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Effects of native and invasive *Prosopis* species on topsoil physiochemical properties in an arid riparian forest of Hormozgan Province, Iran

Maryam MOSLEHI JOUYBARI[1*], Asgahr BIJANI[2], Hossien PARVARESH[2], Ross SHACKLETON[3,4], Akram AHMADI[5]

[1] Research Division of Natural Resources, Hormozgan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Bandar Abbas 7915847669, Iran;
[2] Department of Environmental Sciences, Bandar Abbas Branch, Islamic Azad University, Bandar Abbas 7915893144, Iran;
[3] Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Birmensdorf 8903, Switzerland;
[4] Centre for Invasion Biology, Department of Botany & Zoology, Stellenbosch University, Stellenbosch 7602, South Africa;
[5] Research Division of Natural Resources, Golestan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Gorgan 4915677555, Iran

Abstract: Biological invasions can alter soil properties within the range of their introduced, leading to impacts on ecosystem services, ecosystem functions, and biodiversity. To better understand the impacts of biological invasions on soil, we compared topsoil physiochemical properties at sites with invasive alien tree species (*Prosopis juliflora*), native tree species (*Prosopis cineraria*, *Acacia tortilis*, and *Acacia ehrenbergiana*), and mixed tree species in Hormozgan Province of Iran in May 2018. In this study, we collected 40 soil samples at a depth of 10 cm under single tree species, including *P. juliflora*, *P. cineraria*, *A. tortilis*, and *A. ehrenbergiana,* as well as under mixed tree species. The results showed that organic matter, moisture, potassium, calcium, nitrogen, and magnesium in topsoil at sites with *A. tortilis* and *A. ehrenbergiana* growing in combination with *P. cineraria* were higher than that at sites where *P. juliflora* was present ($P<0.05$). Sodium at sites with *A. tortilis* and *A. ehrenbergiana* growing in combination with *P. cineraria* and *P. juliflora* was lower as compared to that at sites with just *A. tortilis* and *A. ehrenbergiana*. Electrical conductivity was lower at sites with *A. tortilis* and *A. ehrenbergiana* growing in combination with *P. cineraria*, and it was higher at sites with mixed *Acacia* and *P. juliflora* trees. Based on the generally more positive effect of native *Acacia* and *P. cineraria* on topsoil physiochemical properties as compared to the *P. julifora*, afforestation with native tree species is preferable for soil restoration. In addition, due to the negative effects of *P. julifora* on soil properties, *P. julifora* spread should be better managed.

Keywords: *Prosopis juliflora*; *Prosopis cineraria*; tree species; invasion; topsoil physiochemical properties; Iran

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1 Introduction

Invasive alien species can negatively impact biodiversity, ecosystem services, and people's livelihoods and well-being (Hejda et al., 2009; Vilà et al., 2011; Shackleton et al., 2019). They can be predators, competitors, parasites, and disease transmitters, alter local biotic and abiotic environments, and become major ecosystem engineers in their new habitats (Reinhart and Callaway,

*Corresponding author: Maryam MOSLEHI JOUYBARI (E-mail: m.moslehi@areeo.ac.ir)
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2006; Blackburn et al., 2014), which can destabilize local environmental systems (Weidenhamer and Callaway, 2010; Gioria and Osborne, 2014). A key impact of invasive alien plant species on local soil is that they can alter soil chemistry and composition through mechanisms such as allelopathy, which in turn can alter native plant growth and development (Chou, 2010; Weidenhamer and Callaway, 2010). To better manage biological invasions, there needs to be sufficient scientific evidence of the impacts of introduced species on their recipient ecosystems to guide and justify decision-making.

Trees from the genus *Prosopis* have been introduced to many regions around the world (Shackleton et al., 2014), and subsequent invasions have had significant effects on humans, biodiversity, and local environments (including soil). With regard to soil, it is known that *Prosopis juliflora* has allelopathic effects and can impact adjacent plant communities (Inderjit et al., 2008; Kaur et al., 2012). Phenolic and other compounds such as tryptophan found in leaf and root extracts can induce these negative allelopathic effects. Allelopathic effects also influence cation exchange in soil (Shitanda et al., 2013; El-Shabasy, 2017). *P. juliflora* can also affect soil chemistry in other ways. In fact, one of the motivating factors for introducing *P. juliflora* is that it can increase soil carbon and nitrogen content (Moradi et al., 2013) as well as other nutrients such as potassium and organic matter. However, *P. juliflora* invasions can also decrease calcium, magnesium, and sodium concentrations in soil (Shitanda et al., 2013). Furthermore, *P. juliflora* can alter soil microbial communities (Mosbah et al., 2018). These major changes in soil chemistry, properties, and biological communities may be one of the key factors influencing the prevalence of *P. juliflora* and its spread in desert areas where it has been introduced (Al-Abdali et al., 2019).

In addition to the impacts on soil, *Prosopis* invasions produce dense and impenetrable stands, affecting native biodiversity (El-Keblawy and Al-Rawai, 2007; Shackleton et al., 2015). The *Prosopis* invasions also drastically reduce the growth of palatable forage species, which have negative implications for pastoralists' livelihoods (Pasiecznik et al., 2004; Linders et al., 2020). *P. juliflora* invasions can also impact numerous other ecosystem services, such as water supply (Dzikiti et al., 2013; Shiferaw et al., 2019).

