



Original article

Influence of the invasive shrub *Nicotiana glauca* Graham on the plant seed bank in various locations in Taif region, western of Saudi ArabiaAbdullah S. Alharthi^a, Ahmed M. Abd-ElGawad^{a,b,*}, Abdulaziz M. Assaeed^a^a Plant Production Department, College of Food & Agriculture Sciences, King Saud University, P.O. Box 2460, Riyadh 11451, Saudi Arabia^b Department of Botany, Faculty of Science, Mansoura University, Mansoura 35516, Egypt

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ABSTRACT

Invasive species have been considered as one of the most serious threats to the biodiversity of various ecosystems, particularly in arid regions. The present study aimed to assess the influence of the invasive shrub *Nicotiana glauca* on the biodiversity of different habitats in Taif region, Saudi Arabia as well as to determine the highest habitat with seed bank of *N. glauca*. Soil samples were collected from three locations (Alwaht, Ash-shafa, and Ar Ruddaf), invaded with *N. glauca*, and analyzed for the soil seed bank. A soil seed experiment was designed in a greenhouse, whereby emerged plant seedlings were left to grow for three months and identified as well as the species density and biodiversity were assessed under and outside the canopy of *N. glauca*. Also, the floristic composition, life forms, and chorotype spectra of the plant species of the seed bank were analyzed. A total of 42 species, belonging to 23 families, were recorded in the soil seed bank. Asteraceae, Poaceae, and Cyperaceae were the major families (42.9%). The life form spectra of the recorded species were dominated by Therophytes (59.5%). Chorotype spectra analysis revealed that Mediterranean, Saharo-Arabian, and Irano-Turanian were the most represented elements. The species richness and evenness were higher outside the canopy, which indicates a negative effect of the invasive shrub *N. glauca* on the plant biodiversity in the study area, particularly in Ar Ruddaf location. This could be attributed to the competition or allelopathic effect of *N. glauca*. In contrast, the density of *N. glauca* seeds was higher under the canopy compared to outside. The soil nutrients and moisture under the canopy were higher than outside canopy. The present study provides a deeper understanding of the most susceptible habitats or communities to the invasion by *N. glauca* and thereby open the challenge toward control of this noxious plant and vegetation restoration.

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1. Introduction

Invasive species are defined as those non-native species that threaten habitats and thus damage the structure and function of both terrestrial and aquatic ecosystems (Pejchar and Mooney, 2009; Keller et al., 2011). Invasive species are considered fundamental causes of reduction in native species abundance and con-

tributing to biodiversity loss and damage of ecosystem services in various environments (Didham et al., 2005; Shochat et al., 2010; Duenas et al., 2018; Linders et al., 2019). Subsequently, the invasive species lead to community changes and ecosystem-level shifts, so they are an increasing challenge worldwide for the management of biodiversity and ecosystem functioning (Brooks et al., 2004).

Invasive plants are known to alter the nutrient cycling, soil moisture dynamics, and energy budgets, therefore affecting native flora, fauna and ecosystem services (Liao et al., 2008; Hulme et al., 2013). Invasive plants usually precede native plants in the exploitation of water and nutrient resources, hence colonizing new habitats. This is because most invasive plants have important characteristics such as short life-cycles, rapid growth, high reproductive ability, and highly competitive efficiency. As a result, they succeed in various habitats and become superior to those of native species (Abd El-Gawad and El-Amier, 2015; Bonanomi et al., 2018; Rai and Singh, 2020; Wang et al., 2019; Incerti et al., 2018).

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There are many hypotheses describing the interactions involved in plant invasions. According to the evolution of increased competitive ability hypothesis, introduced plants have the potential to reallocate resources as a defense mechanism against the native species (Blossey and Notzold, 1995). Based on the novel weapons hypothesis, invader plants become able to produce allelopathic agents as novel biochemical weapons, that interfere with the native plants and influence the plant-soil microbial interactions (Callaway and Ridenour, 2004). On the other hand, the biological resistance hypothesis states that ecosystems with high biodiversity are more resistant to invaders than ecosystems with low biodiversity (Lonsdale, 1999; Jeschke et al., 2012). According to the enemy release hypothesis, the success of the invasion is due to absent enemies in the exotic range (Heger and Jeschke, 2014). The propagule pressure hypothesis posits that high propagule pressure (quality, quantity, and frequency of invasive organisms) is a cause of invasion success (Lockwood et al., 2005, 2013). According to fluctuating resource hypothesis in plant invasion (Davis et al., 2000), resource release through disturbance events make a site vulnerable to invasion at any particular point in time or space especially in low-resource environments (Davis and Pelsor, 2001).

The tree tobacco *Nicotiana glauca* Graham (Solanaceae) is a cosmopolitan invasive fast-growing plant, and it is a native perennial shrub of northwest Argentina and Bolivia (Issaly et al., 2020). Now, *N. glauca* is widely naturalized in warm temperate regions of the world (Florentine et al., 2006) and has spread worldwide through human activity. It is a successful invasive shrub in semi-arid areas. It has the ability to grow in a broad range of open and disturbed habitats, including roadsides, disturbed areas, rocky places, coastal beaches, arid grasslands, and flood plains, where it is growing as isolated patches, maybe up to 70 individual in each population (Nattero and Cocucci, 2007). *N. glauca* grows in a wide range of elevations and soil conditions that enabling it to grow vigorously and spread as a monospecific stand (Florentine et al., 2006; Thomas et al., 2016; Al-Robai et al., 2019). *N. glauca* is a reservoir plant of dangerous viruses that infect many plant species including cultivated plants such as tobacco mosaic virus (TMV) and tomato infectious chlorosis crinivirus (TICV) that have been discovered in *N. glauca*, as host, in several parts of the world (Duffus et al., 1996; Favara et al., 2019). Also, this plant has been reported to produce anabasine which is a poisonous chemical compound to both human and animals (Scharenberg et al., 2019).

Throughout the past few decades, many exotic plants invaded large areas in Saudi Arabia, particularly in the southwestern region, where $\approx 74\%$ species of the flora exist (Thomas et al., 2016). *N. glauca* is one of the major invaders in Saudi Arabia, where it grows in high altitude areas between 800 and 2700 m.a.s.l. and invade new habitats (Thomas et al., 2016).

Although *N. glauca* has been ranked among the top six invasive plants that are damaging the biodiversity and altering the ecosystems in Saudi Arabia, no study dealt with the distribution and impacts of this noxious shrub. We hypothesize that understanding the ecological characteristics of *N. glauca* at an early rather than late-stage will supports suitable control ways of this noxious plant and, in consequence, restore natural vegetation. Therefore, the present study is aimed to assess the impact of *N. glauca* on the seed bank of natural native vegetation of the different habitats Taif region, Saudi Arabia as well as determine the habitats with high seed bank of *N. glauca*.

2. Material and methods

2.1. Study areas

The study was carried out during 2019 in Taif Governorate, which is located on the slopes of Al-Hijaz Mountains in the western

region of Saudi Arabia (Fig. 1). The climate is arid with precipitation of 181 mm/year as the 30-year mean total annual rainfall, mainly occur between April and November. The average annual temperature is 22.8 °C, with the minimum mean temperatures (15 °C) in January and the maximum (29 °C) in July (Vincent, 2008).

