

# Prospects and limitations of soil amendment and irrigation techniques for the water-saving public urban greenery and ephemeral weed management in the sandy soils of the United Arab Emirates

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**Abstract:** Public urban greenery greatly contributes to the residential and tourist value of cities in the Gulf Region, but due to the hyper-arid climatic conditions, the cost of irrigation and plant maintenance is very high. Existing strategies to reduce the monetary and ecological costs involve the cultivation of native xerophytic plantations, and/or the use of soil improvers to increase water- and nutrient-holding capacity of the sandy soils. Various soil improvers based on mineral, organic, or synthetic materials have entered the United Arab Emirates (UAE) market in recent years, but there is considerable uncertainty about how they should best be used in combination with ornamental plant stands involving xerophytic native plants. The present study investigated the effect of soil amendment and deep pipe irrigation on perennial ornamental plant stands involving native plants (*Tephrosia appolinea* (Gel.) Link in combination with *Aerva javanica* (Burm. f.) Juss. ex Schult.) and native-exotic plants (*T. appolinea* in combination with *Ruelia simplex* C. Wright) either or not topsoil and subsoil amendment with bentonite and hydrophobic sand under the irrigation water supply of less than 50% of reference evapotranspiration (ET<sub>0</sub>). After one year of cultivation, *T. appolinea* and *A. javanica* (native vs. native) produced high biomass and exhibited high water use efficiency (WUE) as compared with *T. appolinea* and *R. simplex* (native vs. exotic) combination given that no significant differences were found under the soil amendment treatments. All stands thrived under irrigation water supply far below what is usually supplied to exotic ornamental stands in public parks of the Al Ain City, the UAE. However, subsoil amendment in combination with deep pipe irrigation reduced the occurrence of weeds and increased the overall plant rooting depth. Our results suggest that subsoil amendment and irrigation up to 60–80 cm depth can potentially control ephemeral weed infestation, which is a great challenge in various plant production systems of the Gulf Region. The results of the present study suggest that the impact of soil amendment on the WUE of exotic plants is marginal and might not be economically justified. Replacing exotic with native ornamental plant species seems to have a far greater water-saving potential than the amendment of the soil, while weeds can be suppressed in the absence of topsoil moisture.

**Keywords:** native and exotic plant communities; competitive strength; soil improvers; urban plantation; subsoil amendment; weed management

**Citation:** Ayesha ALAM, Elke GABRIEL-NEUMANN. 2024. Prospects and limitations of soil amendment and irrigation techniques for the water-saving public urban greenery and ephemeral weed management in the sandy soils of the United Arab Emirates. Journal of Arid Land, 16(9): 1288–1302. <https://doi.org/10.1007/s40333-024-0028-9>; <https://cstr.cn/32276.14.JAL.02400289>

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Received 2024-04-08; revised 2024-07-31; accepted 2024-08-23

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## 1 Introduction

Public urban greenery greatly adds to the residential and tourist value of urban cities (Addas, 2023). Over the past few decades, the UAE has been ambitious to become the largest tourist attraction in the world (Khoder, 2024). Tourism requires the expansion of urban infrastructure and urban greenery in major cities of the country. However, the maintenance of public urban greenery in the UAE comes at a high cost due to certain factors.

Firstly, water scarcity is a big problem due to the high water requirements of urban greenery. The UAE has hyper-arid climatic and ecological conditions that are not ideal for the cultivation of plantation (Masdar, 2019). The potential annual evapotranspiration in the UAE is above 2500 mm, while average precipitation is below 100 mm (Elnesr et al., 2010). Thus, all agricultural plant cultivation in the country relies on supplying considerable amounts of treated sewage effluent (TSE) or desalinated irrigation water at the rate of 1200 L/(plant.a). In the UAE, TSE is recycled or reclaimed water that is provided by recycling plants operated by municipalities for landscape irrigation (Alam and Ali, 2021; Soliman, 2021).

Secondly, moisture losses from the sandy soils are large. The majority of soils of the UAE belong to the order Entisols and Aridisols and are characterized by an ochric epipedon (King et al., 2013). The topsoil is often sandy with organic matter contents below 0.5%. The water-holding and cation exchange capacities of agricultural soils of the UAE mostly remain in a low range even under cultivation. Typically, soil improvers such as activated charcoal and biochar are added to the soil in public greenery (Saady et al., 2021; El-Refaey El-Bially et al., 2023) under the supply of desalinated or TSE water enriched with nutrients. In the absence of shading soil surface temperatures regularly exceed 60°C during the warm season, and the zone of evaporation then extends to a soil depth of 60–80 cm (Williams et al., 1999; Kreye et al., 2020). Conventional surface irrigation of plants thus involves relatively high evaporation losses, which also accelerates the accumulation of salt in the soil. The low water-holding capacity of the sandy soils requires that plants are supplied with small amounts of water at a high frequency to avoid deep percolation. This, however, is often technically and logistically difficult. Especially when the temperature is high, a low water-holding capacity of the soil increases the risk of plant damage due to a short-term drought. Park managers sometimes over-irrigate valuable plants like date palms, flower beds, or exotic ornamental trees to minimize the risks of nutrient leaching, groundwater rise, and salinization.