P. juliflora was introduced to Iran and other parts of the Middle East, where it has become invasive and co-exists with the native *Prosopis cineraria* and other local tree species (Nascimento et al., 2020; Sharifian et al., 2022). In Iran, *P. juliflora* was introduced to mitigate desertification and serve as a wood resource, despite its ecological role and some positive effects, it is now considered as a threatening invasive tree in many ecosystems in the country (Nahali, 2000; Sharifian et al., 2022). Despite the well-known negative effects of *P. juliflora,* the tree is still recommended for land restoration programs in Asia (Edrisi et al., 2020), and more evidence of the effects of this tree on local desert systems is needed to guide decision-making.

The Sahara-Sindian forests of Iran are a highly fragile ecosystem, and undesired changes can drastically alter the succession paths of vegetation after disturbances, with implications for local pastoralists. In particular, the introduction, utilization, and dissemination of *P. juliflora* pose a major threat to local arid forest systems. However, there is limited scientific evidence on the effects of *P. juliflora* invasions in Iran, and further information is needed to guide robust decision-making regarding the use and management of invasive trees and the selection of tree species for restoration in arid landscapes. Therefore, the aim of this study was to better understand the impacts of *P. juliflora* invasions on soil properties. To this end, we compared topsoil physiochemical properties at sites with invasive alien tree species (*P. juliflora*), native tree species (*P. cineraria, Acacia tortilis*, and *Acacia ehrenbergiana*), and mixed tree species in Hormozgan Province of Iran.

2 Materials and methods

2.1 Study area

The study was located in an arid riparian forest (26°31′34″N, 57°06′13″E), which is 75 km southeast of Minab City, Hormozgan Province of Iran. It covers 980 hm^2 and ranges between 0 to 100 m a.s.l. The annual average temperature is 28°C and the average annual precipitation is 226 mm. The study area has a sandy soil texture and extremely light soil. The flora of the study area is categorized as Sahara-Sindi, and common tree species include *A. tortilis* and *P. cineraria*, with *Acacia oerfota*, *Ziziphus spina-christi*, *A. ehrenbergiana* being less common. Annual and perennial grasses, such as *Cymbopogon olivieri*, *Chrysopogon aucheri*, *Cenchrus ciliaris*, *Pennisetum divisum*, and *Taverniera* sp., are dominant in the lower stratum. The increasingly invasive *P. juliflora* is also becoming common in the area (Bijani et al., 2020).

2.2 Site selection

After scoping the area in May 2018, we selected a 5-hm^2 site that included all focal tree species for the study, including *P. juliflora*, *P. cineraria*, *A. tortilis*, and *A. ehrenbergiana*. Specifically, we chose five sites with a canopy diameter greater than 2 m for each of the four target tree species (with no other tree species nearby). In addition, sites with the combinations of *P. cineraria* and *A. tortilis*, *P. cineraria* and *A. ehrenbergiana*, *P. juliflora* and *A. tortilis*, and *P. juliflora* and *A. ehrenbergiana* (canopy diameter greater than 2 m) were also selected. The distance between sampling sites is 14 to 59 m.

2.3 Soil sampling

At the five sites, for each of the four individual tree species (*P. juliflora*, *P. cineraria*, *A. tortilis*, and *A. ehrenbergiana*), we collected four soil samples at a depth of 10 cm in four directions under the tree canopy, including north, east, south, and west (Fig. 1). The four samples were then mixed so that one composite soil sample was obtained from each individual site. A total of 20 samples were obtained from the sites with single tree species (Fig. 1a). For the sites with mixed tree species (i.e., *P. cineraria* growing in combination with *A. tortilis*, *P. cineraria* growing in combination with *A. ehrenbergiana*, *P. juliflora* growing in combination with *A. tortilis*, and *P. juliflora* growing in combination with *A. ehrenbergiana*), five sites were randomly selected for each pair (El-Keblawy and Abdelfatah, 2014), and samples were obtained at a depth of 10 cm in four directions (north, east, south, and west) where the two tree canopies were overlapped (Fig. 1b). The four samples were mixed to obtain one composite soil sample for each sample site. A total of 20 samples were obtained from the sites with mixed tree species (Fig. 1b). Finally, 40 soil samples were used for analysis.

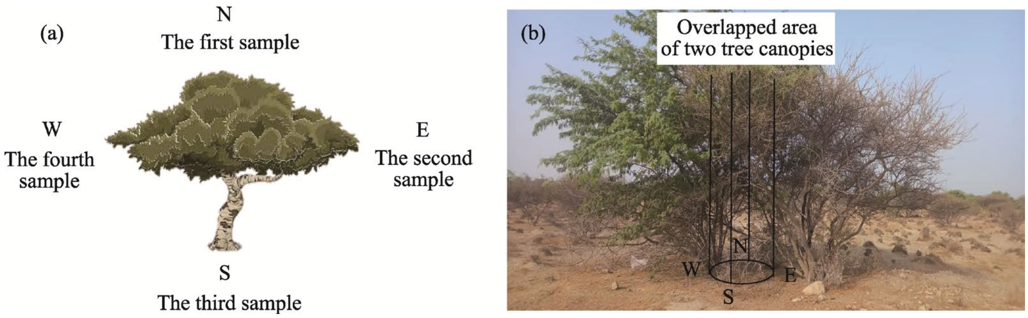

Fig. 1 The schematic images of the soil sampling method at the sites with single tree species (a) and the sites with mixed tree species (b). N, north; E, east; S, south; W, west.