2.2. Plant and soil sampling

Within the study area, three locations were chosen around Taif region, with elevations ranging from 1600 to 2500 m.a.s.l. These were the most invaded location in Taif region. Moreover, six stands were chosen to represent different habitats, including two stands from Alwaht (WHT), three stands from Ash-shafa (SHFA), and one stand from Ar-Ruddaf (RDF) (Table 1 & Fig. 1). The number of stands per each location was determined to cover the area, i.e. according to the area size of the location and the invaded patches. From each stand, three soil samples were collected under the canopy of three *N. glauca* shrubs or outside canopy, in May 2019. In detail, the litter layer was removed, and surface soil sample with volume $\approx 4000 \text{ cm}^3$ (area [20 × 20 cm] and depth [10 cm]) was taken from three random locations under the canopy of *N. glauca* shrubs and merged as a composite soil sample. A similar three soil samples were collected outside the canopy of *N. glauca*, by at least 5 m. A total of 36 samples (6 stands × 3 replications [shrubs] × 2 treatments [under and outside canopy]) were collected in plastic bags, labeled, and transferred to the greenhouse in the College of Food and Agricultural Sciences, King Saud University, Saudi Arabia.

2.3. Soil seed bank experiment

The seed density of the seed bank was assessed through the seedling emergence techniques (Baker, 1989). In brief, each sample was thoroughly mixed to confirm seed distribution well, also some materials such as rocks, woods, and leaves were removed. The soil was spread equally in rectangular perforated plastic trays (45 × 45 × 7 cm) lined with less than 2 cm in the depth of the sterilized sand substrate. The trays were arranged on the benches in a greenhouse, and water was added daily in the first month, then it was every three days for the two additional months. The number of germinated seedlings for each species was recorded weekly.

The experiment lasted for three months, October, November, and December 2019, after this period, no more seedlings emerged. During the time of experiment, all seedlings that grew and became clearly recognized were identified, recorded, and removed. The identification of the plants was performed according to Collenette (1999), Chaudhary (1999), Chaudhary (2000), and Chaudhary (2001). Also, the number of species in each tray was counted, and the relative density for each species was determined according to the following equation:

$$\text{Relative density}(\%) = 100 \times \frac{\text{Number of individual of one species}}{\text{Total number of all individuals of all species}}$$

The chorotypes and life forms of all identified plants were investigated according to Raunkiaer (1937).

2.4. Soil analysis

The collected soil samples, under- and outside canopy, were physically and chemically analyzed. Moreover, fresh soil samples were collected in a moisture tin, and directly the soil moisture was determined by the weight loss method. Soil samples were air dried at room temperature till complete dryness and then sieved through a 2-mm sieve to remove any contaminants. The soil texture was determined according to Bouyoucos (1962), while soil electrical conductivity (EC) and pH were determined in the soil

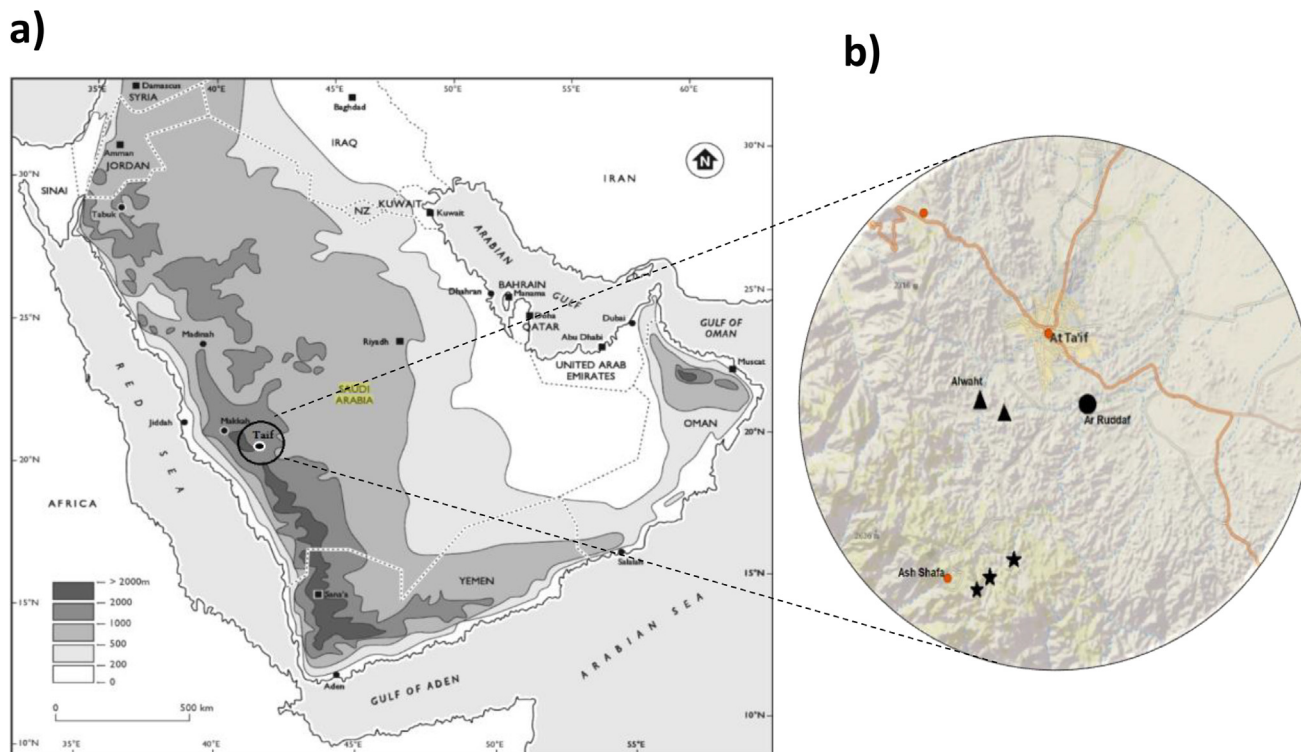


Fig. 1. Map showing the study area. **A)** Location of the study area in southwestern Saudi Arabia. **B)** Taif region and location of the study sites in Alwaht (black triangles), Ash-shafa (black stars) and Ar Ruddaf (black circle).

Table 1
Locations and stands data used for soil seed bank study under the canopy of *N. glauca*.

Location	Stands	Lat/long	Elevation (m.a.s.l.)
Alwaht	WHT1	21°10'05" N – 40°21'24"E	1819
	WHT2	21°09'39" N – 40°21'38"E	1865
Ash-shafa	SHFA1	21°04'14" N – 40°21'30"E	2059
	SHFA2	21°04'33" N – 40°21'44"E	2078
	SHFA3	21°04'54" N – 40°22'10"E	2046
Ar Ruddaf	RDF	21°13'22" N – 40°26'18"E	1674

solution (1:5) (Rowell, 1994). The Cl and SO₄ were determined in the soil solution using the titration method, whereas Ca, Mg, Na, and K, were determined using a flame photometer according to Rhoades (1982). Available nitrogen was determined by the Kjeldahl method as described by Bremner and Mulvaney (1982), while available phosphorus was determined colorimetrically as described by Nelson and Sommers (1982).

