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Research Article

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

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Abstract

The allelopathic effects of the invasive *Prosopis juliflora* (Sw.) DC. was studied on seed germination and seedling growth of *Acacia nilotica* (L.) Willd. ex Del., *Acacia tortilis* (Forssk.) Hayne, *Cenchrus ciliaris* L. and *Enteropogon rupestris* (J.A. Schmidt) A. Chev. 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 highest density and observed affecting the plant diversity there in. Its growth characteristics and dense thicket formation restrict light to the ground flora and hence diminishes 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 percentage and seedling growth of the study plant species. Germination of *A. nilotica* and *A. tortilis* was not affected by all aqueous extracts of different organ parts of *P. juliflora* while leaf and root extracts at higher concentrations inhibited germination of *C. ciliaris* and *E. rupestris*. Shoot and root growth of the study species were inhibited by leaf and root at higher concentrations. Seed germination of all species except *A. nilotica* was inhibited by soil amended with decaying plant parts and under canopy soil. The effect is species specific and annuals (grasses and herbs) were affected more than perennials. Leaf seems to contain greater number/ amount of inhibitors than does root and bark. Bark seems to contain the least. Heavy accumulation of toxic substances at under canopy soil of *P. juliflora* may be one of the reasons for its invasiveness and low plant diversity.

Key words: Aqueous extract; canopy closure; germination percentage; plant diversity; seedling growth

Introduction

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. IAS are causing enormous damage to biodiversity and on agricultural system we depend on. These alien species outcompete, infect or transmit diseases, compete, hybridize with the native ones or attack them (Wittenberg and Cock 2001). With increasing trade and globalization, movement of people and goods also increased. This facilitated the spread of IAS.

Prosopis juliflora (Sw.) DC. 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). In Ethiopia, *Prosopis juliflora* was introduced and cultivated for shade, timber, forage, food and medicine (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.

Currently, *P. juliflora* poses a threat to indigenous biodiversity where ever it is established in Ethiopia in general, in the Middle Awash area in particular because of its weedy and invasive nature. In the Middle Awash, about 30,000 hectare of grass land, rangelands, water points and croplands are estimated to be occupied by *P. juliflora* (Mehari 2008). Areas that are currently invaded by *P. juliflora* were important sources of forage for livestock for the

Afar people. The invasion by *P. juliflora* reduces grass availability and stocking density by livestock. It impacts the plant biodiversity by creating a physical barrier on seedlings of other plant species, preventing sunlight to reach to the under canopy vegetation, lowering the water table and by releasing various chemicals that may have negative effect on the native plant species.

The success of *P. juliflora* is largely attributed to the high number of seeds produced and their efficient dispersal mechanisms (Shiferaw et al. 2004). In addition, its fast growing ability, dormant seeds, attractive and rewarding pods, seeds maintaining viability in the droppings of livestock and wild animals, resistance to browsing, incredible ability of re-sprouting and fast coppice growth (Shiferaw et al. 2004), and high water use efficiency (Felker et al. 1983) contribute to its invasion. Now *P. juliflora* has become the national no. 1 invasive species in Ethiopia (EARO and HDRA 2005).

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). The leaves of *P. juliflora* contain various chemicals including tannins, flavinoids, steroids, hydrocarbons, waxes and alkaloids (Pasiecznik et al. 2001). These are known to have effects on the germination and growth of other plant species. 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. Low light under *P. juliflora* canopy also make other plant species' survival difficult.

Appropriate controlling mechanism should be implemented to eradicate and/or minimize the risk posed by this naughty invasive species on the native flora. There are four kinds of controlling mechanisms: mechanical, chemical, fire and biological (Pasiecznik et al. 2001). Mechanical controlling by cutting has been used widely in Ethiopia but the high sprouting and coppicing ability of *P. juliflora* made controlling by cutting difficult. Thus the aim of this study was to evaluate the allelopathic effects of *P. juliflora* on selected valuable dominant native plant species and to compare its canopy characteristics with common tree species in the study area.

Materials and methods

The study area

The study area is located at Melka-Werer in Amibara Wereda, Middle Awash, in 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 to 860 m. Thirty years of meteorological data obtained from Werer Agricultural Research Center shows bimodal type of rain fall in the Middle Awash (Figure 1). 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 With mean monthly rainfall around 70 mm. The area is characterized by high moisture deficit because of high evapo-transpiration. The mean annual evapo-transpiration is 2702 mm which much exceeds the mean annual rainfall of the area which is about 562 mm. The mean maximum temperature is 34.1°C and the mean minimum temperature is 19°C. The maximum and the minimum temperatures are 38°C and 14.2°C in June and November respectively.

