 [a]	24.25 ± 0.957 [a]	24 ± 0.816 [a]	24.25 ± 0.500 [a]	0.894
A. tortilis	16.5 ± 5.686	13.5 ± 4.041 [a]	9.75 ± 8.5 [a]	2 ± 1.414 [b]	1.5 ± 1.291 [b]	1.75 ± 1.500 [b]	7.75 ± 8.342 [b]	0.002
C. cillaris	8.25 ± 2.630	2.75 ± 2.062 [b]	2 ± 1.414 [b]	2.5 ± 0.577 [b]	2.25 ± 1.500 [b]	2.25 ± 1.708 [b]	5 ± 1.155 [b]	0.000
E. rupesteris	12.5 ± 3.109	8.25 ± 2.872 [a]	5 ± 2.000 [b]	4.25 ± 1.500 [b]	3 ± 0.816 [b]	1 ± 0.816 [b]	7 ± 7.572 [b]	0.003

a, not significantly different; b, significantly different ($P<0.05$) from controls (Duncan's multiple range test).

5. CONCLUSIONS AND RECOMMENDATIONS

The occurrence of *P. juliflora* in all habitat types in the area studied and its high population number indicate it is on invading the study area. Low plant diversity and its high density show it's highly competitiveness and on threatening other plant species in the area. Even if its canopy closure is not significantly different from other studied plants, its dense thicket formation and branches start near to the ground may block sunlight and wind. As a result, little plant diversity was observed under the canopy of *P. juliflora*. Generally, a significant inhibition of seed germination by leaf and root extract of *P. juliflora* especially at higher concentration on grass species, facilitation of germination rate of the studied tree species in the beginning and retardation of germination speed of grasses by all the plant parts considered, inhibition of germination of all study species except *A. nilotica* by soil amended with decaying plant parts and under canopy soil, inhibition of shoot and root growth of the study plants by leaf extracts, facilitation of shoot and root growth of the study species by bark extract at lower concentrations and inhibition of shoot and root growth at higher of root extracts was observed. These indicate *P. juliflora* contains allelo-chemicals in its organ parts in various amounts and types. Leaves seem have greater inhibitory effects than roots and barks. Barks seem contain the least inhibitory compounds. The effect is also species specific. Allelochemicals release from *P. juliflora* various parts affect more on annuals (especially grasses) than perennials. From the under canopy soil experiment it was also observed that under canopy soil contains more allelochemicals that inhibit germination of other plant species especially grasses than outsides. Generally low plant diversity in *P. juliflora* invaded

areas was observed as a result of the combined effect of its allelochemicals and shade effects together with its extensive and deep rooted system.

Since *A. nilotica and A. tortilis* was not affected more by the allelopathy of *P.juliflora,* it is good to plant *A. nilotica* around rivers and water bodies and *A. tortili*s at open *Acacia* woodlands to control *P. juliflora* invasion and lessen the damage on the native plant species. Dissemination of seeds to various areas by the movement of cattle, goats and camels feces has been observed playing a major role in increasing the rate of expansion of the species invasion. Controlling movement of the livestock may play important role in preventing further invasion of new areas. Invasion can also be lessened by using crushed pods as a fodder for livestock. Irrigation channels play also a significant role in transporting the seeds to different areas including farming lands. Therefore removing *P. juliflora* trees found close to irrigation channels may decrease dissemination of seeds by water bodies and as a result decrease invasion rate.

6. REFERENCES

Abiyot Berhanu and Getachew Tesfaye (2006). The *Prosopis* dilemma, Impacts on dry land biodiversity and some controlling methods. *Journal of the Dry lands* **2:** 158-164.

Akobundu, I.O. (1987). *Weed Science in the Tropics: Principles and Practices.* John Wiley & Sons Ltd., London.

Al-Humaid, A.I. and Warrag, M.O. (1998) Allelopathic effects of mesquite (*Prosopis juliflora*) foliage on seed germination and seedling growth of Bermudagrass (*Cynodon dactylon). Journal of Arid Environ* **38:** 237–243

Al-Wakeel, S.A.M., Gabr, M.A., Hamid, A.A. and Abu-El-Soud, W.M.(2007). Allelopathic effects of A. nilotica leaf residues on *Pisum sativum* L. *Allelopathy J.* **19:** 2

Anaya, A.L., Pelayo-Benavides, H.R. (1997). Allelopathic potential of *Mirabilis jalapa* L. (Nyctaginaceae): Effects on germination, growth and cell division of some plants. *Allelopathy J.* **4:** 57–68.

Asfaw Hunde and Thulin, M. (1989). *Mimosoideae*. In: Hedberg, I. and Edwards, S. (eds.) Flora of Ethiopia: *Pittosporaceae* to *Araliaceae*, Vol. 3. Addis Ababa University, Addis Ababa and Uppsala University, Sweden.