2.5. Data analysis

The plant species diversity of the seed bank of all stands was determined by calculating species richness (Simpson index) and species evenness (Shannon-evenness) according to the following equations:

$$Simpson\ index\ (S) = \frac{\sum_i [n_i \times (n_i - 1)]}{[N \times (N - 1)]}$$

$$Shannon - Wiener\ index\ (H) = \sum_{i=1}^S P_i \ln(P_i)$$

$$Shannon - Evenness\ index\ (E) = \frac{H}{\ln S}$$

where $P_i = n_i/N =$ proportional abundance of species, i in a habitat made up of s species, $n_i =$ the number of quadrats containing species i and $N = \sum n_i$.

To measure the influence of the invasive shrub *N. glauca* on the biodiversity of the invaded locations, the relative interaction index (RII) was calculated according to Armas et al. (2004), using to the following formula:

$$RII = \frac{(Species\ diversity_{under\ canopy} - Species\ diversity_{outside\ canopy})}{(Species\ diversity_{under\ canopy} + Species\ diversity_{outside\ canopy})}$$

The RII value ranges from -1 to +1, which represents the intensity of reduction or increase in species diversity due to shrub presence.

The data of soil analysis of different locations were subjected to one-way ANOVA followed by Tukey’s HSD test using CoStat 6.3 program (CoHort Software, Monterey, CA, USA)

3. Results

3.1. Floristic analysis of the plant species of the seed bank

The soil seed bank of the studied stands has an overall 42 plant species comprising a total of 3643 individuals. Out of them, 1810 individuals of *N. glauca* were recorded in the seed bank under the canopy, while 233 individuals were recorded outside canopy. Among the recorded plants, four species (*Solenostemma argel*, *Spergula fallax*, *Cenchrus ciliaris*, and *Pennisetum setaceum*) only exist in the soil seed bank under canopy of *N. glauca*, while eight species were recorded outside the canopy (Fig. S1).

The recorded species are belonging to 24 families, with Asteraceae, Poaceae, and Cyperaceae as major families, which represent 42.9% of all species (Table 2 & Fig. 2a). Among the 42 species, 15 species were recorded in WHT1 location (35.7% of the total), while 11 species (26%) were recorded in WHT2 location. On the other

Table 2

The floristic characteristics of the recorded plant species in the seed bank under (U) and outside (O) canopy of *N. glauca* within the different locations.

No.	Family	Botanical name	Chorotype	Life form	WHT 1		WHT2		SHFA1		SHFA2		SHFA3		RDF	
					U	O	U	O	U	O	U	O	U	O	U	O
1	Aizoaceae	<i>Aizoon canariense</i> L.	SA + SZ	Th	0.22*	1.05	-	-	-	0.92	-	-	-	3.03	-	26.32
2	Apocynaceae	<i>Solenostemma argel</i> (Del.) Hayne	SA	Ch	-	1.05	-	-	-	-	-	-	-	-	-	-
3	Boraginaceae	<i>Heliotropium curassavicum</i> L.	NEO	Ch	-	-	-	-	-	-	-	-	-	-	16.18	-
4	Caryophyllaceae	<i>Spergula fallax</i> (Lowe) Krause	ME + SA + SZ	Th	-	-	-	-	0.92	-	-	-	-	-	-	-
5	Amaranthaceae	<i>Chenopodium carinatum</i> R. Br.	SA + SZ	Th	0.22	-	-	-	3.79	-	-	2.63	7.04	7.58	-	-
6		<i>Chenopodium glaucum</i> L.	ME + ES	Th	-	-	0.58	0.50	-	-	-	-	-	-	-	-
7		<i>Chenopodium album</i> L.	COSM	Th	-	-	-	-	-	-	-	-	-	-	11.76	-
8	Asteraceae	<i>Coryza bonariensis</i> L.	AM	Th	0.43	-	-	-	-	-	1.97	5.63	-	-	-	-
9		<i>Lactuca serriola</i> L.	ME + IT + ES + SZ	Th	0.43	-	-	-	0.19	-	0.11	0.66	-	-	-	-
10		<i>Picris babylonica</i> Hand-Mazz.	SA	Th	-	-	-	-	-	-	0.11	-	-	-	-	-
11		<i>Pulicaria arabica</i> (L.) Cass.	ME + IT	Th	-	-	-	-	2.08	20.28	-	-	-	-	-	-
12		<i>Pulicaria undulata</i> (L.) C.A. May	SA	Ch	0.43	2.11	0.58	1.51	2.27	3.69	-	10.53	5.63	1.52	1.47	5.26
13		<i>Sonchus oleraceus</i> L.	ES + ME + IT	Th	-	-	0.58	0.50	0.38	1.38	-	1.97	-	1.52	-	5.26
14		<i>Verbesina encelioides</i> (Cav.) Benth. & Hook.	PAN	Th	0.43	10.53	-	-	-	-	-	-	-	-	-	-
15	Cyperaceae	<i>Cyperus laevigatus</i> L.	ME + SA + IT	He	-	-	-	-	0.76	0.46	0.56	-	-	-	-	-
16		<i>Cyperus rotundus</i> L.	PAN	He	-	-	-	-	1.33	-	-	1.97	-	-	-	-
17		<i>Eleocharis geniculata</i> (L.) Roem. Schult.	PAN	He	-	-	-	-	0.57	0.92	2.12	0.66	-	-	-	-
18		<i>Eleocharis mitracarpa</i> Steud.	PAN	He	-	-	-	-	0.57	-	0.11	1.97	-	-	-	-
19	Euphorbiaceae	<i>Euphorbia prostrata</i> Aiton	COSM	Th	1.94	26.32	43.93	39.70	12.88	5.07	2.91	37.50	1.41	3.03	-	-
20	Frankeniaceae	<i>Frankenia pulverulenta</i> L.	ES + ME + IT	Th	-	-	-	-	-	-	-	-	-	-	7.35	-
21	Juncaceae	<i>Juncus bufonius</i> L.	COSM	Th	-	-	-	-	4.17	1.38	0.78	1.97	-	-	-	-
22	Lythraceae	<i>Lythrum hyssopifolium</i> L.	IT	Th	-	-	-	-	3.98	3.23	0.22	-	-	-	-	-
23	Malvaceae	<i>Malva parviflora</i> L.	ME + IT	Th	-	-	-	-	0.76	-	0.11	1.97	-	-	-	-
24	Molluginaceae	<i>Mollugo cerviana</i> (L.) Seringe	TR	Th	1.30	-	-	-	-	-	-	-	-	-	2.94	-
25	Myrtaceae	<i>Eucalyptus camaldulensis</i> Dehn.	AUST	Nph	-	-	-	-	-	-	-	-	-	-	8.82	10.53
26	Papaveraceae	<i>Argemone ochroleuca</i> Sweet.	TR	Th	0.65	-	-	-	1.33	1.84	0.11	0.66	-	-	2.94	-
27	Plantaginaceae	<i>Plantago amplexicaulis</i> Cav.	SA	Th	1.30	9.47	1.16	-	-	-	-	3.29	2.82	3.03	-	-
28		<i>Veronica anagallis-aquatica</i> ssp. <i>anagallis-aquatica</i> L.	COSM	He	-	-	-	-	0.76	3.23	0.78	-	-	-	-	-
29	Poaceae	<i>Cenchrus ciliaris</i> L.	SA + SZ	He	-	-	-	-	-	-	-	-	-	4.55	-	-
30		<i>Eragrostis papposa</i> (Roemer & Schultes) Steudel	PAN	Th	-	-	1.01	0.19	0.19	-	1.12	12.50	57.75	22.73	-	-
31		<i>Erigeron canadensis</i> (L.) Cronquist.	AM	Th	0.22	1.05	1.16	0.50	-	-	-	-	2.82	-	-	-
32		<i>Hyparrhenia hirta</i> (L.) Stapf	ME + SA + IT	Th	0.22	2.11	0.58	3.52	0.19	-	-	3.29	-	7.58	-	-
33		<i>Pennisetum setaceum</i> (Forsk.) Chiov.	ME + PAL	He	-	-	1.51	-	-	-	-	-	-	-	-	-
34		<i>Polypogon monspeliensis</i> (L.) Desf.	ME + SA + IT	Th	0.22	4.21	-	-	-	1.38	-	0.66	-	-	-	-
35		<i>Polypogon viridis</i> (Gouan) Breistr.	ME + IT	He	-	-	-	-	14.20	30.41	0.34	4.61	-	-	-	-
36	Portulacaceae	<i>Portulaca oleracea</i> L.	COSM	Th	-	-	-	-	-	-	0.22	0.66	1.41	1.52	-	-
37	Primulaceae	<i>Samolus valerandi</i> L.	PAL	He	-	-	-	-	2.46	0.92	-	1.32	-	-	-	-
38	Solanaceae	<i>Nicotiana glauca</i> Graham	PAN	Nph	92.01	42.11	50.29	51.26	39.02	17.51	88.04	9.21	11.27	43.94	36.76	52.63
39	Typhaceae	<i>Typha domingensis</i> (Pers.) Poir	ME + IT + PAL	He	-	-	-	-	8.14	6.45	1.68	-	1.41	-	1.47	-
40	Urticaceae	<i>Forsskaolea tenacissima</i> L.	SA + SZ	Ch	-	-	1.16	-	-	-	-	-	2.82	-	-	-
41	Verbenaceae	<i>Verbena officinalis</i> L.	COSM	Th	-	-	-	-	-	0.67	-	-	-	-	-	-
42	Zygophyllaceae	<i>Peganum harmala</i> L.	ME + SA + IT + ES	Ch	-	-	-	-	-	-	-	-	-	-	1.47	-