2.4 Measurement of soil physiochemical properties

The collected soil samples were sieved through a 2-mm mesh and transferred to the laboratory for the measurement of soil physiochemical properties. Soil acidity, soil organic matter, electrical conductivity (EC), exchangeable cations (sodium, potassium, calcium, nitrogen, and magnesium), and soil moisture were analyzed. Soil acidity was determined by using potentiometric method. The soil solutions were prepared with soil and distilled water at a ratio of 1:20, and soil pH was measured 24 h later with a pH meter (HM30V, TOA Electronics Ltd., Tokyo, Japan) (Smith and

Doran, 1996). Soil organic matter content was determined using dry oxidation after burning the soil samples at 430°C. EC was determined on a saturation paste extract (Black, 1965). Exchangeable cations were calculated by ammonium acetate extraction method and quantified by an atomic absorption spectrophotometer (UNICAM 919, Unicam Ltd., Cambridge, UK) (Thomas, 1982). Soil moisture was calculated by measuring the difference between wet weight and dry weight (placed in an oven at 105°C for 24 h) (Fadoul and Mohamed, 2016).

2.5 Data analysis

The data were analyzed using SPSS 24.0 statistical software. One-way analysis of variance ($P<0.05$) was used to evaluate the difference in topsoil physicochemical properties among individual tree species, including *P. cineraria*, *P. juliflora*, *A. tortilis*, and *A. ehrenbergiana*, and mixed tree species with the combinations of these tree species. Duncan's multiple range test was used to compare group means ($P<0.05$). The normality of the data distribution and homogeneity of variance were evaluated by Shapiro-Wilk test and Levon's test, respectively.

3 Results

3.1 Effects of *Prosopis cineraria*, *Prosopis juliflora*, and *Acacia tortilis* as well as the combinations of these tree species on topsoil physiochemical properties

Soil organic matter, soil moisture, soil acidity, and EC differed significantly among sites with single tree species and also those with *P. juliflora* growing in combination with *A. tortilis* (Table 1). Soil organic matter was higher at sites with only *A. tortilis* (1.36%) and *P. cineraria* (1.27%) and those with *P. cineraria* growing in combination with *A. tortilis* (1.46%), as compared to those with only *P. juliflora* (1.07%) and *P. juliflora* growing in combination with *A. tortilis* (1.03%). Similar to soil organic matter, soil moisture was the highest at sites with *P. cineraria* growing in combination with *A. tortillas* (14.97%), followed by sites with single *P. cineraria* and *A. tortilis*; and it was lower at sites with single *P. juliflora* and *P. juliflora* growing in combination with *A. tortilis* (6.50%). Similarly, sites with single *P. juliflora* had lower soil acidity than those with native tree species. EC showed a different trend from other soil physiochemical properties. It was the highest at sites with only *P. juliflora* (2.23 S/cm), as opposed to sites with native tree species.

Table 1 Comparison of the effects of *Prosopis cineraria*, *Prosopis juliflora*, and *Acacia tortilis* as well as the combinations of these tree species on topsoil physiochemical properties

Topsoil physiochemical property	*P. cineraria*	*P. juliflora*	*A. tortilis*	*P. cineraria*× *A. tortilis*	*P. juliflora*× *A. tortilis*
Soil organic matter (%)	1.27 ± 0.10^{ab}	1.07 ± 0.31^{b}	1.36 ± 0.12^{ab}	1.46 ± 0.35^{a}	1.03 ± 0.11^{b}
Soil moisture (%)	13.52 ± 4.28^{a}	8.26 ± 2.41^{bc}	12.66 ± 8.45^{ab}	14.97 ± 4.21^{a}	6.50 ± 0.75^{c}
Soil acidity	7.30 ± 0.07^{abc}	7.23 ± 0.23^{bc}	7.54 ± 0.21^{a}	7.50 ± 0.26^{ab}	7.12 ± 0.13^{c}
Electrical conductivity (S/cm)	1.19 ± 0.36^{b}	2.23 ± 0.21^{a}	1.41 ± 0.37^{b}	1.18 ± 0.39^{b}	1.57 ± 0.48^{b}

Note: Different lowercase letters indicate significant differences among tree species ($P<0.05$). Mean±SD.

Exchangeable cations (sodium, potassium, calcium, and magnesium) at sites with *A. tortilis*, *P. cineraria*, and *P. juliflora* were different from those at sites with mixed tree species (Fig. 2). Sodium (172.7 mg/L) and calcium (209.6 mg/L) concentrations were significantly higher at sites with only *P. juliflora* as compared to sites with mixed tree species (Fig. 2a and c). Calcium was significantly lower at sites with *P. juliflora* growing in combination with *A. tortilis* (144.2 mg/L), which was similar for potassium (211.7 mg/L) and magnesium (45.22 mg/L). Magnesium was the highest at sites with only *A. tortilis* (86.96 mg/L) as well as at sites with *A. tortilis* growing in combination with *P. cineraria* (88.34 mg/L) (Fig 2d). Nitrogen at sites with only invasive *P. juliflora* was significantly lower than that at sites with the native tree species (Fig 2e). Sites with *A. tortilis* growing in combination with *P. cineraria* had the highest nitrogen (0.71 g/kg).