Calera, M.R., Mata, R., Anaya, A.L., and Lotina-Hennsen, B. (1995). 5-O-BD-galactopyranosy lª7-methoxyª3ƒ4ƒdihydroxi-4-fenilcumarin, an inhibitor of photophosphorylation in spinach chloroplasts. *Photosynth Res.* **45:** 105–110.

Chaturvedi, A. N., Sharma S. C. Andsrivastava, R. (1988). Water consumption and biomass production of some forest tree species. *International Tree Crops Journal* **5:** 71-76.

Chellamuthu, V., Balasusbramanian, T.N., Rajarajan, A., and Palaniappan, S.N. (1997). Allelopathic influence of *Prosopis juliflora* (Swartz) DC. on field crops. *Allelopathy J*. **4:** 291–302.

Coder, K. D. (1999). Allelopathy in Trees. University of Georgia Daniel B. Warnell School of Forest Resources. Extension publication FOR99-004.

EARO and HDRA (2005). *Controlling the spread of Prosopis in Ethiopia by its utilisation*. Ethiopian Agricultural Research Organization (EARO) and Henry Doubleday Research Association (HDRA), Addis Ababa.

EL-Keblawy, A. and AL-Rawai, A. (2007). Impacts of the invasive exotic *Prosopis juliflora* (Sw.) DC. on the native flora and soils of the UAE. *Plant Ecol*. **190:** 23-25.

EL-Khatib, A.A., Hegazy, A.K., and Galal, H.K. (2004). Allelopathy in the rhizosphere and amended soil of *Chenopodium murale* L. *Weed Biology and Management* **4:** 35-42.

Felker, P., Cannell, G. H., Osborn, J. F., Clark, P. R. and Nash, P. (1983). Effects of irrigation on biomass production of 32 *Prosopis* (mesquite) accessions. *Experimental Agriculture* **19:**187-198.

Galindo, J.C.G., Hernandez, A., Dayan, F.E., Tellez, M.R., Macias, F.A., Paul, R.N., and Duke, S.O. (1999). Dehydrozaluzanin C, a natural sesquiterpenolide, causes rapid plasma membrane leakage. *Phytochemistry* **52:** 805–813.

GISP (2004). Africa invaded: The growing danger of invasive alien species. Global Invasive Species Program, Cape Town.

Gordon, D. R. (1998). Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida. *Ecol. Appl.* **8:** 975-89.

Hailu Shiferaw, Demel, T., Sileshi, N., and Fassil, A. (2004): Some biological characteristics that foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, north-eastern Ethiopia. *Journal of Arid Environ* **58:** 134-153.

Hillman, J.M. (1997). Potentially Allelopathic Effects of Poison Hemlock (*Conium maculatum*) on Native Plant Revegetation at Wilder Ranch State Park. [Online]. http://ucce.ucdavis.edu/freeform. Accessed 15, Nov 2008.

Hobbs, R. J. and Mooney, H. A. (1986). Community changes following shrub invasion of grassland. *Oecologica* **70:** 508-513.

Jacoby, P. and Ansley, R. J. (1991) Mesquite: classification, distribution, ecology and control. In: Noxious Range Weeds (*Eds.*) L. F. James, J. O. Evans, M. H. Ralphs and R. D. Child. West view Press, Boulder.

Jennings, S.B., Brown, N.D., and Sheil, D. (1999). Assessing forest canopies and under storey illumination: canopy closure, canopy cover and other measures. *Forestry* **72 (1):** 59–74.

Khan, D., Ahmad R., and Ismail, S. (1987). Germination, growth and ion regulation in *Prosopis juliflora* (Swartz) DC under saline conditions. *Pakistan Journal of Botany* **19:** 131- 138.

Korhonen, L., Korhonen, K.T., Routiainen, M., and Stenberg P. (2006). Estimation of Forest Canopy Cover: a comparison of Field Measurement Techniques. *Silva Fennica* **40 (4):** 577-588.

Lehman, M. E. and Blum, U. (1999). Evaluation of ferulic acid uptake as a measurement of allelochemical dose: Effective concentration. *J Chem Ecol*. **25:** 2585–2600.

Lowe, S., Browne, M., Boudjelas, S., and Poorter, M. D. (2004). *100 of the World's Worst Invasive Alien Species: A selection from the Global Invasive Species Database*: The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN).

Nakano, H., Fujii, Y., Suzuki, T., Yamada, K., Kosemura, S., Yamamura, S., and Hasegawa, K. (2001). A growth-inhibitory substance exuded from freeze-dried mesquite (*Prosopis juliflora* (Sw.) DC.) leaves. *Plant Growth Regul*. **33:** 165–168.

Nakano, H., Nakajima, E., Hiradate, S., Fujii, Y., Yamada, K., Shigemori, H., and Hasegawa. K. (2004). Growth inhibitory alkaloids from mesquite (*Prosopis juliflora* (Swartz.) DC. leaves. *Phytochemistry* **65:** 587–591.