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. ciliaris* and *E. rupestris* were selected among the many that occur in the area based on field observations and information obtained from Werer Agricultural Research Center.

Plant material

Leaves, bark and roots 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. ciliaris* and *E. rupestris* (grasses) were also collected for the allelopathy trial.

Vegetation data collection

Three habitat types (*Acacia* woodland, riverine and wetland) were identified. Four plots with 400 m^2 were laid out in each of these habitats,

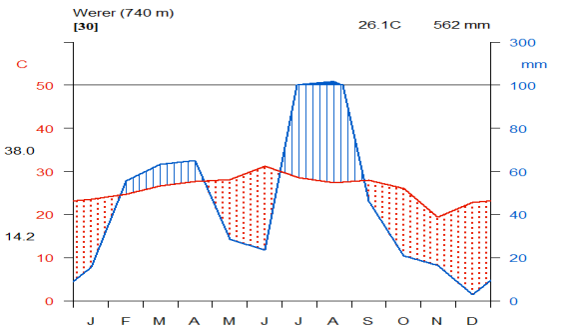

Figure 1. Mean monthly rain fall and maximum and minimum temperature for the last thirty years. Source: Werer Agro-meteorological Station (WAS).

two in open *Acacia* woodland (in flat and open slopes), one in riverine and one in wetland 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 /ha). Plant specimens were collected and identified at the National Herbarium (ETH), Addis Ababa University.

Variation in canopy characteristics
Canopy diameter, canopy closure, branching nature and branch angle

50 individual trees of dominant plant species: *A. nilotica*, *A. tortilis* and *P. juliflora* were taken randomly and their canopy diameter, canopy closure, branching nature and branch angle were measured and compared by using a measuring tape, a densiometer, a measuring tape and an angle measuring device respectively. Height from the ground to the first branch and average angle of tree branching were taken for branching nature and branch angle measurement.

Allelopathic effects of P. juliflora
Initial leachate bioassays

An aqueous extract was prepared by adding 0, 0.5, 0.8, 1, 2 and 6 g of leaves, bark and roots of *P. juliflora* (powder) in 100 ml of distilled water. Then the solution was shaken 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 (Hoque et al. 2003).

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 distil water only. Four replications with 25 seeds each of receptor plants (*A. nilotica, A. tortilis, C. ciliaris* 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 emerged visibly.

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. 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. ciliaris* and *E. rupestris*) with four replications were sown in each amended soil type in Petri dishes. Germination count was done at two days interval until no new seed germination was observed for two consecutive counts.

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. ciliaris* 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, the percentage was recorded (Hillman 1997).

Statistical analysis

Data were 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. Mean germination capacity was shown using bar graphs.

Results and discussion

Vegetation characteristics

Twenty seven species were recorded in the sampling plots (Appendix 5). Out of these, thirteen are trees and shrubs and the remaining fourteen are herbs. 9 species were observed in the riverine plot, whereas 8 in the wetland, 12 species in *Acacia* woodland respectively. Among these species *P. juliflora* was recorded in all plots and its density was the highest (Appendix 5). The number of species recorded in open *Acacia* woodlands was low. This is due to the relatively high density of *P. juliflora* which 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 domingensis* Pers. and *Sporobolus spicatus* (Vahl) Kunth 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. *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. 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 in *P. juliflora* dominated lands. 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.

The Acacia woodland vegetation type in the area is being changed into *P. juliflora* dominated shrub land (Figure 2). Field observations and information from the elderly indicated that open areas that were previously range and farm lands are more readily invaded by *P. juliflora* than areas that were already covered 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).

According to the 1986 and 2001 land use cover classification map (Ame 2002), the area coverage of *P. juliflora* was increasing from 5.45% in 1986 to 6.75% in 2001 with an average increase of 0.08% per year. New areas that were important forage lands for the pastoral people are now invaded by this noxious invasive weed. High coppicing ability, effective dispersal mechanism, deep tap root system, dormant seeds, attractive and rewarding pods help for its invasion. Livestock, camels and goats play a significant role in spreading of *P. juliflora* seeds via their faeces (Shiferaw et al. 2004) by carrying them into different areas. Rivers and water canals also play a significant role in the dissemination of seeds to different areas. Swamp areas, road sides and irrigation canals are highly invaded by *P. juliflora*. This shows *P. juliflora* establishes well in areas where water is available and also where surface runoff water present for its seed dispersal (Figure 3). This may be also the reason why *P. juliflora* invaded most of the area along river Awash in the rift valley.