Thirdly, ephemeral weed infestation is considerable factor in exploitation of resources. Consequently, due to over-irrigation, the water retention at the topsoil encourages the emergence of ephemeral weeds. Weeds are unwanted species considered the biotic limiting factor in the dynamics of crop production globally. There are 8000 known weed species and only 250 of them are beneficial from an agricultural perspective (Ahmad et al., 2016). Weeds are considered twice (34%) as catastrophic as pest and pathogen infestation (Oerke, 2006; Schonbeck, 2022) through which 50% yield losses have been reported in maize (Soltani et al., 2016) and 52% in soybean (Soltani et al., 2017). Desert weeds (*Salsola tragus* L., *Cenchrus echinatus* L., *Cynodon dactylon* L. Pers., *Tribulus terrestris* L., and *Eragrostis Pilosa* (L.) P. Beauv) sustain survival under extreme stress conditions and spread rapidly at the expense of resources provided to the main cultivated crop or plantations (Chipomho et al., 2021; Ali et al., 2023b). Particularly desert ephemerals are the most harmful plants in arid and semi-arid areas for damaging plant performances (Godfree et al., 2017). Under the action of phytotoxins and allelochemicals (Algandaby and El-Darier, 2018), they compete for water, nutrients, and space by producing enormous quantities of seeds with varied seed dormancy cycles to propagate (Swami et al., 2017). These weed species possess a quick penetrating root system (Liu et al., 2016), a drought escape mechanism (Shavrukov et al., 2017), high metabolic rates, progressive cell division, expansion, and triggered photorespiration (Bodner et al., 2015; Kooyers, 2015) for plant development. The major pinpoint is the persistence of seeds in the soil for passive weed invasion that remains dormant for longer spans and is capable of re-emergence despite weed control practices at the soil

seed bank level (Qasem, 2019). This adapting behavior of ephemerals is a gap in the scientific world to investigate paths and ways to control weeds in arid land ecosystems.

Lastly, exotic plantations have high maintenance costs. The majority of the public urban greenery in the Gulf Region is comprised of exotic plantations such as *Bougainvillea glabra* Choisy, *Plumeria alba* L., *Ruelia simplex* C. Wright, *Catharanthus roseus* (L.) G. Don, *Tagetes erecta* L., *Jasminum sambac* (L.) Aiton, *Lantana camara* L., etc. These plantations have high visual aesthetic characteristics and add great value to enhance the beauty of the outdoor urban settings. Recently, the Museum of the Future in the emirate of Dubai had a mass culture of *R. simplex* in the surroundings for the elevation of the visual aesthetic. Various public and privately managed properties of the Al Ain City cater to exotic plant species for landscaping purposes. The introduction of exotic plants into the Gulf Region's landscapes has multiple consequences. They form shallow root systems and desiccate due to water losses from the soil surface under high temperatures. Their shallow root system depends on a reservoir of water as deep as 50 cm and is unable to access the water stored in the subsoil. Considering the disadvantages of the existing plantation choices, the urban landscapes experience the least environmental and economic feasibility.

Proposed strategies to minimize the problems of water scarcity, soil porosity, inappropriate plant choices, and weed infestation include an integrated approach of cultivating native xerophytes and using soil improvers to enhance the water and nutrient retention ability of the sandy soils (Ali et al., 2023a; Lasheen et al., 2023; Ramadan et al., 2023). In recent years, the UAE market has seen the introduction of many soil improvers made from mineral, organic, or synthetic materials. However, there is much disagreement over the optimal way to use these improvers in combination with exotic plant stands. It is advisable to mix most soil improvers with the topsoil at the rates above 10 t/hm<sup>2</sup> before planting annual crops or bedding plants (FAO, 2020). However, the soil improvers retain moisture in the topsoil that eventually evaporates due to the high surface temperatures and stimulates the ephemeral weed cycle. Very little is known about the application of soil improvers at different soil depths and how these improvers can amplify the water use efficiency (WUE) of xerophytic plantations in urban greenery and suppress weed infestation.

In previous investigations, various weed control strategies have been proposed by controlling irrigation systems, timing, and water quantities management in different ecosystems (Coolong, 2013; Patel et al., 2020; Fawad and Khan, 2022). In this study, three different soil amendment treatments constituting potash bentonite and hydrophobic sand either at topsoil or subsoil were established with surface and subsoil irrigation. Potash bentonite is a clay mineral commonly used in agricultural practices as soil improvers enriched in montmorillonite that increases water-holding and cation exchange capacity of the soil (Mi et al., 2020; Zhang et al., 2020). Hydrophobic sand is an industrial-grade sand coated with silanes impermeable to water but allows root penetration (Doklega et al., 2023). An integrated approach of subsoil amendment in combination with deep pipe irrigation with less than 50% of reference evapotranspiration (ET<sub>0</sub>) supply is proposed as a strategy to sustain ornamental native and exotic plantations in urban greenery. It is further anticipated that subsoil amendment and irrigation would allow desert plants to exploit their full water-saving potential and exhibit high WUE as compared with exotic plants. Under subsoil irrigation, the dry topsoil with less availability of fertilizer would impede weed emergence and encourage the native plantations to exhibit greater competitive strength as compared with exotic plants (Makhlouf et al., 2022; Saady and El-Metwally, 2023).

## 2 Materials and methods

### 2.1 Study area

The study area was established during January 2021–July 2022 in an abandoned plant nursery located on the northern Towayya Park (24°14'41"N, 55°41'46"E) of the Al Ain City, the UAE.