* mean value of relative density of emerged plants of soil seed bank, WHT: Alwaht, SHFA: Ash-shafa, RDF: Ar-Ruddaf (RDF), MD: Mediterranean, COSM: Cosmopolitan, SA: Saharo-Arabian, AM: American, TR: Tropical, ES: Euro-Siberian, IT: Irano-Turanian, AU: Australian, SZ: Sudano-Zambeian, Pan: Pantropical, PAL: Palaetropical. Life forms: Ch: Chamaephytes, He: Hemicryptophytes, Nph: phanerophytes, Th: Therophytes.

hand, 25 species (59.5%) were recorded in SHFA1 location, and 27 species (64%) were recorded in SHFA2 location. Finally, 15 species (35.7%) were recorded in SHFA3 location, and 13 species (31%) recorded in RDF location. The recorded species can be classified into four life forms according to Raunkiaer (1937) as shown in

Fig. 2b. The studied sites were dominated by Therophytes, which are represented by 25 species, followed by the Hemicryptophytes (10 species), Chamaephytes (5 species), and Nanophanerophytes (2 species).

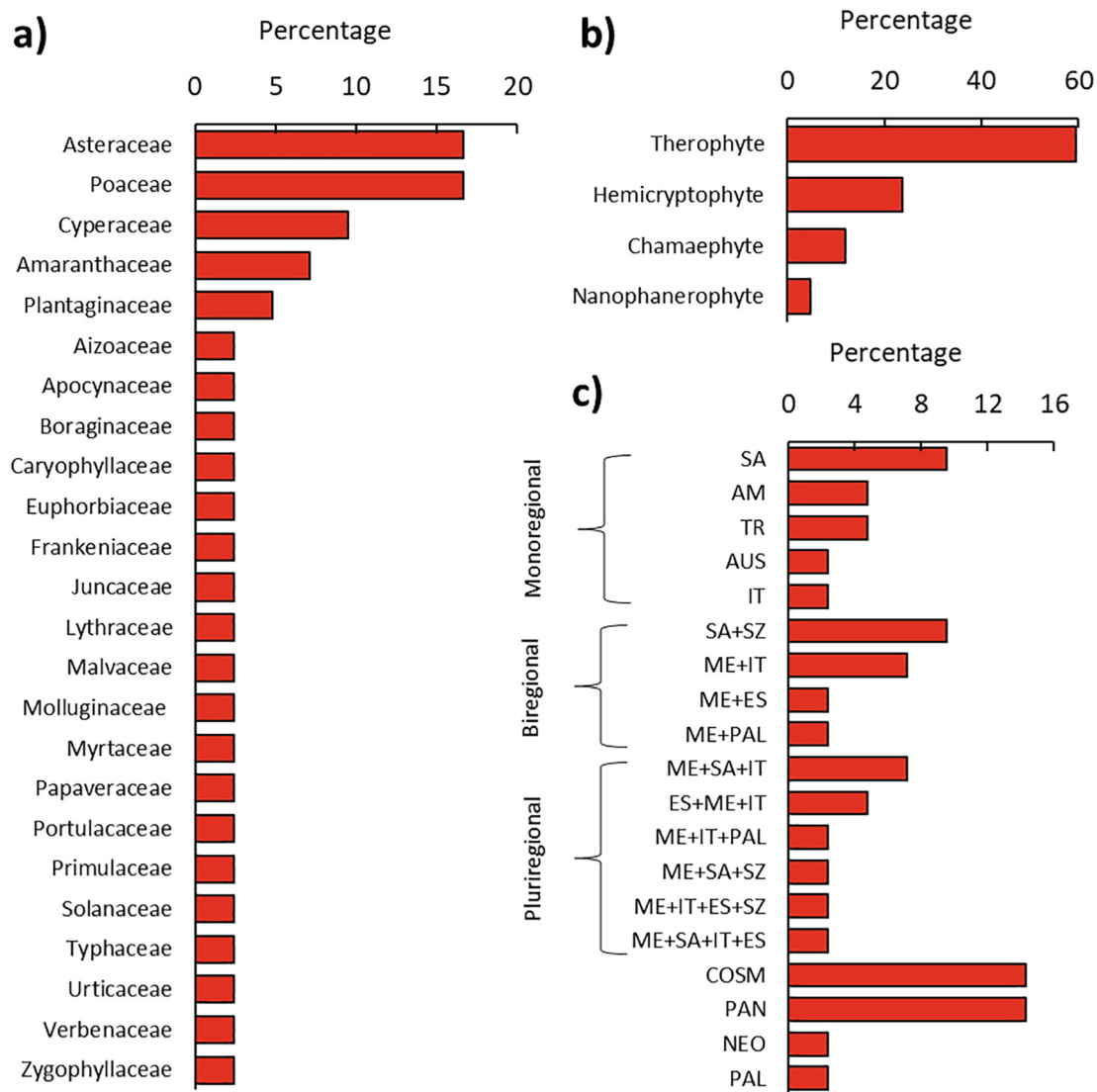


Fig. 2. Floristic composition of the seed bank species within the study sites. a) Plant families, b) life forms according to Raunkiaer's classification, and c) Chorotype spectra.

