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USING EXOTIC SHRUBS AS A RESTORATION TOOL IN TUNISIAN ARID AREAS: EFFECTS ON UNDERSTOREY VEGETATION AND SOIL NUTRIENTS

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ABSTRACT

In this study, the effects of exotic and native shrubs *Acacia salicina* and *Retama raetam* on understory vegetation and soil properties were assessed. Two sub-habitats, a canopied and an un-canopied sub-habitat (open grassland), were distinguished for each shrub species. Soil moisture was measured in both sub-habitats at 10 cm depth, and soil samples collected from the upper 10 cm soil, excluding litter and stones. Aboveground biomass, species density and species richness were also estimated. The soil organic matter, total N and extractable P were significantly higher under shrubs than open areas at all soil water contents. Soil water content did not differ significantly between studied shrubs. Aboveground biomass, species richness and the density of perennial species were significantly higher under shrub canopies than open areas. Among the two studied shrubs species, *Retama raetam* displayed the strongest positive effect, but without significant differences, on the understory vegetation. From this perspective, exotic shrubs can be regarded as a powerful and promising candidate that can be invested in not only the elaboration of multiple restoration programs but also in the generation of islands of resources.

KEYWORDS: Arid ecosystems, exotic shrub, native shrub, restoration, soil characteristics.

INTRODUCTION

Biological invasion stands for the phenomenon of introducing species by humans (intentionally or accidentally) to regions where they have never occurred before, and would not have reached without human assistance (Hoffmann and Courchamp 2016). Biological invasions have achieved an unprecedented level and the number of the introduced species is still growing worldwide (Chabrerie et al. 2019). Recently, there has been a spate of interest in the spread and impacts of non-native trees and shrubs on biodiversity and ecosystem functioning (Holland- Clift et al. 2011, Keppel and Watling 2011, Aslan et al. 2012, Brand et al. 2012, Meinhardt and Gehring 2012, Rascher et al. 2012, Rodewald, 2012, Saure et al. 2013). Significant scientific efforts have been devoted and particularly oriented towards exploring the effects of introduced tree species on ecosystem services and landscapes (Noumi et al. 2015). The invasion of such tree species as Lodgepole pine (*Pinus contorta* Dougl.) in New Zealand, Mesquite (*Prosopis* in Africa and Monterey pine (*Pinus radiate* D. Don) in Australia and southern Africa have been reported (Davis et al. 2016). By promoting Australian acacias to the developing world, aid and development agencies have failed to learn from the mistakes carried out with mesquite (*Prosopis juliflora*) and jatropha (*Jatropha curcas*), which correspond to plants with weedy attributes entailing more harm than good when grown in Africa as aid. Additionally, numerous research works demonstrated that numerous exotic plant species exhibit toxic compounds, with negative effects on the survival and abundance of native plant species (Noumi et al. 2009, Noumi 2015). As a matter of fact, multiple land managers and restitution practitioners have been basically concerned with establishing communities of native plant species to withstand additional invasion of exotic species. For this reason, investing woody plants for the reestablishment of decayed arid and semi-arid ecosystems has been adopted worldwide as an influential measure to preserve soils (Castillo et al. 1997), fight desertification (Reynolds 2001), provide natural resources (Guevarat et al. 2003), and therefore enhance plant species and cover diversity (Cortina and Maestre 2005). A myriad of studies interested in arid and semiarid regions highlighted that appropriate species selection is a key factor for durability of environmental restoration (Cao et al. 2007). However, the restoration impact of establishing a single long-lived shrub species on shifting sand fixation in arid sandy landscapes, especially its effects on soil and vegetation composition still remains an obscure area to be deciphered and further investigated. Nonetheless, in Mediterranean arid and semiarid areas, very few studies have conducted manipulative field experiments to address the intrinsic effects of woody species on soil properties and understorey vegetation dynamics. This knowledge is primordial in order to fully and deeply understand community dynamics as well as elaborate sound management programs. Woody species could be used in restoration actions in degraded arid areas, provided that they display a positive effect on ecosystem composition and function.

The focus of this paper is upon the effect of two shrub species, namely exotic and native (*Acacia salicina* Lindl. and *Retama raetam*, respectively) on vegetation structure and soil properties in Tunisian dry lands. The main objective of this study is twofold: *(1)* to test if exotic shrubs present a negative impact in terms of soil properties and vegetation dynamics, and *(2)* to provide practical suggestions for shrub plantation management and ecological restoration.