Previously, the study area was a plant nursery from 2009 to 2016, later all the existing plantations were completely removed in 2017. Before the onset of the experiment, the study area was fallow land with predominant ephemeral weed bushes. All the weeds were removed before the plantation of experimental species. The physical-chemical properties of the soil were highly porous sand, saline (pH: 7.8), and low cation exchange capacity. The experimental site was equipped with a surface irrigation system supplied with treated sewage effluent (TSE) from the pipeline grid of the Al Ain Municipality.

## 2.2 Experimental treatments

The experimental design consisted of two plant combinations under four different subsoil amendments and irrigation supplies. Two native and one exotic plant species were selected for cultivation. In the first plant combination (native vs. native), native plant *T. appolinea* (a native legume shrub) was cultivated in combination with native plant *A. javanica* (native shrub), while in the second combination (native vs. exotic), native plant *T. appolinea* was cultivated in combination with exotic plant *R. simplex* (exotic ornamental shrub). A total of five plants of each species were cultivated in hedgerows. A total of 56 plots (2.7 m×0.5 m) with a central cavity of 5 cm depth for irrigation were constructed given that native vs. native combination was cultivated in 28 plots and native vs. exotic was cultivated in the remaining 28 plots.

For the experimental trial, the plant combinations mentioned above were subjected to a total of 4 topsoil/subsoil amendments, and irrigation treatments were established and tested against the control plot with no amendment. Every treatment comprised 7 replicates. In the first treatment, plant plot was not amended and provided with surface irrigation water taken as control plot. In the second treatment, potash bentonite was uniformly added to the depth of the upper 25 cm layer of soil at the rate of 10 kg/m<sup>2</sup> provided with surface irrigation. Potash bentonite is a clay-rich mineral that increases the water-holding and cation exchange capacity of the soil. In the third treatment, a 1–2-cm thick layer of hydrophobic sand was uniformly added to 60 cm depth of the soil of the plots provided with surface irrigation. Hydrophobic sand is sand coated with silanes that prevent the percolation of water through it and root growth is not impaired by it. In the fourth treatment, a 1–2-cm thick layer of hydrophobic sand was added at a depth of 60 cm of the soil, and 4 acrylic pipes of 75 cm length (sanitary grade) were embedded in a row in the middle of the basins projecting the one opening of the pipes 15 cm out of the soil, and soil was refilled till the depth of 55 cm. Later potash bentonite was added to the depth of 40–50 cm of the soil at the rate of 10 kg/m<sup>2</sup>, and soil was refilled completely. In this treatment, irrigation water was poured through embedded pipes, given that water reached a depth of 60 cm leaving the topsoil dry. The experimental design is shown in Table 1.

**Table 1** Experimental design indicating different plant combination, soil amendment, and irrigation treatments

Treatment 1		Treatment 2		Treatment 3		Treatment 4	
Control		Topsoil amendment		Subsoil amendment with hydrophobic sand		Subsoil amendment with deep pipe irrigation	
No amendment		Potash bentonite with 10 kg/m <sup>2</sup> rate at 25 cm depth		A 1–2-cm thick layer of hydrophobic sand at a depth of 60 cm		A 1–2-cm thick layer of hydrophobic sand at a depth of 60 cm of soil, 75 cm long deep pipes, and potash bentonite with 10 kg/m <sup>2</sup> rate at 40–50 cm depth	
native vs. native	native vs. exotic	native vs. native	native vs. exotic	native vs. native	native vs. exotic	native vs. native	native vs. exotic

Note: Total: 56 plant plots.

The plants were obtained from nursery and planted in the basins provided with a full supply of water as per ET<sub>0</sub> requirements of 2000 L/m<sup>2</sup> for 4 weeks. After 4 weeks, irrigation supply was reduced to 50% of ET<sub>0</sub> given that every plot received 1000 L/m<sup>2</sup> of treated sewage effluent per plant per year. All experimental treatments and plant combinations except with deep pipes were supplied with treated sewage effluent water on the surface with the help of measuring containers.

In the treatment with deep pipes, irrigation water was supplied equally through deep pipes to the subsoil level until the plants were harvested.

### 2.3 Dry weight and WUE

Weeds were sampled after 24 weeks of plantation (December 2021), which indicated as the first harvest, followed by a gap of 6 weeks (February 2022), 10 weeks (March 2022), and 12 weeks (March 2022) from the first harvest under the influence of reduced irrigation amounts and stressed climatic temperature. Temperature during the harvest time (July 2021–July 2022) was recorded in the range from 19°C to 44°C. Similarly, humidity was recorded in the range from 24% to 61%. A rainfall of 8.6 mm was observed between the first and second harvests. All the climatic data were recorded with the help of portable wireless sensors (HT. w Sensor, SensorPush, New York, USA) and installed at the study area.

Shoots were sampled after one year of cultivation and dried in an air-drying oven at a temperature of 65°C for 48 h. The dried samples were weighed to estimate the biomass in each treatment. WUE was calculated by using the following equation (Hatfield and Dold, 2019):

$$WUE = \frac{\text{Biomass yield (dry weight)}}{\text{Irrigation water supplied}}. \quad (1)$$

Roots were sampled by using an auger of 50 cm in length, and rooting densities were estimated in grams per 1.6 L bulk density of sandy soil.

### 2.4 Statistical analysis

Experiment is a randomized complete block design with 4 treatments and 7 replicates ( $n=56$ ). It is hypothesized that soil amendment and irrigation practices will have an impact on competitive relationships between native and exotic plant species. Subsoil amendment and irrigation will increase the competitive strength of xerophytes and negatively affect weed emergence in the study area. Shoots and roots biomass were analyzed using one-way analysis of variation (ANOVA) considering subsoil amendment treatments as factors and means were compared by using Tukey's post hoc test. Measurements of weed biomass were carried out in the subsequent harvesting to study the effect. Effect of treatments was tested with ANOVA at a 5% level of significance and means were compared by using Tukey's post hoc test.