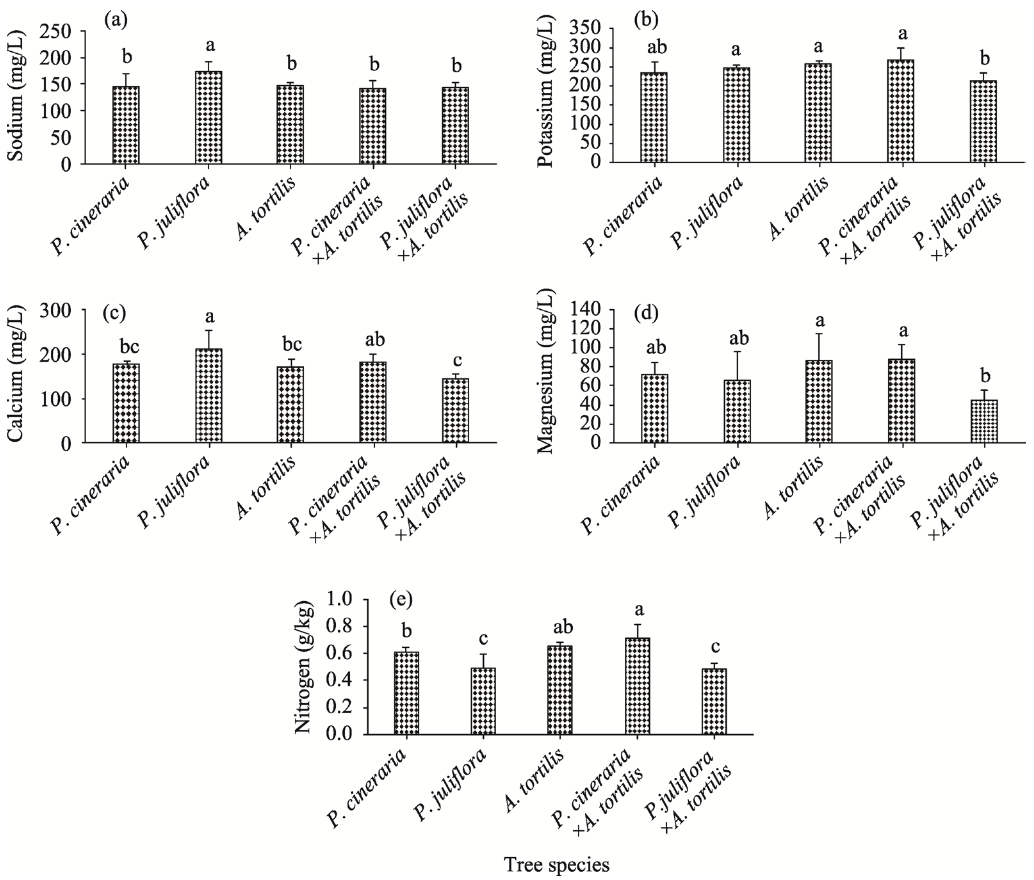

Fig. 2 Effects of *Prosopis cineraria*, *Prosopis juliflora*, and *Acacia tortilis* as well as the combinations of these tree species on topsoil exchangeable cations. (a), sodium; (b), potassium; (c), calcium; (d), magnesium; (e), nitrogen. Different lowercase letters indicate significant differences among tree species ($P<0.05$). Bars are standard deviations.

3.2 Effects of *P. cineraria*, *P. juliflora,* and *Acacia ehrenbergiana* as well as the combinations of these tree species on topsoil physiochemical properties

There was no significant difference in soil organic matter among sites with different tree species (Table 2). Soil moisture was significantly higher at sites with only *P. cineraria* (13.52%) and at sites with *P. cineraria* growing in combination with *A. ehenbergiana* (13.66%) as compared to sites with only *P. juliflora* (8.26%) and *P. juliflora* growing in combination with *A. ehenbergiana* (8.03%). The highest soil acidity was observed at sites with only *A. ehrenbergiana* (7.60), which was significantly higher than that at sites with only *P. juliflora* (Table 2). The highest EC was observed at sites with only *P. juliflora* (2.23), which was significantly higher than that at sites with native tree species.

Table 2 Comparison of the effects of *P. cineraria*, *P. juliflora*, and *Acacia ehrenbergiana* as well as the combinations of these tree species on topsoil physiochemical properties

Topsoil physiochemical property	*P. cineraria*	*P. juliflora*	*A. ehrenbergiana*	*P. cineraria*× *A. ehenbergiana*	*P. juliflora*× *A. ehenbergiana*
Soil organic matter (%)	1.27±0.10[a]	1.07±0.31[a]	1.02±0.19[a]	1.30±0.22[a]	1.02±0.24[a]
Soil moisture (%)	13.52±4.28[a]	8.26±2.41[b]	9.21±2.02[ab]	13.66±5.70[a]	8.03±1.80[b]
Soil acidity	7.30±0.07[b]	7.23±0.23[b]	7.60±0.16[a]	7.45±0.25[ab]	7.18±0.20[b]
Electrical conductivity (S/cm)	1.19±0.36[c]	2.23±0.21[a]	1.47±0.40[bc]	1.13±0.53[c]	1.79±0.39[ab]

Note: Different lowercase letters indicate significant differences among tree species ($P<0.05$). Mean±SD.