MATERIALS AND METHODS

Study area and vegetation

The experiment was conducted in a fenced area ‘El Gonna’ (34º41’66’’N, 10º30’22’’E), 20 km west of Sfax in Southern Tunisia. Before fencing, the area was used as summer rangeland grazed mainly by sheep and goats in a wide grazing system. In 1995, the area was protected from grazing and planted with 1 year old *Acacia salicina* and *Pinus halepensis* at a density of 200 individuals per hectare. According to the classification proposed by the United Nations Environmental Program resting on the aridity index (AI, the ratio of mean annual precipitation to mean annual potential evapotranspiration), the climate is arid (0.05 < AI < 0.20). Temperatures range from an annual mean minimum of 2ºC to a mean maximum of 24°C. The predominant soils are alkaline sandy loam, with friable caliches at 10 - 25 cm depth and gypsum outcrops. Topography is mainly hilly. The area is occupied by an overgrazed *Stipa tenacissima* L. steppe with species such as *Retama raetam*, *Hammada scoparia*, *Lycium shawii*, *Gymnocarpos decander*, and *Artemisia herba alba* and *Artemisia campestris*. This is suggestive of vegetation recovery after grazing exclusion (Jeddi 2009).

Vegetation sampling

Over the spring 2020 growing season, we selected two different shrubs (exotic and endogenous) in two communities with contrasting water availability. At each community, forty individual shrubs (20 *A. salicina* + 20 *R. raetam*) were randomly selected and height and canopy diameter determined (Tab. 1). For each shrub, two 1 × 1 m quadrats were located beneath the canopy at two aspects (North and South). Open area refers to quadrats located in the inter-tree areas outside the crown projection. Within each quadrat, all aboveground plant mass was collected and sorted into individuals and species, and oven dried (70°C for 48 hr.). Plant density and richness were estimated.

Tab. 1: Heights and crown diameters of the two shrub species (mean ± standard error).

Shrub species	*R. raetam*	*A. salicina*
Height (m)	1.22 ± 0.20	1.42 ± 0.25
Crown diameter (m)	1.66 ± 0.33	1.56 ± 0.40

Soil sampling

Soil volumetric water content was measured at different habitats (dry and wet) at 10 cm depth with a TDR probe (ThetaProbe ML2x, Delta T, Cambridge, UK). Ten random points were selected per habitat (20 under *A. salicina* (10 Northern + 10 Southern), 20 under *R. raetam* (10 Northern + 10 Southern) and 10 open areas for were used during the study period. Soil moisture assessment was initially conducted during the dry period, then subsequently after 40 mm of rain, at the intervals of 5, 10 and 15 days. Soil fertility was assessed from samples from the upper 10 cm over the dry period, with five replicates per quadrat. Soil samples were air-dried and sieved (2 mm) for chemical analyses, and oxidizable soil organic matter (Walkly black procedure; Nelson and Sommers 1982); extractable phosphate (Olsen's bicarbonate extraction) and total nitrogen (Kjeldahl method) (Olsen and Sommers 1982) determined.

Data analysis

One-way ANOVA was used to assess differences among sub-habitats (under *A. salicina*, under *R. raetam* and open area) in individual species density, species richness, aboveground biomass, dry matter, soil nutrients and soil water content. When the difference between group means was significant, a multiple comparison of means test (post hoc Tukey's honestly significant difference test) was carried out. No transformations were needed to meet parametric assumptions for ANOVA. The SPSS program version 17.0 (SPSS, Inc., Chicago, IL, USA) was applied for statistical analyses.

RESULTS AND DISCUSSION

Shrub and vegetation characteristics

Community has a significant effect on different vegetation parameters (Tab. 2, Fig. 1). In case water resources were restricted, the vegetation under wet community had much higher values compared to those under dry community. Above ground biomass, species richness and density was twice as high in the wet compared with the dry community. Results indicated no differences between the northern and southern aspects, especially for vegetation characteristics (species density and richness) (Tab. 2). The presence of shrubs improved all studied characteristics (aboveground biomass, species richness and density), but without differences between exotic and endogenous shrubs (Fig. 1). In the wet community, mean aboveground biomass ranged from 13.15 $mg \cdot m^{-2}$ in the open to 81.43 and 54.57 $mg \cdot m^{-2}$ under *Retama* and *Acacia*, respectively. In the dry community, mean aboveground biomass varied from 9.17 $mg \cdot m^{-2}$ in the open to 15.07 and 13.74 $mg \cdot m^{-2}$ under *Retama* and *Acacia*, respectively. Species richness and density was higher under the shrub canopy than in the open. In the wet community, mean species density ranged from 4.12 individuals/m^2 in the open to 10.21 and 8.95 individuals/m^2 under *Retama* and *Acacia*, respectively, and from 1.97 individuals/m^2 in the open to 4.21 and 3.67 individuals/m^2 for *Retama* and *Acacia*, respectively in the dry community. This tendency was also recorded for species richness (Fig. 1). Shrub presence enhanced all variables, with results under endogenous shrubs higher than under exotics.