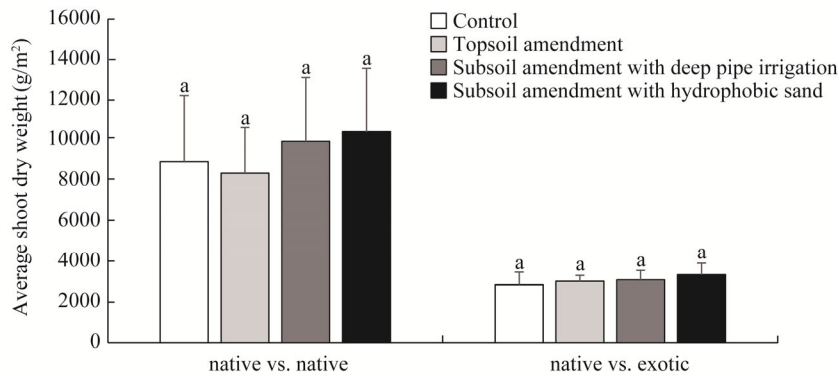
## 3 Results

### 3.1 Establishment of above-ground biomass

Native plants *T. appolinea* and *A. javanica* established fully developed vertical shoots and produced pods, inflorescence, and flowers. Exotic plant *R. simplex* covered more surface area horizontally due to lateral shoot extension and stoloniferous habit of growth. A variety of weed species were observed inside the plots such as *C. echinatus*, *Euphorbia prostrata* Aiton, *Euphorbia hirta* L., *C. dactylon*, *T. terrestris*, and *E. pilosa* due to long-term pervasiveness of their dormant seeds in the desert soils. However, the dominant weed species found was *T. appolinea* because of the regeneration of new seedlings into the plot followed by *A. javanica*, while *R. simplex* did not form additional plants in the middle of the plot that could be counted as weeds.

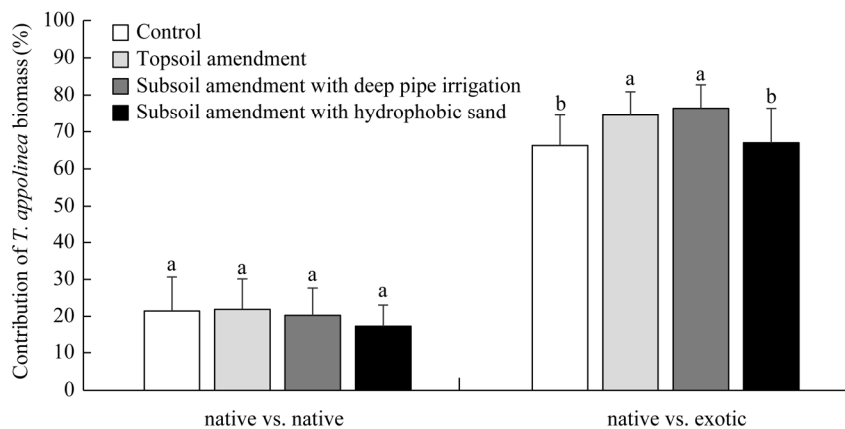
### 3.2 Shoot and root biomass

Plant shoots were harvested, and shoot dry weights were recorded under given subsoil amendment and irrigation treatments. Overall, native vs. native combination produced high total shoot biomass as compared with native vs. exotic combination. In native vs. native plot, *A. javanica* dominated over *T. appolinea* by producing the highest biomass, while in native vs. exotic plot, *T. appolinea* plant dominated largely over *R. simplex* plants. One-way ANOVA confirmed that treatments did not show a significant effect on the total biomass (Fig. 1).



**Fig. 1** Average shoot dry weights of plants in native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicate significant differences at  $P < 0.05$  level among different treatments.

As a common native plant, *T. appolinea* produced the highest average biomass (1543.03 ( $\pm 282.45$ ) g DW) in native vs. native and 1986.43 ( $\pm 364.42$ ) g DW in native vs. exotic plot under subsoil amendment with deep pipe irrigation treatment. In native vs. native plot, there were no significant differences found in the biomass of *T. appolinea* under the influence of soil amendment treatments, while subsoil amendment with deep pipe irrigation and topsoil amendment treatments encouraged significantly higher *T. appolinea* biomass in native vs. exotic plot (Fig. 2).

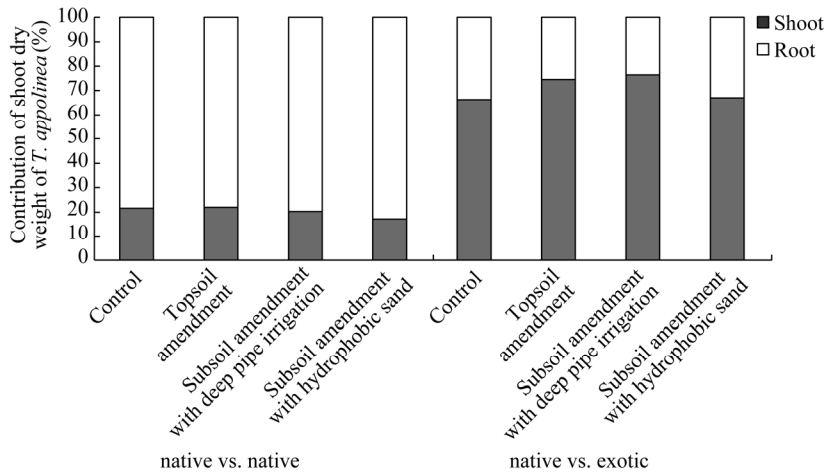


**Fig. 2** Contribution of *Tephrosia appolinea* (Gel.) Link biomass in total biomass from native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicate significant differences at  $P < 0.05$  level among different treatments.