Exchangeable cations (sodium, potassium, calcium, and magnesium) were significantly different between sites with invasive *P. juliflora* and native tree species (Fig. 3). Sodium (172.7 mg/L) and calcium (209.6 mg/L) were significantly higher at sites with only *P. juliflora* compared to sites with native tree species (Fig. 3a and c). In contrast, magnesium was significantly lower at sites with *P. juliflora* as compared to sites with single native tree species (Fig. 3 d). Potassium was the highest at sites with *P. cineraria* growing in combination with *A. ehrenbergiana*, and that was the lowest at sites with only *P. juliflora* and only *A. ehrenbergiana* (Fig. 3b). Nitrogen was the highest at sites with only *P. cineraria* (0.61 g/kg) and at sites with *P. cineraria* growing in combination with *A. ehrenbergiana* (0.63 g/kg), and was lower at sites with only *P. juliflora* (Fig. 3e).

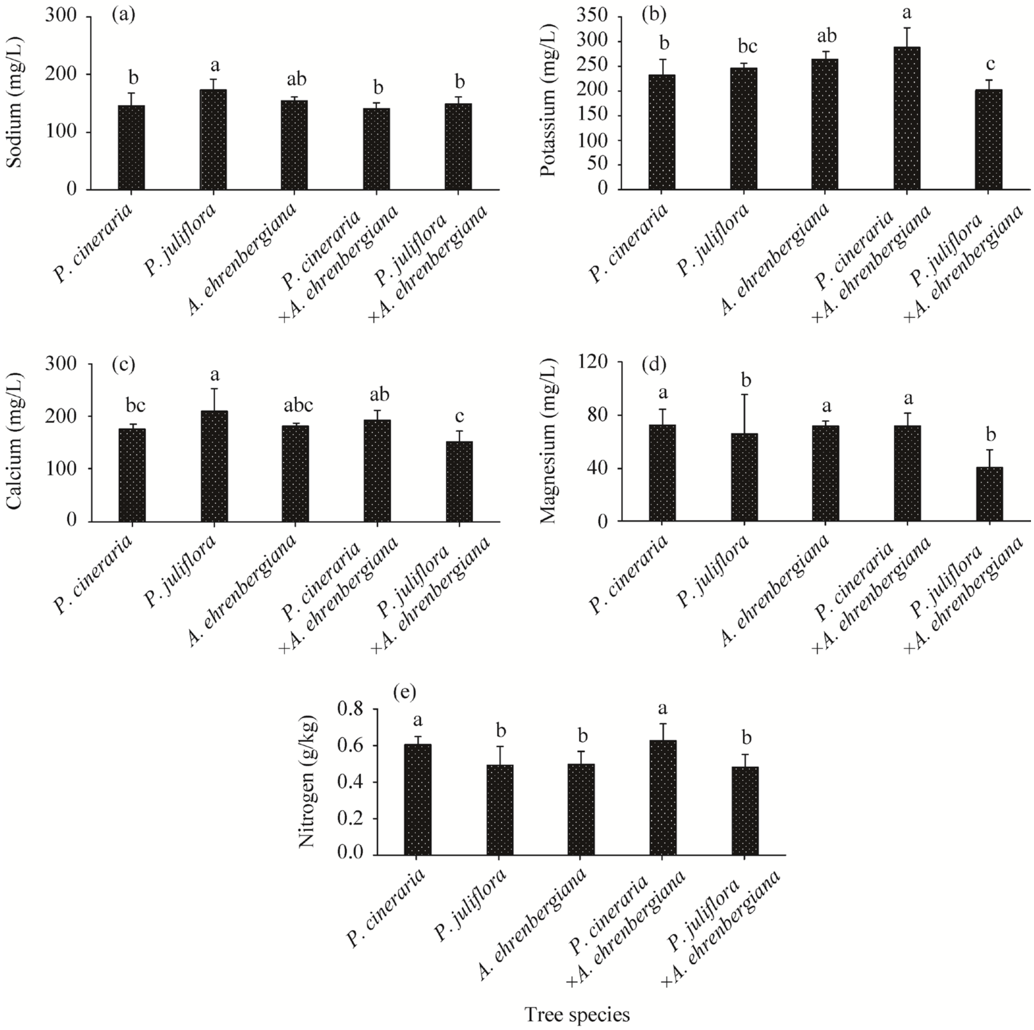

Fig. 3 Effects of *P. cineraria*, *P. juliflora*, and *Acacia ehrenbergiana* as well as the combinations of these tree species on topsoil exchangeable cations. (a), sodium; (b), potassium; (c), calcium; (d), magnesium; (e), nitrogen. Different lowercase letters indicate significant differences among tree species ($P<0.05$). Bars mean standard deviation.