Results indicated that exotic and endogenous shrubs contributed to the rise of plant species richness, density and aboveground biomass under their canopy (particularly on the north side) through the enhancement of soil fertility and soil water disposal. Species richness, density and biomass of annual plants was higher under shrub canopies in the wet winter season, 2020. Assessed soil fertility values were also higher under shrub canopies. The higher total plant cover and biomass under tree canopies agrees with earlier studies (Belsky et al. 1989, Abdallah et al. 2008). Some studies, however, confirmed that exotic plant incursions are not related to declines in species richness of native plants (French and Major 2001, Fleishman et al. 2005). Indeed, Wernberg et al. (2004) emphasized that while species richness of epibiota on plants along a shoreline in Denmark did not differ substantially between the exotic plant *Sargassum muticum* and the native *Halidrys siliquosa*, the overall abundance of epibiota was greater on the exotic plant compared to the native plant. In the current study, clear differences in terms of the density, richness and biomass of different species in the three subhabitats along both communities were inferred. These differences were likely to result from the impacts of the shrubs under study. In this respect, Callaway and Pugnaire (1999) asserted that positive interactions are likely to occur among trees and understorey plants, especially in dry environments, where shade, conservation of soil moisture and nutrient accumulation correspond possibly to the major facilitation mechanisms.

Tab. 2: Results of the three-way ANOVA models for the effects of communities, species, exposition and their interactions on the aboveground biomass. Significant (P < 0.05) effects are indicated in bold characters.

		March 2020	
Source of variation	df	*F*	*P*
Community	1	7.144	**0.005**
Species	1	0.043	0.008
Exposition	1	0.727	0.836
Community x Species	1	5.088	0.394
Community x Exposition	1	8.877	**0.003**
Species x Exposition	1	0.264	0.607
Community x Species x Exposition	1	0.040	0.841

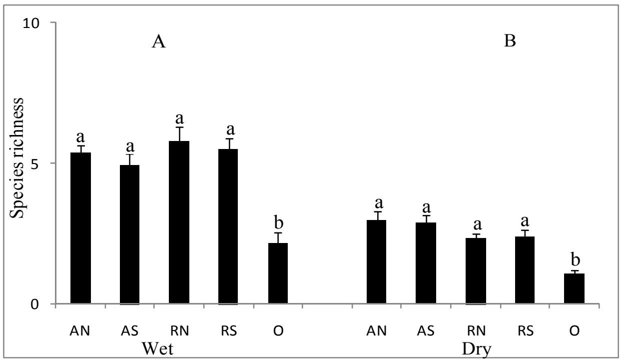

*Fig. 1: Aboveground biomass (*mg·m^{-2}*), species density (individuals/m^2) and species richness under different shrub species canopies and in open area between two communities (dry and wet). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test). AN- Northern acacia, AS - Southern acacia, RN - Northen retama, RS - Southern retama, O – open.*

Shrubs and soil properties

The organic matter, total nitrogen and extractable phosphorus were higher under shrubs than in open plots, with differences between aspects (Fig. 2). In the wet community, OM, TN and extractable P were higher than 1.5, which is twice higher under the canopy than in the open area, especially in the southern exposition. There were significant differences in soil features among community treatment (Fig. 2). The organic matter, total nitrogen and extractable phosphorus were implicitly higher in the wet community compared to dry one. Before rainfall, no difference was detected between different treatments (Fig. 3). Five days after a rainfall of 40 mm, there was more substantial soil water in the northern exposition of different shrubs, less in the southern one and least in the open patch (Fig. 3, $P < 0.05$). The recorded values remained constant for 10 days in wet and dry communities. At 15 days post-rainfall event, neither shrubs nor communities had any impact on soil moisture levels.

The present study demonstrated that soil fertility indices (organic matter, total nitrogen and extractable phosphorus) were substantially higher under the canopy area of shrubs than in open area. Soils under woody canopies are more fertile than those from the surrounding grassland (Belsky et al. 1989, Callaway et al. 1991, David et al. 2004, Abdallah et al. 2008, 2012, Noumi et al. 2012). Under arid bioclimate, nutrients such as nitrates, phosphorus, series of anions and cations and various trace elements, are intrinsic for the nutrition of plants (Bell 1982), and act as determinants at the level of vegetation dynamics. Under the canopies of shrubs and trees, soils are more fertile than those from the surrounding grassland (Belsky et al. 1989, Callaway et al. 1991). In this regard, our work revealed that the various soil fertility indices (organic matter, total nitrogen and extractable phosphorus) were significantly higher in the canopy area of shrubs compared to open areas.