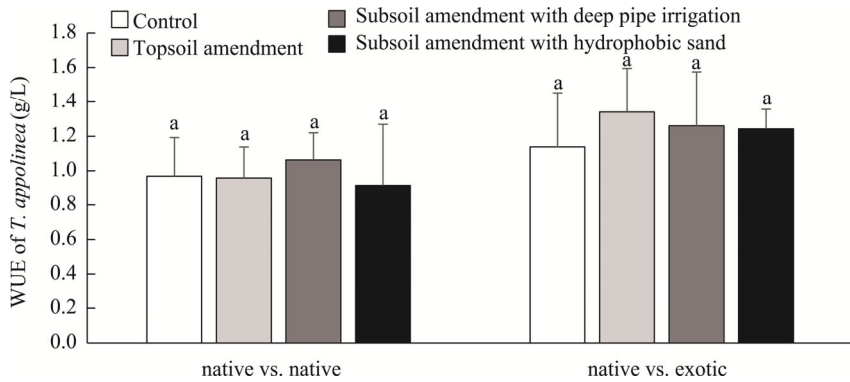
Contribution of shoot biomass of *T. appolinea* in total biomass is shown in Figure 3. Contribution of shoot biomass was significantly higher in native vs. exotic plot than in native vs. native plot. *T. appolinea* exhibited an average WUE of 1.0–1.2 g/L in combination with native vs. exotic plot regardless of subsoil treatments (Fig. 4). However, *A. javanica* exhibited the highest average WUE of 4.0–5.0 g/L, while *R. simplex* showed the lowest WUE (Fig. 5). The full establishment of native plants and high biomass as compared with exotic plants exhibited high WUE under a stressed irrigation supply.

Rooting densities exhibited high root dry weights in native vs. exotic plot as compared with native vs. native plot, however, no significant effect with the same treatment was overserved (Fig. 6). To understand the competitive growth of native plants in combination with exotic plants, we calculated the shoot:root ratio. Consequently, high shoot:root ratio was found in native vs. native

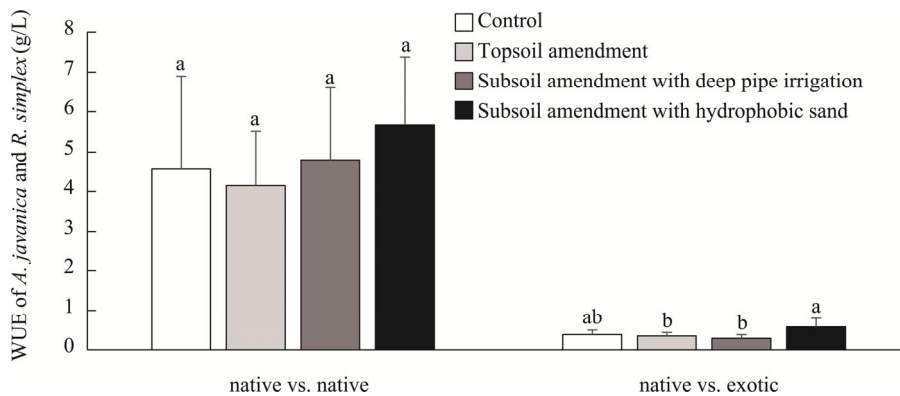
plot as compared with native vs. exotic plot with no significant differences under different treatments (Fig. 7). In a broader scale, native vs. native plot produced higher above-ground biomass, and native vs. exotic plot invested resources in the formation of root biomass.



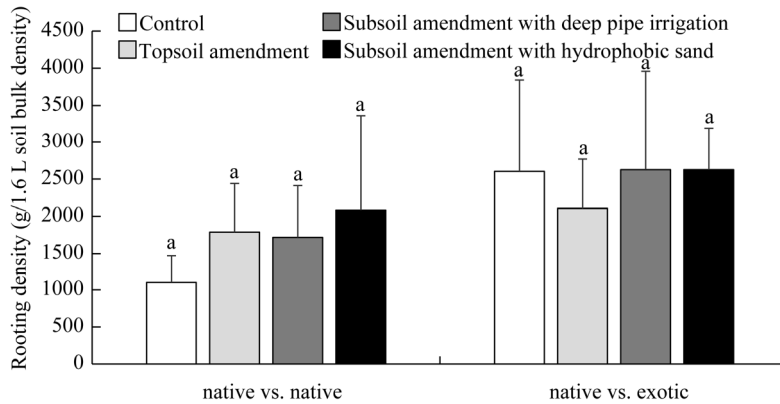
**Fig. 3** Contribution of shoot dry weight of *T. appollinea* in total weights from native vs. native and native vs. exotic plots under different treatments