4 Discussion

P. juliflora is a notorious global invader with multiple negative effects (Shackleton et al., 2014), and despite this, the planting of this tree species is still promoted in many arid lands for improving the soils and restoring degraded ecosystems (Edrisi et al., 2020), including in Iran. To provide evidence to guide better decision-making, we assessed the effects of *P. juliflora* on topsoil physiochemical properties in comparison to native tree species in Iran. The results showed that generally native tree species had similar or even better effects on topsoil physiochemical properties as compared to *P. juliflora*, suggesting that promoting native tree species for soil restoration in arid lands of Iran might be better than the use of non-native tree species. This is in line with the findings and suggestions of Sharifian et al. (2022).

More specifically, we found that soil organic matter at sites with single native tree species (*A. tortilis* and *P. cineraria*) and the combinations of native tree species (*P. cineraria* growing in combination with *A. tortilis*) was higher than that at sites with only *P. juliflora* or *P. juliflora* in the combination with native tree species. These results are consistent with the findings of Goel et al. (1989), Kahi et al. (2009), and Kaur et al. (2012), who also found the differences in soil organic matter between *P. juliflora* and native tree species. Annual fall of litter from trees constitutes the most important source of organic matter in soil, but this is also affected by some additional factors, such as decomposition under the influence of microbial activity, mineralization, the release of exchangeable cations, and soil moisture and oxygen (Kahi et al., 2009; El-Shabasy, 2017). These factors might explain the differences found in this study.

Soil moisture at sites with *A. tortilis*, *A. ehrenbergiana*, and *P. cineraria* was higher than that at sites with *P. juliflora*. These results are consistent with those found by Guevara et al. (2010). *P. juliflora* has extensive horizontal and vertical root systems that can absorb more moisture around itself (limiting the topsoil moisture available to other plants), which is less common in other tree species. Furthermore, *P. juliflora* is known to have a higher density of rhizobia and associated arbuscular mycorrhizal fungi than *A. tortilis* and *A. ehrenbergiana* (Guevara et al., 2010), which allows *P. juliflora* to obtain more water and thus leads to drier soil. Invasive *Prosopis glandulosa* in South Africa also has higher ground-water uptake (due to its larger root network and higher density) than native tree species, which may lead to the increased mortality of native trees where they co-exist with *P. glandulosa* (Schachtschneider and February, 2013; Dzikiti et al., 2017). This alteration to local soil moisture by *P. juliflora* compounded with climate change may lead to greater impacts on water availability in this region in the future (Sintayehu et al., 2020).

Similarly, we found that sites with *P. juliflora* had lower soil acidity than those with native tree species, which is consistent with the findings of Goel and Behl (1999), Garg and Singh (2003), Bavaraja et al. (2007), and Shitanda et al. (2013). Soil acidity is an important factor in plant nutrient utilization, which increases the solubility of soil nutrients and the surface uptake of elements. A decrease in soil acidity can therefore be considered as a major ecological and ecosystem impact (Inderjit et al., 2008). It is likely that *P. juliflora* has inhibitory compounds in its litter and secretes organic acids from its roots (Goel and Behl, 1999; Shitanda et al., 2013), which can affect soil acidity. Most of the compounds in the topsoil are phenolic compounds, which are the result of allelopathy caused by *P. juliflora*. These compounds lead to the decrease in soil acidity at sites with *A. tortilis* and *A. ehrenbergiana* in combination with *P. juliflora* (Bavaraja et al., 2007; Inderjit et al., 2008). In Sahara-Sindi forests, species prefer alkaline soil, so the reduction of soil acidity by *P. juliflora* may lead to a decrease in native plant species growth. This could have significant impacts on native plant communities and biodiversity in this region over the long-term (Bijani, 2020).

We found that EC in the topsoil at sites with *P. juliflora* was higher than those with *P. cineraria*, *A. tortilis*, and *A. ehrenbergiana*, which is similar to the findings of Abbasi et al. (2011) and Moradi et al. (2013). Humus plays an important role in enhancing EC and is one of the reasons for its increase under tree canopies (Garg and Singh, 2003). Organic matter acts as a sponge, increasing the secretion of soil micro-organism gels and soil moisture retention potential (Kazemi et al., 2015). The higher soil moisture produced by soil organic material makes the soil more active. These factors can cause the release of inorganic ions, increasing the solute concentration and consequently lead to an increase in the EC of soil. Trees also influence the amount of EC by absorbing solutes from their roots and bringing them to the surface (Moradi et al., 2013). It is therefore likely that the strong rooting system of *P. juliflora* can lead to an increase in soil EC as compared to *A. tortilis* and *A. ehrenbergiana* (Kahi, 2009).

Sodium and calcium concentrations were generally higher in soil under the canopy of invasive *P. juliflora.* Conversely, magnesium, nitrogen, and potassium were generally lower at sites with *P. juliflora* as compared to sites with just native *Acacia* and *Prosopis*. This is similar to the findings of Garg and Singh (2003), Bavaraja et al. (2007), and Kahi (2009), who also found differences in topsoil exchangeable cations at sites with invasive *P. juliflora.* It should be noted that the combination of cations and metal ions in the soil accelerates the inhibitory effect of allelopathy (Zhang et al., 2015). This might be the main reason for the generally lower levels of calcium, potassium, and magnesium at sites with *A. tortilis* and *A. ehrenbergiana* in combination with *P. juliflora* as opposed to sites with only *Acacia* species.