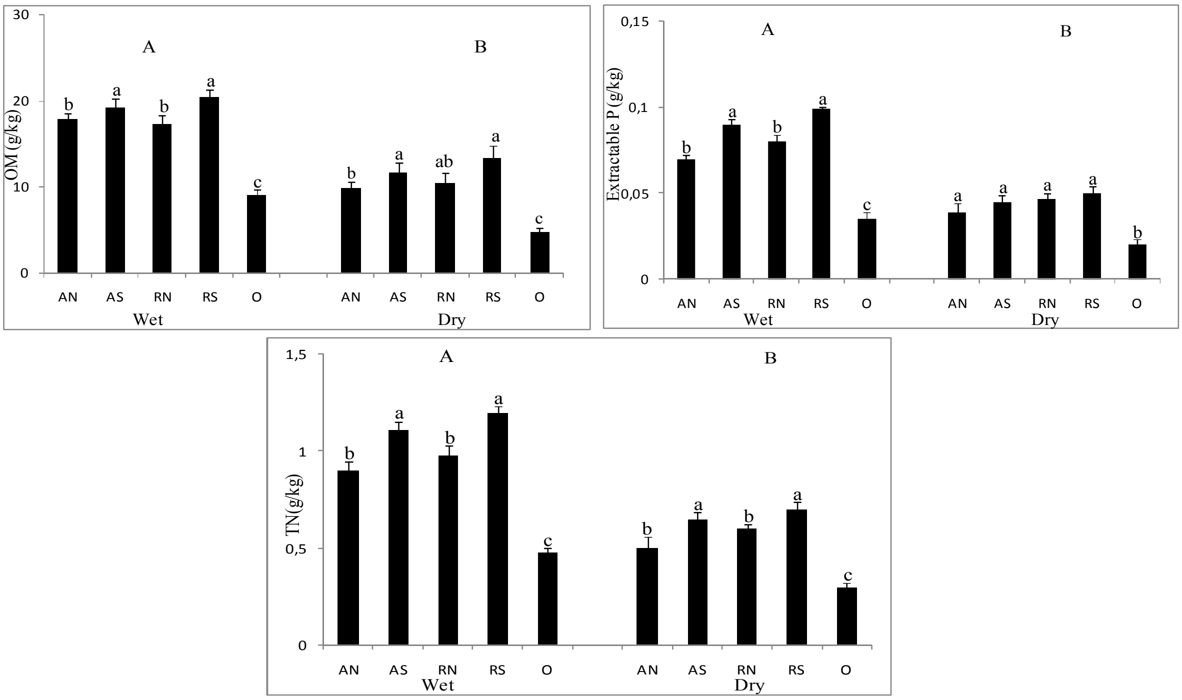

Fig. 2: Organic matter (OM), extractable phosphorus (P) and total nitrogen (TN) under different shrub species canopies and in open area between two communities (dry and wet). Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test). AN- Northern acacia, AS - Southern acacia, RN - Northen retama, RS - Southern retama, O – open.

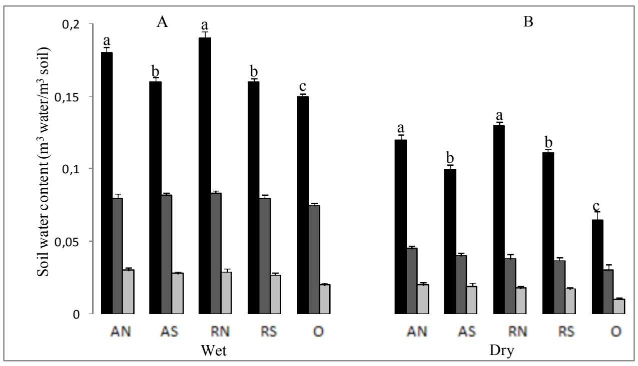

Fig. 3: Temporal change of soil water content under different shrub species canopies and in open area between two communities (dry and wet). Sampling were carried out 5,10 and 15 days after a rain of 40 mm. Mean values which are not followed by the same letter are statistically significant (Tukey's HSD-test). AN- Northern acacia, AS - Southern acacia, RN - Northen retama, RS - Southern Retama, O – open.

CONCLUSIONS

The results of this study confirmed the positive effect of woody plants on the understorey vegetation composition in arid ecosystems. The net effect of shrubs on their own environment, whether it is positive or negative, is strongly dependent on the nature of the woody cover. Because studied shrubs are a leguminous species, it was not surprising that it showed a strong positive effect on soil fertility and understorey vegetation attributes. It is generally propagated by seeds and further work is necessary to determine how it can be re-established in areas where it was once prevalent but has now disappeared.

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