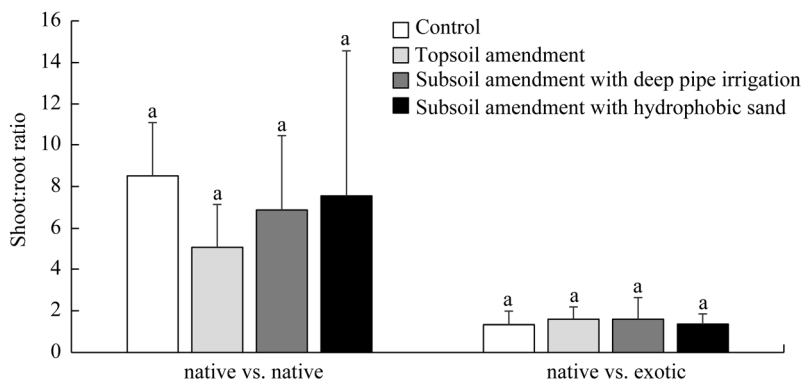
**Fig. 4** Water use efficiency (WUE) of *T. appollinea* from native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicate significant difference at  $P < 0.05$  level among different treatments.



**Fig. 5** WUE of *Aerva javanica* (Burm. f.) Juss. ex Schult. and *Ruelia simplex* C. Wright from native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicates significant differences at  $P < 0.05$  level among different treatments.



**Fig. 6** Rooting density of plants from native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicate significant differences at  $P < 0.05$  level among different treatments.



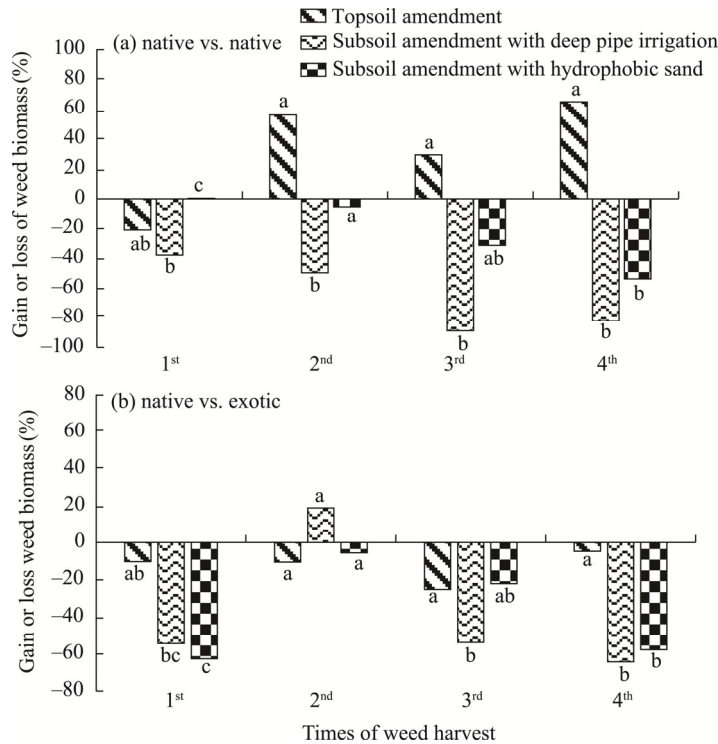
**Fig. 7** Shoot:root ratio of plants from native vs. native and native vs. exotic plots under different treatments. Different lowercase letters within the same plot indicate significant differences at  $P < 0.05$  level among different treatments.

### 3.3 Weed biomass estimation

During the experimental trial, four consecutive times of weed harvests were conducted under a stressed irrigation. Figure 8 shows the percentage of weed biomass from three treatments compare with control. During the first harvest, a decline in weed biomass was observed, however, the occurrence of rainfall before the second harvest encouraged weed biomass in the plots due to moisture retention. Later, a significant decline in weed biomass was recorded in subsoil amended with hydrophobic sand and deep pipe irrigation treatments in the third and fourth harvests in both native vs. native and native vs. exotic plots. It is also noticed that topsoil amended with bentonite plots encouraged weed growth in native vs. native plot, while deep pipe irrigation significantly reduced weed emergence during the third and fourth harvests.

## 4 Discussion

Native and exotic ornamental plant communities are gaining much attention in the restoration of desert ecology (Jones et al., 2015) concerning climate change (Gupta, 2024), saving water resources (Rupp et al., 2018), and developing potential soil microbial feedback mechanisms (Kulmatiski, 2018). Plants possess three kinds of strategies to adapt to the competition, i.e., vertical growth, which enhances their dominance in competitive situations; shade tolerance, which improves their performance in shaded environments; and lateral growth, which enables them to evade competition entirely (Gruntman et al., 2017). Various studies have revealed that in



**Fig. 8** Gain (bars above the axis line) or loss (bar below the axis line) in weed biomass during four times of harvests under different treatments, as compared with the control in native vs. native plot (a) and native vs. exotic plot (b). Different lowercase letters indicate significant differences at  $P < 0.05$  level among different times of weed harvest and treatments.