Noor, M., Salam, U., and Khan, M.A. (1995). Allelopathic effects of *Prosopis juliflora* (Swartz). *J Arid Environ*. **31:** 83–90.

Panchal, Y. C. and Prabhakar-Shetty. (1977). Chemical control of *Prosopis juliflora* (Sw) DC. Paper No. 153. Program and Abstracts of Papers, Weed Science Conference, Delhi, India.

Pasiecznik, N. M., Felker, P., Harris, P. J. C., Harsh, L. N., Cruz, G., Tewari, J. C., Cadorer, K., and Maldonado, L.J. (2001). The *Prosopis juliflora-Prosopis pallida* Complex: A Monograph. pp.172. HADRA, Coventry.

Pasiecznik, N. M., Harris, P. J. C., and Smith, S. J. (2004). Identifying Tropical Prosopis Species: A Field Guide. pp. 36. HADRA, Coventry.

Politycka, B. (1998). Phenolics and the activities of phenylalanine ammonia-lyase, phenol-b-glucosyltransferase and b-glucosidase in cucumber roots as affected by phenolic allelochemicals. *Acta Physiol Plant*. **20:** 405–410.

Rafiqul Hoque, A.T.M., Ahmed, R., Uddin M.B., and Hossain M.K. (2003). Allelopathic Effect of Different Concentration of Water Extracts of *Acacia auriculiformis* Leaf on Some Initial Growth Parameters of Five Common Agricultural Crops . *Pakistan Journal of Agronomy* **2 (2):** 92-100.

Raghubanshi, A.L., Rai, L.C., Gaur, J.P., and Singh, J.S. (2005). Invasive plant species and biodiversity in India. *Current Science* **88(4):** 539-540.

Ruijven, J.A., Gerlinde, B., Deyn, .D., and Berendse, F. (2003). Diversity reduces invisibility in experimental plot communities: the role of plant species. *Ecology Letters* **6:** 910-918.

Sebsebe Demissew and Friis, I. (2001). Vegetation maps of Ethiopia and Eritrea. A review of existing maps and the need for a new map for the Flora of Ethiopia and Eritrea. In: I. Friis & O. Ryding (eds.), Biodiversity Research in the Horn of Africa Region, Proceedings of the 3rd International Symposium on The Flora of Ethiopia and Eritrea. *Biol. Skrif.* **54:** 399-439

Shetie Gatew (2008). The ecological distribution and socio-economic impacts of *Prosopis juliflora* (Sw.) DC. in the Amibara wereda, Afar National Regional State. MSc. Thesis, Addis Ababa University, Addis Ababa.

Singh, H.P, Batish, D.R, Pandher, J.K., and Kohli, R. K. (2005). Phytotoxic effects of *Parthenium hystrophorous* residues on three Brassica species. *Weed Biology and Management* **5:** 105-109.

Singh, G., rathod, T.R., Mutha, S., Upadhyaya, S. and Bala, N. (2008). Impact of different tree species canopy on diversity and production of under storey vegetation in Indian desert. *Tropical Ecology* **49(1):** 13-23.

Solbrig, O. T. and Cantino, P. D. (1975) Reproductiveadaptations in *Prosopis* (Leguminosae, Mimosoideae). *Journal of the Arnold Arboretum* **56:** 185-210.

Srinivasu, V., and Toky, O. P. (1996). Effect of alkalinities on seed germination and seedling growth of important arid trees. *Indian Journal of Forestry* **19:** 227-233.

Sundararaj, D. D., Balasundramaniyam, G., and Soundrapandian, G. (1996). Pretreatment of the seeds of *Prosopis juliflora* DC for improving germination. *Madras Agricultural Journal* **53:** 259-261.

Wacker, T.L., Safir, G.R., and Stephens, C.T. (1990). Effects of ferulic acid on *Glomus faculatum* and associated effects on phosphorous uptake and growth of asparagus (*Asparagus officinalis*). *Journal of Chemical Ecology* **16:** 901-909.

Wittenberg, R. and Cock, M.J.W. (2001) Invasive alien species. How to address one of the greatest threats to biodiversity: A toolkit of best prevention and management practices. CAB International, Wallingford.

Zeila, A. A., Mwangi, E., and Swallew, B. (2004). *Prosopis juliflora*: Boon or bane for dry land agro forestry? (No. 1): A quarterly publication of Eastern and Central Africa Region of the World Agro-forestry Center.

Zeray Mehari (2008). Invasion of *Prosopis juliflora* (SW.) DC and Rural Livelihoods. The Case of Afar Pastoralists at Middle Awash Area of Ethiopia. MSc. Thesis, Norwegian University of Life Science, Oslo.

APPENDICES

Appendix 1. Seedlings of the study species after germination testing.

Appendix 2. Aqueous extracts of different organ parts of *P. juliflora*.