Canopy characteristics

P. juliflora starts branching closer to the ground than the other two tree species. This makes under canopy seedling establishment difficult as a result of a physical barrier created by lower branches. Even though the branching angle of *P. juliflora* is not greater than *A. nilotica* and *A. tortilis*, its branches stretch out sideways and intercept each other. This results in interference with light and hence the death of under story vegetation.

Canopy diameter of *P. juliflora* is less than the others. While its canopy closure is not significantly different from *A. tortilis* and *A. nilotica*, it is still greater than both (Appendix 1). This relatively high canopy closure resulted in dense canopy under *P. juliflora* and hence the death of under canopy vegetation. This may be one of the reasons for low plant diversity observed under the *P. juliflora* fields (Singh et al. 2008).

Figure 2. Invasion of the Acacia wood land vegetation type in the area by *Prosopis juliflora* (Photo Samuel Getachew).

The depressive effect of *P. juliflora* canopy in the abundance of annuals is higher than it is for perennials (El-Keblawy and Al-Rawai 2007). The seedlings of most annuals and perennials had not been seen except seedlings of *P juliflora*. This may be attributed to the allelopathic nature of *P. juliflora* and its shade effects that hinder other species' seedlings to germinate. El-Keblawy and Al-Rawai (2007) also reached to 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.

Allelopathic effects of P. juliflora
Germination

As compared to the control seed germination of *A. nilotica* and *A. tortilis* was not affected by all treatment types of leaf, bark and root extracts (Table 1), while *C. ciliaris* and *E. rupestris* seed germination was inhibited by aqueous extracts of all leaf treatments of *P. juliflora*. Bark facilitated germination especially in smaller concentrations for the grass species. *C. ciliaris* seed germination was facilitated by bark at smaller concentrations. It significantly facilitated germination at 2%, while with the increased concentration above 2%, germination declined but not significantly (Table 1). *E. rupestris* seed germination was also facilitated by bark at smaller concentrations. Maximum germination percentage was recorded at 0.8% concentration level of bark, while seed germination went on decreasing above 0.8% and inhibited significantly at 6% concentration level (Table 1). Root extracts inhibited seed germination of the grass species significantly at higher concentrations for the grass species. *C. ciliaris* and *E. rupestris* seed germination was inhibited significantly by 6% root and all concentration of leaf aqueous extracts respectively.

Inhibitions of seed germination of the grasses by leaf and root at higher concentrations indicate *P. juliflora* release growth retarding substances. Leaves seem to have a higher amount of inhibitory compounds than roots. It was also observed that germination of seeds of the dominant tree species was not affected more by the aqueous

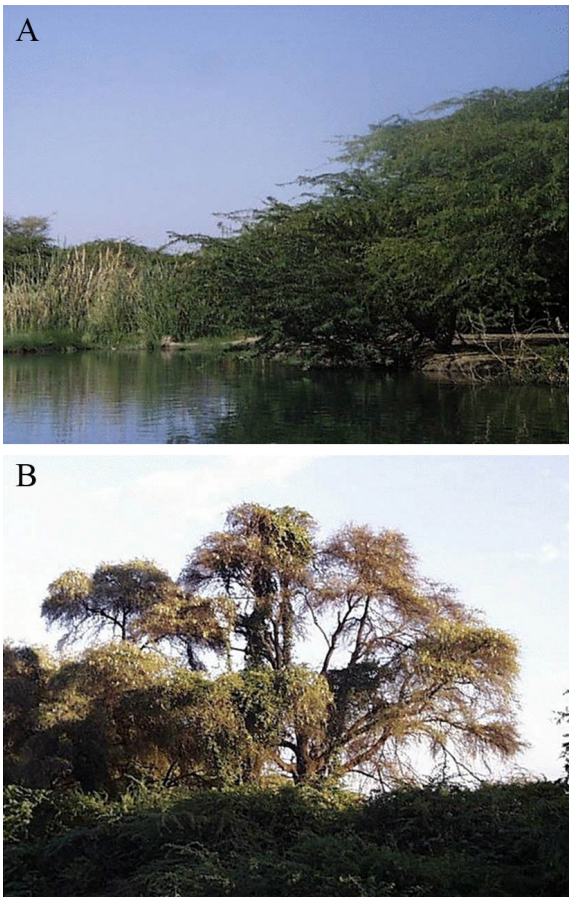

Figure 3. *Prosopis juliflora* invading swampy areas (A), *Prosopis juliflora* spreading along river side of Awash (B) (Photo Samuel Getachew)