situations where native and exotic plants compete to grow in communities, exotic plants tend to prevail and overrun ecosystems (Leffler et al., 2014; Jauni and Ramula, 2015; Saady et al., 2020b). Exotic plants frequently adjust to the ecological conditions of native plant habitats and establish themselves by growing vigorously and exploiting nutrients. As a result, they are sometimes referred to as invasive species (King and Wilson, 2006). However, in desert ecosystems, native plants can tolerate salinity, drought, and heat stresses due to severe climate and restricted water and nutrient availability (El-Metwally and Saady, 2021; El-Bially et al., 2022; El-Mageed et al., 2022). On the other hand, exotic plants are not functionally capable of adapting to desert ecosystems (Nobel, 1984). In this study, native plants, specifically *T. appolinea* and *A. javanica*, exhibited substantially higher biomass production in native vs. native plot under all four treatments compared with *T. appolinea* and *R. simplex* in native vs. exotic plot. This suggests that native plants substantially invested the resources in the formation of overall biomass. *A. javanica* plant accounted for around 70%–90% of the total biomass in native vs. native plot, whereas *T. appolinea* provided 10%–30% shoot biomass only. Figure 5 clearly shows the substantially high WUE of *A. javanica* (4.0–5.0 g/L) and low WUE of *R. simplex* (<0.1 g/L) given that plants were provided with half of the standard water supply (stressed irrigation supply). WUE of desert ornamental *A. javanica* was significantly higher than that of *Primula vulgaris* Huds. shoots (Caser et al., 2017), woody ornamental (Still and Davies, 1993), and ornamental herbaceous plants (Nazemi et al., 2019). It is notable to mention that native plantations thrived on the 50% of irrigation water that is usually supplied to the ornamentals in the UAE, which is approximately 2000 L/(km<sup>2</sup>·a). The biomasses produced by various species of *A. javanica* under varied fertilizer supplies in a field experiment (Pathiratna et al., 2004; Saady et al., 2020a; Abd-Elrahman et al., 2022) were much lower than the data presented in this study (Fig. 1). Specifically, the biomasses produced under inorganic, organic, organic/inorganic, and no fertilizer supplies were 2700, 3400, 4000, and 1700 kg/hm<sup>2</sup>, respectively, which are substantially lower than those reported in this

study (Fig. 1). However, the subsoil amendment and irrigation treatment did not influence significantly the shoot and root biomasses. Yet, it was hypothesized that *A. javanica* dominated due to its substantial size, as the size of a plant, access to sunlight, and the depth of its taproot impacted the growth of competing plants (Walker et al., 1999). *A. javanica* plant allocated most of its nutrients towards shoot development rather than root growth, resulting in relatively high shoot:root ratio and low densities of roots (Figs. 6 and 7). However, it is unclear whether the sampled roots belonged to native or exotic plants due to displaced root growth in search of water, and no differentiation between species was found between roots.

*T. appolinea* plant was regarded as a common plant for assessing its competitive ability against both native and non-native plant species. Based on this study, it is evident that xerophytic indigenous plant outperformed exotic species *R. simplex* in terms of shoot biomass. According to Figure 3 and in combination with *R. simplex* (exotic), *T. appolinea* accounted for 60%–80% of the overall biomass. Nevertheless, the performance of *T. appolinea* was consistent in both plant combinations. WUE of *T. appolinea* remained consistent in the range of 1.0–1.2 g/L in both combinations regardless of amendment treatments provided. When the subsoil was treated with bentonite, *T. appolinea* contributed 76% (2359.53 g/m<sup>2</sup>) of the total above-ground biomass, whereas, with the topsoil modified with bentonite, *T. appolinea* contributed 74% (2249.52 g/m<sup>2</sup>) (Fig. 2). These findings align with that of Ngegba et al. (2007), who observed a two to threefold increase in biomass (15–20 Mg/hm<sup>2</sup>) of *T. appolinea* when planted alongside maize plants. Consequently, shoot:root ratio and WUE were significantly lower, and rooting densities were higher in native vs. exotic plot. This suggests that *T. appolinea* allocated more resources to below-ground biomass rather than above-ground biomass (Fig. 5). *T. appolinea*, a legume found in arid areas, exhibits a significant level of nutrient allocation activity in its roots under the action of nitrogen fixation bacteria (Hussain et al., 2019). As a result, *T. appolinea* probably acquires the bulk of resources inside rooting zone, specifically between 0–60 cm. Subsequently, there were fewer resources available for exotic plants in this area (Anum et al., 2022). Furthermore, legumes exhibit mycotrophy (symbiotic association with mycorrhiza) and possess greater resilience in withstanding stressful situations than exotic plants (Hawkes et al., 2006). Bentonite amendment and deep pipe irrigation had a positive impact on the competitive strength of *T. appolinea*, but the overall impact of soil amendment on plant growth was small. Deep pipe irrigation to the subsoil level and retention in bentonite-amended soil did not play a significant role in the development of shoots in native vs. native plot, however, a slight increment was observed in the biomass of *T. appolinea* in native vs. exotic plot. This proves that deep roots of *T. appolinea* and *R. simplex* relied on subsoil pools and acquired water and nutrients (Pierret et al., 2016; Kou et al., 2022). Thus, the hypothesis is supported by the finding that *T. appolinea* contributed a greater amount to the overall above-ground biomass when growing alongside an exotic plant under a limited irrigation supply. Regarding rooting densities, it is assumed that tap root system of native plants penetrated the soil to a depth of 80 cm, resulting in a reduced number of root fragments in the upper 50 cm of soil in control plots. This might be due to the subsoil amended with hydrophobic sand had the largest densities of roots, suggesting that the impediment created by the hydrophobic sand at a depth of 80 cm led to the production of lateral roots (Chiatante et al., 2007).