The chorotype analysis of the recorded species from the seed bank revealed that 23.8% of the species were monoregional, and the Saharo-Arabian element was the most represented chorotype. On the other side, 21.4% of the recorded species were Birregional, where Saharo-Arabian + Sudano-Zambeian element was the most recorded chorotype. Also, 21.4% of the recorded species were pluriregional, where the most chorotype were Mediterranean + Saharo-Arabian + Irano-Turanian element. Additionally, the phyto-geographical categories included cosmopolitan, pantropical, palaeotropical, and Neotropical (Fig. 2c). The chorological analysis of the floristic data revealed the dominance of cosmopolitan species, Saharo-Arabian elements and Sudano-Zambeian.

3.2. Impact of *N. glauca* on the plant species abundance of the seed bank

The seeds of *N. glauca* attained higher density under the canopy of mother shrubs than outside canopy in all locations (WHT, SHFA, and RDF). The seeds of *N. glauca* represent 60.4% of the seed bank in the study area. On the other hand, the relative density of the understory plant species showed substantial variations among the studied locations. The relative densities of the plant species

were higher outside the canopy of *N. glauca* in all locations. In WHT1 location, *Euphorbia prostrata*, *Verbesina encelioides*, *Plantago amplexicaulis*, *Polypogon monspeliensis*, and *Hypparrhenia hirta* attained more density outside canopy than under canopy of *N. glauca* (Fig. 3). While in WHT2 location, the *Euphorbia prostrata* showed more abundance under the canopy. In RDF location, *Aizoon canariense*, *Eucalyptus camaldulensis*, *Pulicaria undulata*, and *Sonchus oleraceus* revealed more abundance outside the canopy of *N. glauca*, while *Heliotropium curassavicum*, *Chenopodium album*, and *Cyperus laevigatus* were more under canopy of *N. glauca* (Fig. 3).

When comparing the relative density among the SHFA1, SHFA2, and SHFA3 locations, the relative density of the plant species of the seed bank outside the canopy was higher than under the canopy of *N. glauca* in all locations (Fig. 4). In SHFA1 location, *Euphorbia prostrata*, *Polypogon viridis*, and *Pulicaria arabica* showed more abundance outside the canopy of *N. glauca*, while in SHFA2, *Euphorbia prostrata*, *Eragrostis papposa*, and *Pulicaria undulata* attained higher density outside canopy. In SHFA3, the *Eragrostis papposa* showed more abundance under canopy of *N. glauca*, while *Chenopodium carinatum* and *Cenchrus ciliaris* attained higher abundance outside canopy compared to under canopy (Fig. 4). By pooling the data of

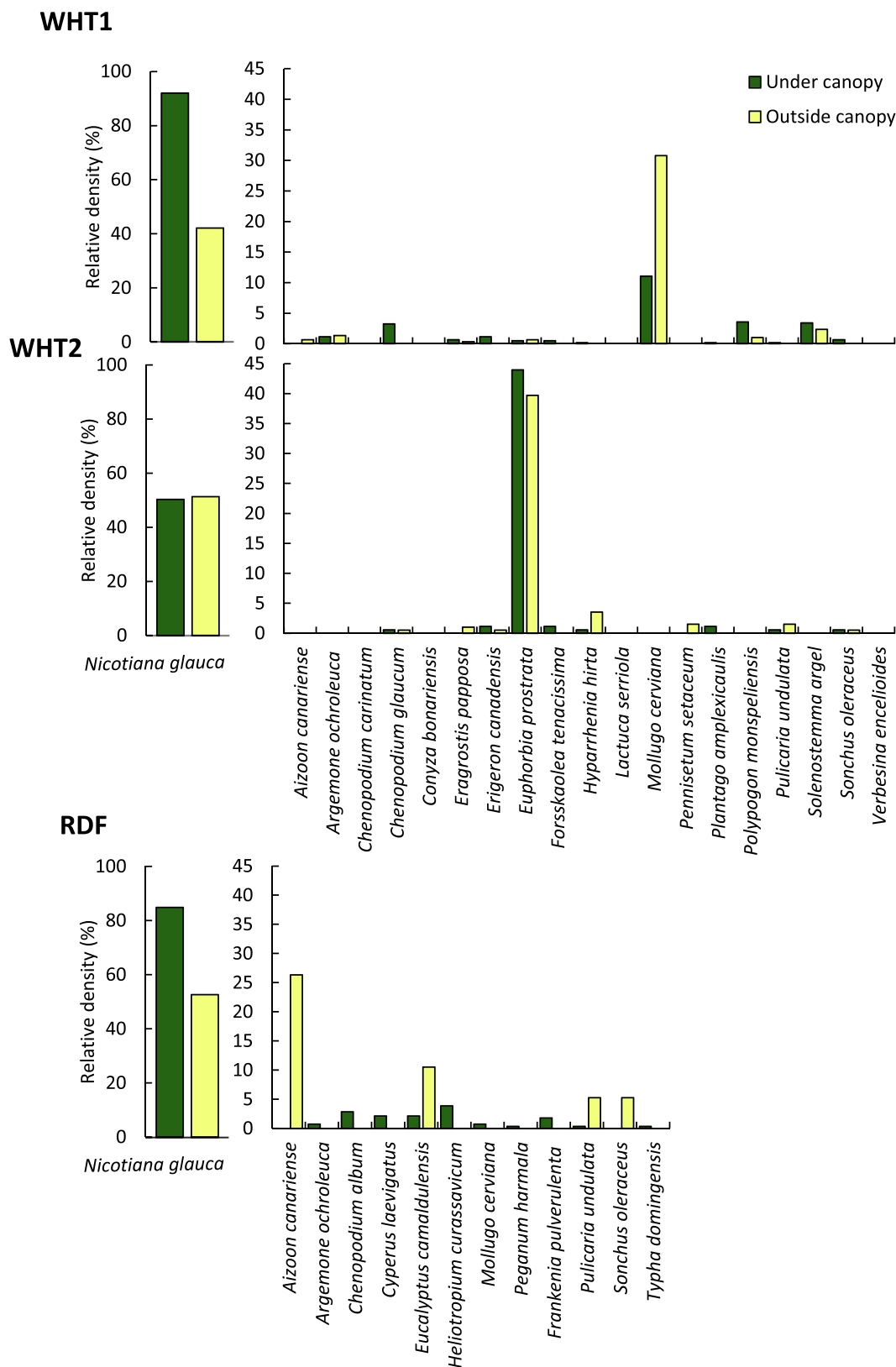
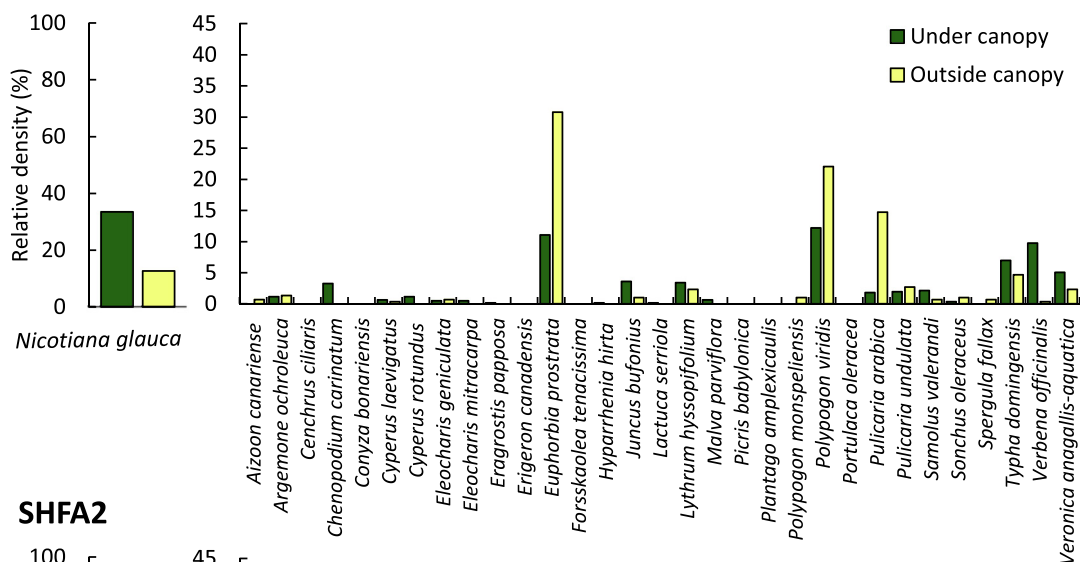