5 Conclusions

Our results highlighted that *P. juliflora* invasions can alter topsoil physiochemical properties which may have knock-on negative effects on native plant communities. The results showed that soil organic matter, soil moisture, and exchangeable cations (potassium, calcium, nitrogen, and magnesium) were generally higher at sites with the native tree species (*A. tortilis*, *A. ehrenbergiana*, and *P. cineraria*) as compared to sites with *P. juliflora*. In addition, we also found that sites with *P. juliflora* led to an increase in EC and a decrease in soil acidity, which could affect the growth of native plants and the stability of local ecosystems in the long-run. This suggests that caution is needed when promoting and using known invasive trees such as *P. juliflora* for restoration initiatives, and that the use of native tree species may be more suitable for building resilient ecosystems in the long-term. More research is needed on which native tree species are most suitable for restoration programs in arid areas.

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References

Abbasi T, Abbasi S A. 2011. Sources of pollution in rooftop rainwater harvesting systems and their control. Critical Reviews in Environmental Science and Technology, 41: 2097–2167.

Al-Abdali S S, Al-Dhuhli A S, Al-Reasi H A. 2019. Preliminary investigations of allelopathic effects and herbicide-based eradication of mesquite (*Prosopis juliflora*). Sultan Qaboos University Journal for Science, 24(1): 11–17.

Bavaraja P K, Sharma S D, Badrinath M S, et al. 2007. *Prosopis juliflora*–An efficient tree species for reclamation of salt affected soils. Karnataka Journal of Agricultural Sciences, 20(4): 727–731.

Bijani A. 2020. Investigation of allelopathic effects of native and alien *Prosopis* on some soil chemical content and characteristics of *Accacia tortilis* and *Acacia ehrenbergiana* in Hormozgan Province (Sirick city). MSc Thesis. Bandar Abbas: Islamic Azad University.

Black C A. 1965. Methods of Soil Analysis. Madison: American Soil Society of Agronomy Press.

Blackburn T M, Essl F, Evans T, et al. 2014. A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology, 12(5): e1001850, doi: 10.1371/journal.pbio.1001850.

Chou C H. 2010. Roles of allelopathy in plant biodiversity and sustainable agriculture. Critical Reviews in Plant Sciences, 18(5): 609–636.

Dzikiti S, Schachtschneider K, Naiken V, et al. 2013. Water relations and the effects of clearing invasive *Prosopis* trees on groundwater in an arid environment in the Northern Cape, South Africa. Journal of Arid Environments, 90: 103–113.

Dzikiti S, Ntshidi Z, Le Maitre D C, et al. 2017. Assessing water use by *Prosopis* invasions and *Vachellia karroo* trees: Implications for groundwater recovery following alien plant removal in an arid catchment in South Africa. Forest Ecology and Management, 398: 153–163.

Edrisi S A, El-Keblawy A, Abhilash P C. 2020. Sustainability analysis of *Prosopis juliflora* (Sw.) DC based restoration of degraded land in North India. Land, 9(2): 59, doi: 10.3390/land9020059.

El-Keblawy A, Al-Rawai A. 2007. Impacts of the invasive exotic *Prosopis juliflora* (Sw.) D.C. on the native flora and soils of the UAE. Plant Ecology, 190(1): 23–35.

El-Keblawy A, Abdelfatah M. 2014. Impact of native and invasive exotic *Prosopis* congeners on soil properties and associated flora in the arid United Arab Emirates. Journal of Arid Environments, 100–101: 1–8.

El-Shabasy A. 2017. Study on allelopathic effect of *Prosopis juliflora* on mineral content of *Acacia ehrenbergiana* in Farasan Islands, KSA. Journal of Medicinal Plants Studies, 5: 130–134.

Fadoul M S, Elamin M A. 2016. Impact of water harvesting techniques on growth of some indigenous tree species in Jebel Awila Locality, Sudan. Global Journal of Science Frontier Research: (D) Agriculture and Veterinary, 16(3): 42–53.

Garg V K, Singh B. 2003. Macronutrient dynamics and use efficiency in three species of short rotation forestry developed on sodic soils in North India. Journal of Tropical Forest Science, 15(2): 289–302.

Gioria M, Osborne B A. 2014. Resource competition in plant invasions: emerging patterns and research needs. Frontiers in Plant Science, 5: 501, doi: 10.3389/fpls.2014.00501.

Goel U, Saxena D B, Kumar B. 1989. Comparative study of allelopathy as exhibited by *Prosopis Juliflora* swartz and *Prosopis cineraria* (L) druce. Journal of Chemical Ecology, 15: 591–600.

Goel V L, Behl H M. 1999. Screening of *Prosopis* germplasm for afforestation of degraded soil sites: performance, leaf nutrient status and influence on soil properties. Journal of Sustainable Forestry, 8(2): 1–13.

Guevara A, Giordano C V, Aranibar J, et al. 2010. Phenotypic plasticity of the coarse root system of *Prosopis flexuosa*, a phreatophyte tree, in the Monte Desert (Argentina). Plant Soil, 330: 447–464.