extracts of *P. juliflora* organ parts while grasses were highly affected (Figure 4). But higher concentration of these allelochemical compounds (in residue amended and under canopy soil) significantly inhibited the tree species (*A. tortilis*) (Appendix 4). This also supports previous 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 for allelopathic nature of *P. juliflora*. Seed germination of *Cynodon dactylon* (L.) Pers. 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 (6 g) pericarp aqueous extracts (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 L., *Triticum aestivum* L. and *Albizia lebbeck* (L.) Benth. (Noor et al. 1995). In pot studies examining the allelopathic effect of *P. juliflora* leaf litter, (Chellamuthu et al. 1997) indicated that germination of *Vigna mungo* (L.) Hepper, *Sorghum bicolor* (L.) Moench 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).

Seedling growth

Leaf aqueous extracts had deleterious effects on shoot growth of the tree species at higher concentrations. *A. nilotica* shoot growth was retarded significantly by leaf extracts at 2 and 6% (Appendix 3). Shoot growth of *A. tortilis* showed a decrease in growth at 6% even if it was not significant. *C. ciliaris* and *E. rupestris* shoot growth was inhibited significantly by leaf aqueous extracts at 6% and all concentration level respectively (Appendix 3). Bark aqueous extracts had a stimulatory effect on shoot growth of the tree and the grass species. *A. nilotica's* shoot growth was facilitated significantly by 6% and *A. tortilis's* by 0.8% and higher concentrations of bark extracts (Appendix 3). Shoot growth of the grass species facilitated significantly at 2% and higher concentrations of bark extracts. Root aqueous extracts seem to have had stimulatory effects at smaller concentrations and deleterious effects at higher concentrations for all the trial species on shoot growth. Shoot growth of *A. nilotica* was

Table 1. Results from the germination experiment of *A. nilotica, A. tortilis, C. ciliaris* and *E. rupestris* subjected to different treatments (a, not significantly different; b, significantly different (P<0.05) from controls (Duncan's multiple range test)).

Species	Treatment type	Concentrations (%)						LSD (0.05)
		0	0,5	0,8	1	2	6	
A. nilotica	leaf	23.500±1.732	23.000±1.633[a]	24.250±0.500[a]	23.750±0.957[a]	23.500±1.000[a]	22.000±2.646[a]	0.211
	bark	23.500±1.732	23.500±1.291[a]	23.500±1.291[a]	24.000±1.414[a]	22.000±0.816[a]	23.750±0.957[a]	0.351
	root	23.500±1.732	22.000±0.000[a]	23.500±1.291[a]	21.250±2.754[a]	21.250±0.957[a]	21.920±1.692[a]	0.376
A. tortilis	leaf	23.000±1.414	24.500±0.577[a]	23.250±2.062[a]	24.000±1.414[a]	23.000±0.816[a]	23.000±0.816[a]	0.475
	bark	23.000±1.414	23.000±0.816[a]	24.250±0.500[a]	24.000±0.816[a]	24.250±0.957[a]	24.250±0.957[a]	0.204
	root	23.000±1.414	23.500±1.000[a]	24.250±0.500[a]	23.000±1.414[a]	24.000±1.414[a]	24.000±1.414[a]	0.686
C. cillaris	leaf	10.000±2.449	6.750±0.957[b]	6.250±1.893[b]	6.000±1.826[b]	2.000±2.160[b]	0[b]	0.000
	bark	10.000±2.449	11.750±4.193[a]	13.250±2.630[a]	13.000±3.742[a]	14.750±1.893[b]	6.500±3.416[a]	0.023
	root	10.000±2.449	8.000±2.708[a]	7.750±3.500[a]	7.250±1.708[a]	7.250±0.500[a]	3.750±3.096	0.063
E. rupesteris	leaf	17.750±1.708	14.500±1.000[b]	11.750±1.708[b]	10.500±1.915[b]	8.250±2.500[b]	0[b]	0.000
	bark	17.750±1.708	17.500±1.915[a]	22.250±3.202[a]	18.000±4.830[a]	15.750±3.096[a]	13.250±3.096[b]	0.021
	root	17.750±1.708	13.250±3.304[b]	9.750±1.258[b]	9.250±3.304[b]	7.750±3.403[b]	7.500±4.041[b]	0.001