Fig. 3. Relative density (%) of the plant species of the seed bank under- and outside the canopy of *N. glauca* in Alwaht (WHT) and Ar Ruddaf (RDF) locations.

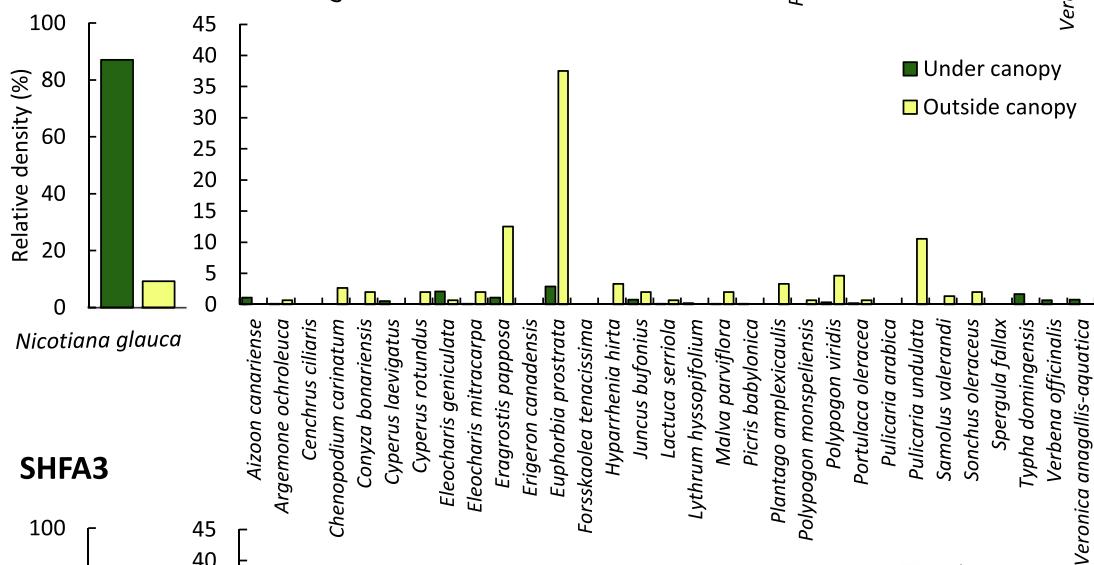
all stands within each location, it was clear that the most affected location was RDF, followed by WHT, and finally, SHFA, where 8, 6, and 4 species were recorded only in the seed bank outside the

canopy of the investigated *N. glauca* shrubs in RDF, WHT, and SHFA, respectively. While 2, 3, and 4 species were recorded only under canopy of *N. glauca* in RDF, WHT, and SHFA, respectively.

SHFA1



SHFA2



SHFA3

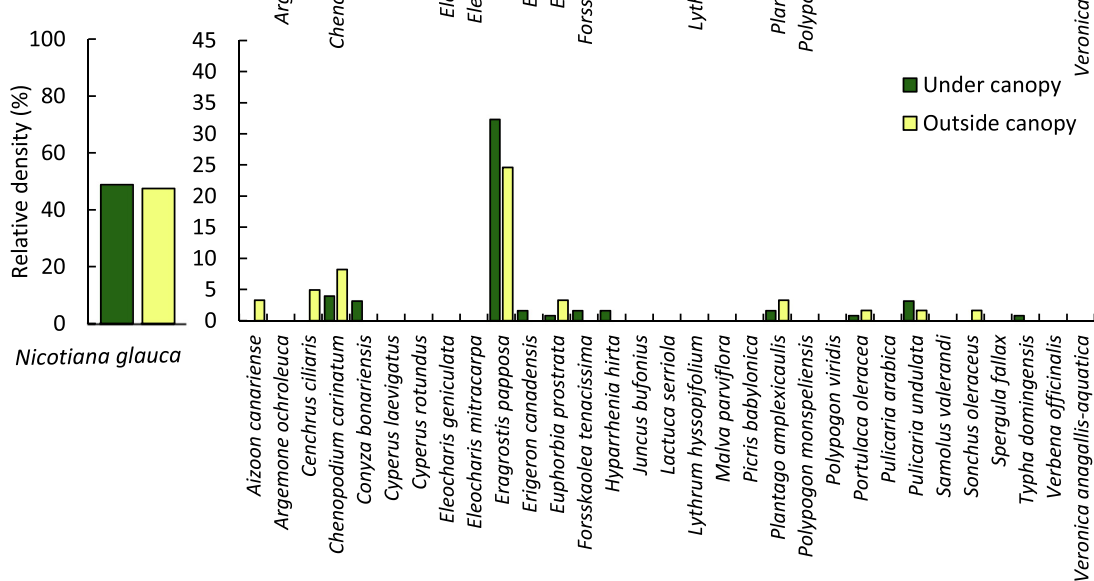


Fig. 4. Relative density (%) of the plant species of the seed bank under- and outside the canopy of *N. glauca* in Ash-shafa (SHFA) locations.

