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Impacts of native and invasive exotic *Prosopis* congeners on soil properties and associated flora in the arid United Arab Emirates

Ali El-Keblawy [a,*], Mahmoud Ali Abdelfatah [b,c]

[a] Department of Applied Biology, Faculty of Science, Sharjah University, P.O. Box 27272, Sharjah, United Arab Emirates
[b] Soil Quality Department, Environment Agency – Abu Dhabi, P.O. Box 45553, Abu Dhabi, United Arab Emirates
[c] Soils and Water Sciences Department, Faculty of Agriculture, Fayoum University, P.O. Box 63514, Fayoum, Egypt

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ABSTRACT

The native *Prosopis cineraria* and exotic invasive *P. juliflora* are present in arid habitats of the United Arab Emirates (UAE). The objective of this study was to assess the impacts of allelopathy and soil properties on plants associated with the two species in arid deserts. Density and other community attributes of the associated species were assessed beneath, at the margin and outside the canopies of 20 *Prosopis* individuals. Aqueous extracts of fresh and old leaves of both *Prosopis* species were assessed on germination of five native plants. Soil samples were collected from beneath and next to canopies of the two species and their chemical properties were analyzed. The effect on the associated flora was depressive for *P. juliflora*, but was positive for *P. cineraria* canopy. The depressive effect of *P. juliflora* was more obvious on the annual compared with perennial plants. The negative effect of the aqueous extract of *P. juliflora* was much greater on germination, especially for annual plants. Canopies of both species improved soil properties that would facilitate the association of other native plants. The allelopathic effect of *P. juliflora*, however, may override its facilitative effect and consequently resulted in a depressive effect on the associated flora.

1. Introduction

Desert shrubs and trees play a major role in stabilizing the fragile desert ecosystems in arid regions. In many deserts, trees are considered as keystone species as they support the life of many other faunal and floral species (Munzbergova and Ward, 2002). Desert trees can influence their understory vegetation in many ways, resulting in a broad range of detrimental or beneficial outcomes. The beneficial effects of desert trees on the environment beneath their canopies include the reduction in the extremes of environmental temperatures (Greenlee and Callaway, 1996), provision of suitable amounts of photosynthetically active radiation to understorey plants (Smith and Knapp, 2001), improved soil texture and nutrient content (Moro et al., 1997; Nobel, 1989; Pugnaire et al., 2004), increased soil moisture (Belsky, 1994) and protection against herbivory (McAuliffe, 1984). Conversely, desert trees can also have negative effects on seedling survival and establishment in their understorey community. These competitive interactions may be through light deprivation, competition for water and nutrients, or leaching of allelopathic compounds (Bais et al., 2003; Brewer, 2002; Moro et al., 1997; Nobel, 1989). Detrimental and beneficial mechanisms do not act in isolation from each other in nature. The relative importance of these two processes in a particular plant community determines the structure of that community (Callaway and Walker, 1997).

Biological invasions are recognized as one of the most important causes of ecosystem degradation and biodiversity loss worldwide (Mack et al., 2001; Vitousek et al., 1996). The depressive effect of some exotic species on the associated flora has been attributed to allelopathy, which is an interference mechanism by which plants release chemicals that affect other plants (Bais et al., 2003; Brewer, 2002; Callaway and Ridenour, 2004). This allelopathic interference has been argued to be one of the mechanisms by which exotics may become successful invaders (Inderjit et al., 2008; Stinson et al., 2006).

A congeneric, or phylogenetic, approach was used to examine allelopathy as a mechanism for invasion. This approach involves comparative studies of exotic species with natives in the same genus (Inderjit et al., 2008). Native plants typically do not share a co-evolutionary history with the exotic invasive species, and

* Corresponding author. Permanent address: Department of Biology, Faculty of Education in Al-Arish, Suez Canal University, Egypt.
E-mail addresses: akeblawy@sharjah.ac.ae, akeblawy@jmail.com (A. El-Keblawy).

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therefore greater allelopathic effects of the invasive are expected on the native plants in such ecosystems. The 'novel weapons hypothesis' indicated that allelochemicals produced by the invaders are new to the native plant communities (Bais et al., 2003; Callaway and Ridenour, 2004). Assessment of the impact of allelopathy of two congeneric species on the germination of their associated species might shed light on the mechanisms of the coexistence of native plants with native and exotic competitors. Only a few studies compared the allelopathic effects of invasive and native competitors on the associated native plants (but see Inderjit et al., 2008).

Prosopis juliflora and *P. cineraria* are among a few trees growing in the arid deserts of the UAE and currently occupying the same habitats. They constitute a major ecological feature in the Northern Emirates of the UAE. *P. cineraria* is a slow growing tree native to the dry and arid regions of Arabia and India and is beneficial for the growth and development of other species (Abdel Bari et al., 2007). It is rarely, if ever, seen as a weedy species and has not been successfully introduced into other parts of the world (Pasiecznik et al., 2001). *P. juliflora*, however, is an exotic species from Central and South America and grows luxuriantly on sandy soils with high groundwater tables in the UAE. It has been introduced on a large scale in the artificial forests of the UAE because of its faster growth and soil-binding capacity. Recently, it has escaped plantations and come to dominate many plant communities, and is considered a weed. It is highly aggressive and coppices so well that it crowds out native vegetation (El-Keblawy and Al-Rawai, 2005, 2007; Tiwari, 1999).