facilitated by root aqueous extracts by all concentration levels but the facilitation decreased at higher concentrations (6%). *A. tortilis*'s shoot growth was facilitated at 0.8 and 1% while inhibited by higher concentrations (2 and 6%) of root aqueous extracts. *C. ciliaris* shoot growth was facilitated by 0.8 and higher concentrations and *E. rupestris's* shoot growth was facilitated by all concentrations of bark aqueous extracts (Appendix 3).

A. nilotica root growth was retarded significantly by all concentration levels of leaf aqueous extracts (Appendix 4). *A. tortilis's* root growth was also retarded by leaf aqueous extracts even if it was not significant. Root growth of *C. ciliaris* was inhibited significantly by all concentration of leaf aqueous extracts (Appendix 4). Leaf aqueous extracts at high concentration (6%) had deleterious effects on root growth of *E. rupestris*. Bark had a stimulatory effect on root growth of the tree species. Root growth of the grasses was facilitated by bark extracts at lower concentrations while inhibited at higher concentrations. Root aqueous extracts seem to have had stimulatory effects at lower concentration levels and an inhibitory effect at higher concentrations for both the tree and the grass species.

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* L. (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. Leaves seem to have higher allelopathic compounds than roots and bark while bark seems to have the least. This may be due to leaves containing more allelo-compounds in number/amount. The effects are concentration dependent and species specific.

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 (Appendix 4). *A. nilotica* is also highly allelopathic (Al-Wakeel et al. 2007). This might be the reason why its germination was not 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 (Appendix 4). This may be due to plant residues and under canopy soil containing much more allelo-compounds than does each organ parts (leaves, stems and bark). All concentrations of residue amended soil and under canopy soil inhibited germination of *C. ciliaris* seeds. *E. rupestris* seed germination was also inhibited by all concentration of residue amended soil except at 0.5% and by under canopy soil (Appendix 4). Percentage of inhibition was concentration related, i.e. inhibition increased as concentration increased. From this it was observed that under canopy soil had