Hejda M, Pyšek P, Jarošík V. 2009. Impact of invasive plants on the species richness, diversity and composition of invaded communities. Journal of Ecology, 97(3): 393–403.

Inderjit, Seastedt T R, Callaway R M, et al. 2008. Allelopathy and plant invasions: traditional, congeneric, and biogeographical approaches. Biological Invasions, 10(6): 875–890.

Kahi C H, Ngugi R K, Mureithi S M, et al. 2009. The canopy effects of *Prosopis juliflora* (DC.) and *Acacia tortilis* (Hayne) trees on herbaceous plants species and soil physico-chemical properties in Njemps Flats, Kenya. Tropical and Subtropical Agroecosystems, 10(3): 441–449.

Kaur R, Gonzáles W L, Llambi L D, et al. 2012. Community impacts of *Prosopis juliflora* invasion: biogeographic and congeneric comparisons. PLoS ONE, 7(9): e44966, doi: 10.1371/journal.pone.0044966.

Kazemi S H, Hojjati M, Falah A, et al. 2015. Effect of forest management on soil physical and chemical properties of Khalil-Mahale forest. Journal of Forest Research and Development, 1(2): 167–180.

Linders T E, Bekele K, Schaffner U, et al. 2020. The impact of invasive species on social-ecological systems: Relating supply and use of selected provisioning ecosystem services. Ecosystem Services, 41: 101055, doi: 10.1016/j.ecoser.2019.101055.

Moradi M, Imani F, Naji H R, et al. 2013. Variation in soil carbon stock and nutrient content in sand dunes after afforestation by *Prosopis juliflora* in the Khuzestan province (Iran). iForest-Biogeosciences and Forestry, 10(3): 585–589.

Mosbah M, Tounekti T, Khemira H. 2018. Invasive character of *Prosopis juliflora* is facilitated by its allelopathy and a wide mutualistic interaction with soil microorganisms. Journal of Biological Sciences, 18: 115–123.

Nahali M H. 2000. Ecological evaluation of *Prosopis juliflora* and its potential for composting in Hormozgan province. Agricultural Economics and Development, 8(31): 305–323.

Nascimento C E D S, da Silva C A D, Leal I R, et al. 2020. Seed germination and early seedling survival of the invasive species *Prosopis juliflora* (Fabaceae) depend on habitat and seed dispersal mode in the Caatinga dry forest. Peer Journal, 8: e9607, doi: 10.7717/peerj.9607.

Pasiecznik N M, Harris P J C, Smith S J. 2004. Identifying Tropical *Prosopis* Species: A Field Guide. Conventry: HDRA Publishing.

Reinhart K O, Callaway R M. 2006. Soil biota and invasive plants. New Phytology, 170: 445–457.

Schachtschneider K, February E C. 2013. Impact of *Prosopis* invasion on a keystone tree species in the Kalahari Desert. Plant Ecology, 214(4): 597–605.

Shackleton R T, Le Maitre D C, Pasiecznik N M, et al. 2014. *Prosopis*: a global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. AoB Plants, 6: plu027, doi: 10.1093/aobpla/plu027.

Shackleton R T, Le Maitre D C, van Wilgen B W, et al. 2015. The impact of invasive alien *Prosopis* species (mesquite) on native plants in different environments in South Africa. South African Journal of Botany, 97: 25–31.

Shackleton R T, Shackleton C M, Kull C A. 2019. The role of invasive alien species in shaping local livelihoods and human well-being: A review. Journal of Environmental Management, 229: 145–157.

Sharifian A, Niknahad-Gharmakher H, Foladizada M, et al. 2022. Socio-ecological evidence highlights that native *Prosopis* species are better for arid land restoration than non-native ones. Restoration Ecology, doi: 10.1111/rec.13756.

Shiferaw H, Bewket W, Alamirew T, et al. 2019. Implications of land use/land cover dynamics and *Prosopis* invasion on ecosystem service values in Afar Region, Ethiopia. Science of the Total Environment, 675: 354–366.

Shitanda D, Mukonyi K, Kagiri M, et al. 2013. Properties of *Prosopis Juliflora* and its potential uses in asal areas of Kenya. Journal of Agriculture, Science and Technology, 15(1): 15–27.

Sintayehu D W, Dalle G, Bobasa A F. 2020. Impacts of climate change on current and future invasion of *Prosopis juliflora* in Ethiopia: environmental and socio-economic implications. Heliyon, 6(8): e04596, doi: 10.1016/j.heliyon.2020.e04596.

Smith J L, Doran J W. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. In: Methods for Assessing Soil Quality. Soil Science Society American. Madison, USA.

Thomas G W. 1982. Exchangeable cations. In: Page A L, Miller R H, Keeney D R. Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. Madison: American Society of Agronomy.

Vilà M, Espinar J L, Hejda M, et al. 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. Ecology Letters, 14(7): 702–708.

Weidenhamer J D, Callaway R M. 2010. Direct and indirect effects of invasive plants on soil chemistry and ecosystem function. Journal of Chemical Ecology, 36: 59–69.

Zhang X X, Liu Z W, Tian N, et al. 2015. Allelopathic effects of decomposed leaf litter from intercropped trees on rape. Turkish Journal of Agriculture and Forestry, 39: 898–908.