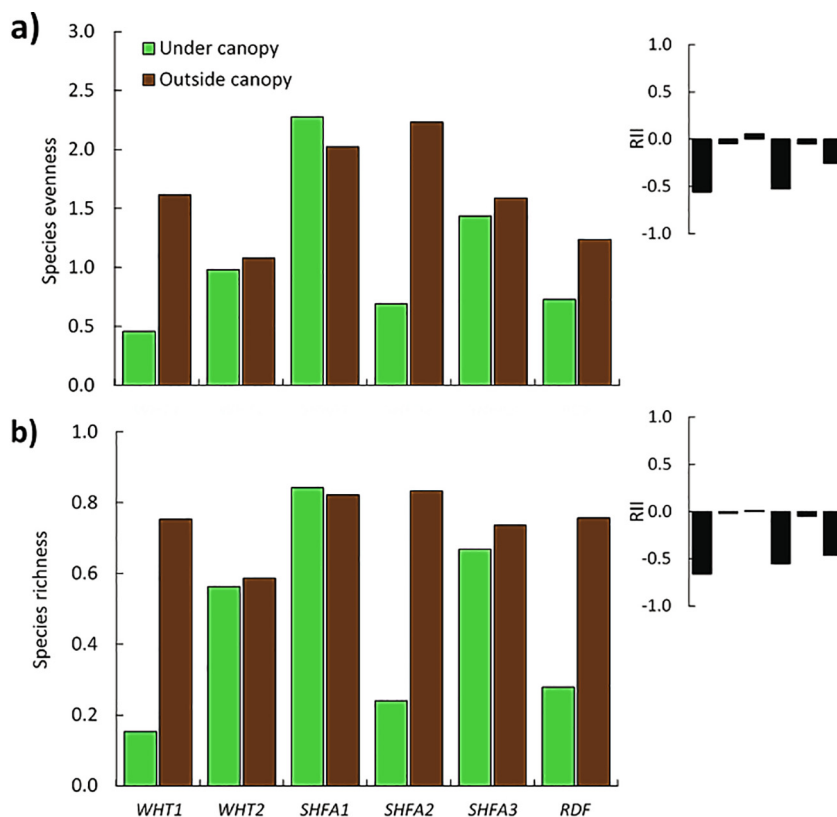


Fig. 5. Plant species richness and evenness of different studied locations as well as the relative interaction intensity (RII) on the right as black columns. a) species evenness and b) species richness.

Table 3 Physical and chemical properties of the soil under- (U) and outside (O) canopy of *N. glauca* of the three studied locations.

Location	Position	N (mg/100 g) ^a	P (mg/100 g)	pH	EC (dS/m)	Cl (mg/100 g)	SO ₄ (meq/L)	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	K (meq/L)	Clay %	Silt %	Sand %	Moisture %
WHT	U	31.50 ^{abc} ± 1.00	3.38 ^b ± 0.99	8.04 ^a ± 0.08	0.23 ^{ab} ± 0.07	0.86 ^{bc} ± 0.12	0.37 ^a ± 0.19	0.73 ^b ± 0.22	0.15 ^b ± 0.05	1.03 ^{ab} ± 0.12	0.24 ^{ab} ± 0.04	2.93 ^b ± 0.59	10.08 ^a ± 4.48	80.05 ^a ± 9.94	0.88 ^a ± 0.18
	O	30.17 ^c ± 2.36	2.00 ^b ± 0.44	8.11 ^a ± 0.08	0.17 ^b ± 0.01	0.62 ^c ± 0.04	0.09 ^a ± 0.01	0.70 ^b ± 0.10	0.16 ^b ± 0.04	0.68 ^b ± 0.18	0.19 ^a ± 0.04	4.18 ^a ± 0.43	8.45 ^a ± 1.30	81.78 ^a ± 1.38	0.71 ^a ± 0.13
SHFA	U	34.67 ^a ± 0.33	3.61 ^b ± 0.64	8.31 ^a ± 0.28	0.36 ^a ± 0.09	1.45 ^{ab} ± 0.36	2.30 ^a ± 2.95	1.93 ^b ± 0.83	0.59 ^a ± 0.21	1.31 ^{ab} ± 0.23	0.16 ^{ab} ± 0.04	1.01 ^d ± 0.13	5.53 ^a ± 1.45	88.86 ^a ± 1.00	1.27 ^a ± 0.61
	O	32.11 ^{abc} ± 1.90	3.47 ^b ± 0.46	8.20 ^a ± 0.15	0.28 ^{ab} ± 0.07	0.94 ^{bc} ± 0.13	0.72 ^a ± 0.10	0.94 ^a ± 0.08	0.37 ^{ab} ± 0.05	1.62 ^a ± 0.44	0.10 ^b ± 0.01	1.58 ^{cd} ± 0.40	5.76 ^a ± 0.23	89.22 ^a ± 2.16	1.14 ^a ± 0.81
RDF	U	34.33 ^{ab} ± 1.53	6.21 ^a ± 1.62	8.48 ^a ± 0.54	0.17 ^b ± 0.03	1.32 ^{abc} ± 0.37	0.42 ^a ± 0.07	0.78 ^b ± 0.10	0.19 ^b ± 0.01	1.40 ^a ± 0.19	0.17 ^{ab} ± 0.06	2.33 ^{bc} ± 0.15	8.17 ^a ± 1.61	80.27 ^a ± 7.56	3.62 ^a ± 3.06
	O	30.33 ^{bc} ± 0.58	3.66 ^b ± 0.71	8.40 ^a ± 0.46	0.22 ^{ab} ± 0.04	1.67 ^a ± 0.32	0.72 ^a ± 0.17	1.43 ^{ab} ± 0.15	0.28 ^b ± 0.11	1.22 ^{ab} ± 0.23	0.17 ^{ab} ± 0.04	3.03 ^b ± 0.31	5.67 ^a ± 0.58	90.33 ^a ± 1.15	3.29 ^a ± 1.48
P-value		0.009^{**}	0.003^{**}	0.538 ^{ns}	0.016[*]	0.003^{**}	0.334 ^{ns}	0.007^{**}	0.001^{**}	0.011[*]	0.017[*]	less than 0.001^{***}	0.098 ^{ns}	0.083 ^{ns}	0.103 ^{ns}

^a Values are means (first line) ± standard deviation (second line). The different superscript letter means values significantly different at the 0.05 level using Tukey's HSD test. EC: electrical conductivity, ^{***}: significant at $p \leq 0.001$, ^{**}: significant at $p \leq 0.01$, ^{*}: significant at $p \leq 0.05$, ^{ns}: non-significance.

3.3. Effect of *N. glauca* on the diversity indexes of the plant species

The presence of *N. glauca* in all studied locations resulted in low species richness and evenness (Fig. 5). The species richness and evenness were more affected by the canopy of *N. glauca* in WHT1 location, and this location attained RII values of -0.56 and -0.66, respectively (Fig. 5). In SHFA1 location, the RII values of the species richness and evenness were -0.53 and -0.55, respectively. While in RDF it showed RII values of -0.26 and -0.46, respectively.

3.4. Soil characteristics under- and outside the canopy of *N. glauca*

The physical and chemical properties of soil under- and outside canopy of *N. glauca* of the three studied locations (SHFA, WHT, and RDF) are shown in Table 3. Moreover, the detailed soil analysis of all stands was presented in Table S1. The N, P, Cl, EC, Ca, Mg, N, K, and clay contents showed significant differences among the studied locations. However, pH, SO₄, silt, sand, and moisture content did not show a significant difference (Table 3).

The soil under canopy in SHFA location attained the highest values of N, EC, and Mg, while the outside canopy soil showed the highest values of Ca and Na. On the other hand, the soil samples collected outside canopy of *N. glauca* attained the highest content of K and clay, while it attained the lowest N, EC, and Cl (Table 3). Generally, the soil under canopy of *N. glauca* attained high nutrients and moisture than outside canopy.