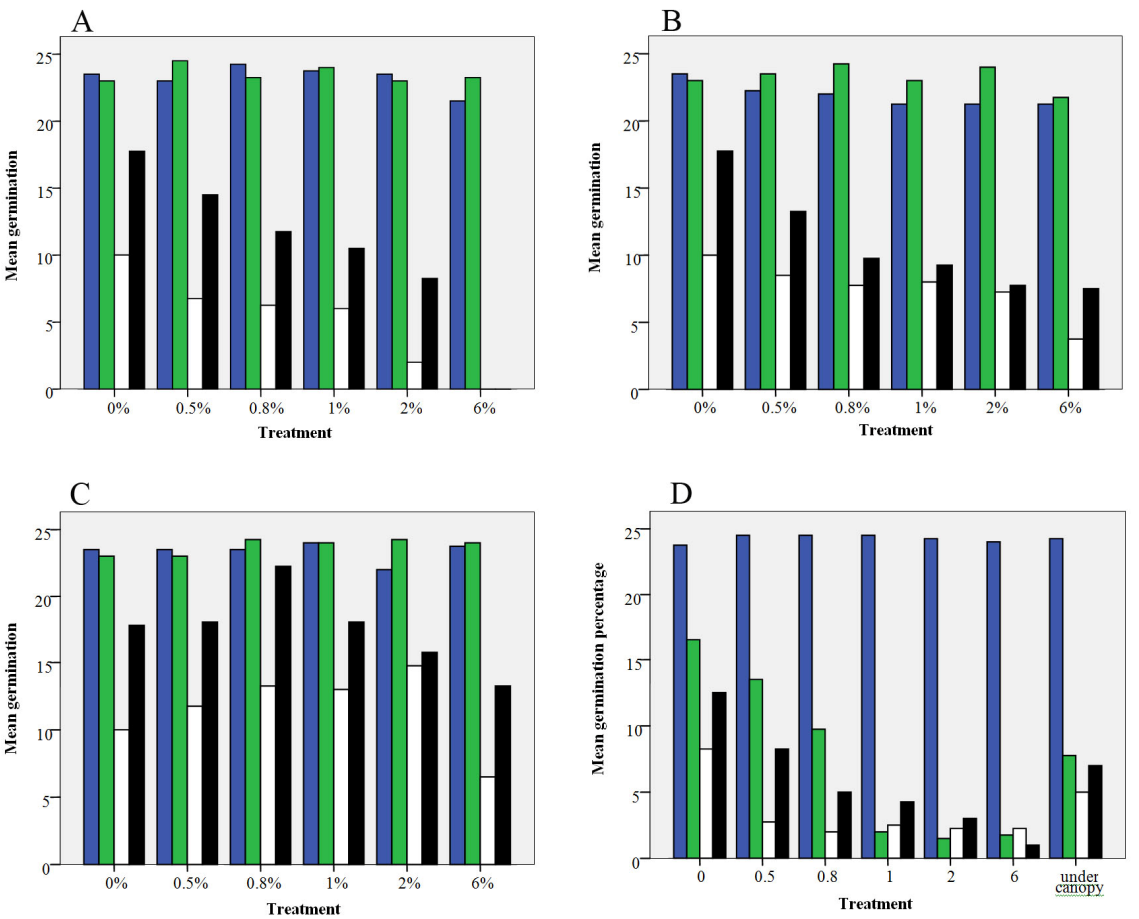

Figure 4. The effect of different concentrations of aqueous extracts of *P. juliflora* obtained from leaf (A), root (B), bark (C), and residues (D) on seed germination of the studied plant species: *A. nilotica*, *A. tortilis*, *C. ciliaris* and *E. rupesteris* (blue, green, open and black columns, respectively).

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.

Conclusions and recommendations

The occurrence of *P. juliflora* in all habitat types in the area studied and its high population number indicate it is invading the study area. Low plant diversity and its high density show its high competitiveness and its threat to 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 starting 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 all concentrations of leaf extracts and higher concentration of root extracts of *P. juliflora* on the grass species, facilitation of seed germination of the grass species by bark extracts at lower concentrations and inhibition of germination of all study species (except *A. nilotica*) by soil amended with decaying plant parts and under canopy soil were observed. Shoot and root growth of both the tree and grass species were inhibited by leaf and higher

concentration of root extracts while shoot-root growth was facilitated by bark and root extracts at lower concentration. These indicate that *P. juliflora* contains allelo-chemicals in its organ parts in various amounts and types. Leaves seem to have greater inhibitory effects than roots and barks. Bark seems to contain the least inhibitory compounds. The effect is also species specific. Allelochemicals released from various parts of *P. juliflora* 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. Inhibition of seed germination of *A. tortilis* by both residue amended and under canopy soil of *P. juliflora* indicate that trees are also being affected by these allelopathic substances of *P. juliflora* at higher concentrations. 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.

Mechanical controlling by cutting for charcoal production and fire wood may be effective to lessen the impacts on the native plant species and to reduce its rate of invasion (Abebe 2012). But due to its high coppicing ability and many sprouting after cutting, cutting will not help to eradicate *P. juliflora* in the area unless it is done some distance below the ground. Dissemination of seeds to various areas by the movement of cattle, goats and camels feaces has been observed playing a major role in increasing the rate of expansion of the species. Controlling movement of the livestock may play an important role in preventing further invasion to new areas. Invasion can also be lessened by using crushed pods as a fodder for livestock. Irrigation cannels also play a significant role in transporting the seeds to different areas including farming lands. Therefore removing *P. juliflora* trees found close to irrigation cannels may decrease dissemination of seeds by water bodies and as a result decrease invasion rate.

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Supplementary material

The following supplementary material is available for this article.

Appendix 1. Mean growth variables of trees and their effects on canopy closure.
Appendix 2. Shoot length (cm) for aqueous extracts of leaf, bark and root of *P. juliflora* of different concentrations.
Appendix 3. Root length (cm) for aqueous extracts of leaf, bark and root of *P. juliflora* of different concentrations.
Appendix 4. Results of germination percentage from residue amended and under canopy soil experiment.
Appendix 5. Trees, shrubs and herbs recorded in the study areas.

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