Both *P. cineraria* and *P. juliflora* possess phenolic compounds. However, the leaf leachates and extracts of *P. juliflora* showed allelopathic effects against native species in its invasion range, whereas extracts from leaves of *P. cineraria* collected and applied in the same way, do not (Goel and Behl, 1998; Inderjit et al., 2008; Kaur et al., 2012). A water-soluble extract from different parts of *P. juliflora*, including litter and rhizosphere soil, has resulted in the inhibition of seed germination of many species. However, most of the tested assay plants do not naturally grow near *P. juliflora*. For example, aqueous extracts from soil under the canopy 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 addition, Al-Humaid and Warrag (1998) concluded that *P. juliflora* leaves contain water-soluble allelopathins that could inhibit seed germination and retard rates of germination and seedling growth in *Cynodon dactylon*. In pot studies of the allelopathic effects of leaf litter of *P. juliflora*, Chellamuthu et al. (1997) indicated that germination of black gram (*Vigna mungo*), and sorghum (*Sorghum bicolor*) was significantly reduced with the maximum reduction occurring at 2% incorporation of *P. juliflora* leaf litter. The selection of bioassay species is crucial to the study of allelopathy because the effect of biochemicals can vary dramatically among test species (Inderjit, 2006; Inderjit and Nilsen, 2003; Perry et al., 2005). The aims of the present study were to assess the impacts of (1) allelopathy of fresh and old leaves of the native *P. cineraria* and exotic invasive *P. juliflora* on the germination of five native plants naturally growing with them, (2) soil chemical properties beneath and around the two *Prosopis* species on their associated plants in the arid environment of the UAE. This is especially important as the two congers are growing together in the same soil type and have the same associated native plants. We assume that the differential response of the native plant germination to the allelochemicals of the two congers would help in understanding the extent of the detrimental effect of allelopathy in both species. In addition, it is assumed that the balance between the facilitative effect of soil properties and the negative effect of allelopathy would also help in understanding the invasive ability of exotic *P. juliflora*.

2. Materials and methods

2.1. Study area

A study site in Fujairah Emirate on the eastern coast of the UAE (25°14′ 27.68″ N and 56°21′ 24.14″ E) was selected to ensure a reasonable degree of physiognomic homogeneity and with homogenous distribution and densities of both *P. juliflora* and *P. cineraria*. Individuals of the two species covering medium and large trees were selected for study. In some communities of *P. cineraria* that were invaded by *P. juliflora*, the invader was found to negatively affect the growth and vigor of the native *P. cineraria*. These places were excluded from the study.

2.2. Impacts on associated flora

A total of 20 stands were located randomly around the two *Prosopis* species (10 stands for each). A *Prosopis* tree (*P. juliflora* or *P. cineraria*) was located near the center of each stand to serve as a focal point. The area of each stand was 225 m^2 (15 × 15 m). In each stand, nine one m^2 quadrats were distributed on three transects; 3 quadrats beneath; 3 at the margin; and 3 beyond the canopy of each selected *Prosopis*. A species list was compiled in each stand. The absolute density (number of plants of a certain species rooted within one m^2) was estimated for each associated plant species beneath, at the margin and beyond the canopies of the two *Prosopis* species. Other community attributes were also estimated, including species number, species richness (average number of species per stand), and species evenness (estimated by Shannon–Weaver index).

2.3. Soil analysis

In each stand, two composite soil samples were collected from the upper 10 cm of the soil, one from underneath (halfway between the trunk and the edge of the canopy) and another from at least 2 m outside the margin of the canopy. A total of 40 soil samples were collected and analyzed for this study. Soil samples were air dried, ground, homogenized, and sieved through a 2 mm sieve to remove large particles. Soil organic matter content, pH, salinity and the nutrients N, P, Na, and K were estimated. Organic matter content was estimated using loss of mass by combustion at 430 °C on the $<$2 mm soil fraction. Soil water extracts (1:2.5 of soil:water) were prepared for determination of electrical conductivity (EC) and pH using conductivity and pH meters. Available nitrogen was extracted using 2 M KCl and determined by the micro-Kjeldahl method. Available phosphorous was estimated using Olsen's solution (sodium bicarbonate) as an extracting agent. Na and K were estimated by using flame photometry. These methods are outlined in Black (1965).

2.4. Assessment of allelopathic effects

Fresh and old leaf samples were collected from underneath *P. cineraria* and *P. juliflora* individuals in the studied community. Fresh leaves fallen within one year were distinguished by their very light color, while leaves older than one year were darker. All samples were air dried at room temperature and subsamples were ground to pass through a 3-mm sieve. Dried materials from all samples were extracted in distilled water at 25 g 100 ml^{-1} for 24 h at 25 °C. Following extraction, coarse plant materials were removed with a 2-mm sieve. Extracts were then passed through a