4. Discussion

Invasive plants are considered major threats to biodiversity in different ecosystems worldwide, and the ability to form persistent seed banks is one of the most important strategies of the invasive plants to colonize new habitats (Abd El-Gawad and El-Amier, 2015; Rai and Singh, 2020). The invasive plants have been recognized to lose biodiversity due to competition with the native plants. In Taif region, *N. glauca* was observed as an invasive plant in several habitats, where it is considered as one of the major invaders in Saudi Arabia (Thomas et al., 2016). It grows in high altitude (800–2700 m.a.s.l.) with a wide range of soil conditions that enables it to grow vigorously and spread as a monospecific stand (Florentine et al., 2006; Al-Robai et al., 2019). In the present study, the soil seed bank analysis of the studied stands revealed that the plant species density under canopy of *N. glauca* was lower than that outside canopy. Also, some species existed only outside the canopy and others were recorded only under the canopy. The presence of these species under canopy could be attributed to the facilitation by *N. glauca* shrub (Badano et al., 2015), while the absence of other species could be ascribed to the competition or allelopathic interference (Alshahrani, 2008; El-Kenany et al., 2017). The invasive species can modify the soil composition and soil microbiota, and thereby facilitate or inhibit the native species (Jordan et al., 2008; Molina-Montenegro et al., 2015).

Most of the recorded species are belonging to Asteraceae, Poaceae, and Cyperaceae. These families were reported as the major families of other locations with similar conditions in Saudi Arabia (Collenette, 1999; Alsherif and Fadl, 2016; Abdel Khalik et al., 2017). Asteraceae was characterized by its high ecological amplitude not only in the arid regions but also all over the world. The wide distribution and dominance of Asteraceae members were attributed to their efficient seed dispersal capacity (Anderberg et al., 2007; Jeffrey, 2007).

The soil seed bank of the study area contained comparable numbers of plant species to that were reported in the seed bank of Wadi Fatima, Western Saudi Arabia, where 56 plant species were recorded (El Karemy and Zayed, 1999). Moreover, the soil seed bank in the central region of Saudi Arabia has been reported to have a comparable number of plant species, where 56 plant species were recorded in the seed bank of Rawdhat Khorim (Al-Yemeni et al., 2000), and 44 species Raudhat al-Khafs, Riyadh region, Saudi Arabia (Assaeed and Al-Doss, 2002).

The prevalence of therophytes in the soil seed bank is consistent with the life forms of the current vegetation in the study area. This result is in harmony with the spectra of various studied vegetation in Saudi Arabia (Collenette, 1999; Alsherif and Fadl, 2016; Abdel Khalik et al., 2017). The composition of the life forms is reported to be closely correlated to the topography (Hegazy et al., 1998; Abd El-Gawad, 2014). The dominance of therophytes could be attributed to the higher reproductive capacity, as well as the morphological, ecological, and genetic plasticity (Abd El-Gawad, 2014). Also, therophytes have been reported as more adaptive species to the drought.

The chorological analysis of the floristic data revealed the dominance of cosmopolitan species, Saharo-Arabian elements and Sudano-Zambezian. These results may indicate the wide ecologic

amplitude and active transport in our study area (Al-Sodany et al., 2014; Alsherif and Fadl, 2016). There are many interpretations of how these species enter the study areas, for example, long-term climate changes, through human activities and animal movements, especially birds that disperse seeds on a large scale. The Arabian Desert climate supports many Sudanian species as a result of the hot climate, but its extremely dry is inconsistent with the establishment of such many plant species in the study area (Al-Sodany et al., 2014).

The seeds of *N. glauca* represent 60.4% of the seed bank in the study area, which is lower than those reported for *Juniperus procera* (65.7%) in Ridah Reserve, the southwestern region of Saudi Arabia (El-Juhany et al., 2008). On the other hand, the relative density of the understory plant species showed substantial variations among the studied locations. The relative densities of the plant species were higher outside the canopy of *N. glauca* in all locations. Overall, the invaded locations can be arranged according to the following sequence: RDF > WHT > SHFA. This observation could be attributed to the degree of the anthropogenic activity or the elevation. The disturbance, climate, and elevation have been reported as important factors for the distribution of the invasive species (Dark, 2004; Griffith and Loik, 2010).

Regarding the impact of *N. glauca* on the diversity indexes of the studied locations, the species richness and evenness were higher outside the canopy, which indicates a negative effect of the invasive shrub *N. glauca* on the plant biodiversity in the study area. The invasive species have been reported to decrease the biodiversity in several habitats, worldwide (Abd El-Gawad and El-Amier, 2015). This impact of invasive species is attributed to competition with the native plants for nutrients, water, and space (Broadbent et al., 2018; Schultheis and MacGuigan, 2018). Moreover, this shrub is characterized by a high growth rate and one shrub can produce 10,000–1,000,000 seeds per year, that are dispersed by hydrochory, the most effective seed dispersal way (Florentine and Westbrooke, 2005). Also, many invasive plants are characterized by the production of allelochemicals that inhibit or kill the native species (Hierro and Callaway, 2003; Florentine and Westbrooke, 2005; Abd El-Gawad, 2014; Abd-ElGawad et al., 2020). The shrub *N. glauca* shrub is characterized by its allelopathic effect against native species such as *Juniperus procera* (Alshahrani, 2008), as well as crops such as *Lactuca sativa* (Florentine and Westbrooke, 2005), *Medicago sativa* and *Triticum aestivum* (El-Kenany et al., 2017). The extract of *N. glauca* has been reported to have several allelochemicals such as alkaloids, flavonoids, glycosides, Sterols, phenolics, and coumarins (El-Kenany et al., 2017). However, further study is recommended for deep characterization of the allelochemical compounds in *N. glauca*, and for determination of their mode of actions and allelopathic activity against a wide range of weeds.

The soil nutrients and moisture under the canopy of *N. glauca* shrub were higher than outside canopy. The invasive species have been reported to change the soil nutrients (Liao et al., 2008). However, the invasive plants usually exhaust water and nutrient resources more than the native species, hence colonizing new habitats (Bonanomi et al., 2018; Incerti et al., 2018; Wang et al., 2019).

5. Conclusion

The invasive shrub *N. glauca* growing in different habitats showed a substantial negative impact on the plant biodiversity. The seed bank outside the canopy of *N. glauca* had higher richness and evenness of the understory species. However, some species were recorded only outside canopy and others under canopy. This contrasted results could be ascribed to either competition or facil-

itation by the invasive shrub, particularly the *N. glauca* has been reported to release allelochemicals. According to the present results, *N. glauca* is a new invasive species in Taif region, is expected to modify the biodiversity and soil properties of the study area in the future, particularly in Ar Ruddaf location, the most susceptible location according to the present data. The present study provides a deeper understanding of the most susceptible habitats or communities to the invasion by *N. glauca* and thereby open the challenge toward control of this noxious plant and vegetation restoration.

CRedit authorship contribution statement

Abdullah S. Alharthi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing - original draft, Writing - review & editing. **Ahmed M. Abd-ElGawad:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. **Abdulaziz M. Assaeed:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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