Concerning weed infestation, a significant reduction in weed biomass was found in subsoil amendment with bentonite, hydrophobic sand, and deep pipes irrigation in both combinations. In native vs. native plot, under deep pipes irrigation treatment, weed reductions of 40%, 50%, 80%, and 70% in consecutive four times of harvests were found, as compared with control (Fig. 8a). While in native vs. exotic plot, a reduction of 60% was found in the first harvest, then an increment of 20% in the second harvest, 50% decline in the third harvest, and 60% decline in the fourth harvest. In native vs. native plot, bentonite amended topsoil encouraged weed growth during the second, third, and fourth harvests, while a slight reduction trend was recorded in the first harvest. All the weeds' data were found statistically significant in the first, third, and fourth harvests except the second harvest due to interference of climatic fluctuations during rainfall. There were consistent climatic factors before and after the second harvest while rainfall of around

68–70 mm (Fatima, 2022) was recorded four weeks before the second harvest at the experimental plot although all the irrigation practices were ceased completely. It was noted that the diversity of weeds increased post-rainfall. As mentioned earlier, the experimental site was primarily an operational nursery, and the experiment was settled after a gap of 5 a. That possibly could be due to the existence of spring weeds commonly known as ephemeral plants, tending to store seeds in the soil for a longer period without germination (dormancy). Ephemeral plants are unique, which inhabit desert ecosystems at higher rates than any other plants (Zeng et al., 2016; Yang et al., 2019). Various studies reported the sensitivity of ephemeral plants to spring rainfall and nitrogen deposition (Mu et al., 2021). These plant species possess short growth rhythms (completing a life cycle as short as two months) with low temperature and rainfall in early spring, leading to the sprouting of new ephemeral plants in the area in late spring (Yuan and Tang, 2010). Hence, a significant increase in weed density during the second harvest is due to ephemeral sprout post-spring rainfall and low surface temperature. A minor variation in rainfall can tip the climate and floral equilibrium and result in heavy ephemeral spread (Qiu et al., 2018). This raises a need for more insights into the impact of rainfall and nitrogen deposition upon ephemeral growth in the desert ecosystem.

Frequent surface irrigation has proved to be harmful to xerophytic plantations as moistened soil surfaces encourage the invasion of massive weed that might cause plant displacement or death over the whole cultivated area (Martínez de Azagra Paredes et al., 2022). This scientific statement concurs with our research findings where surface irrigated topsoil amended plots produced 40%–50% excess weed biomass among all treatments. In all four times of harvest, topsoil amended with bentonite produced the maximum weed biomass as compared with the other two treatments, while all treatments were surface irrigated except with deep pipes. According to this investigation, subsoil amended with hydrophobic sand led to a slight reduction in weeds biomass as compared with topsoil amendment and control due to the absence of a water retention mediator near rooting zone of the weeds. Hence, it is speculated that temporary retention of moisture in topsoil encouraged weed emergence in control and hydrophobic sand-amended plots. Our findings clearly showed that hydrophobic sand played a crucial role in preventing deep percolation of water, hence producing maximized shoot growths. Irrigation through deep pipes reduced weed biomass significantly across all the plots in a short period.

Under stressed irrigation supply, native plant thrived fully and established visually aesthetic shoot biomass. On the other hand, exotic plants invested the majority of the resources in the formation of below-ground biomass to compete for survival in combination with native plant *T. appolinea*. Native as well as exotic plant species not only survived but also showed remarkable growth under deep pipe irrigation due to readily available moisture regime at the required rooting zones and long-term water retention and nutrient adherence due to incorporation of bentonite at subsoil level. The least weed biomass was also recorded in this treatment due to the absence of surface irrigation, introducing a drought stress regime in the upper 20 cm soil layer, thus, eradicating weeds (Mostafazadeh-Fard et al., 2011; El-Metwally and Saady, 2021). However, this study also gives insight to discover the physiological variations in native and exotic plants when growing in competition for resources and weed suppression in the absence of moisture. Certain precise agricultural approaches could be pertinent in the future research.

## 5 Conclusions

In this study, the highest total biomass was recorded in native vs. native plot, i.e., *A. javanica* (native) had the highest biomass as compared with *T. appolinea* (native). Biomass distribution suggested that native plant *T. appolinea* dominated over exotic plant *R. simplex* in the shoot biomass. Shoot dry weights indicated that *A. javanica* (native) was substantially water use efficient as compared with *R. simplex* (exotic) under stressed irrigation. However, root biomass was higher in native vs. exotic plot than in native vs. native plot. It is speculated that exotic plant *R. simplex* contributed the highest to the root biomass, confirming that exotic plants invested their

resources in the formation of below-ground biomass for the subsoil water, whereas native plants invested in above-ground biomass due to their deeper tap root system. These results confirmed that native plants had a high potential to grow aesthetically in the sandy soils and public urban greenery of the Gulf Region without compromising in visual appearance under stressed irrigation. However, soil amendment did not play a significant role in WUE of native plants. The use of bentonite as a soil amendment had a beneficial effect on the competitive ability of *T. appolinea*. However, the overall influence of soil amendment on plant development was minimal. Our study confirmed that the absence of moisture in the topsoil reduced weed emergence substantially. This finding is a milestone in weed science since mulching, plastic film, herbicides, and precision agriculture are uncertain approaches to dealing with it. Our findings suggest deep pipe irrigation and subsoil amendment strategy can reduce the cost and use of herbicide to eradicate weeds without compromising standing plantations. In this way, the risks related to herbicide chemicals exposure to public parks and gardens can be reduced significantly.

## Conflict of 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.

## Acknowledgments

This study was partly funded by the Al Ain Municipality and National Water and Energy Center, United Arab Emirates University. The authors would like to thank the Al Ain Municipality, National Water, and Energy Center, and ASPIRE Research Institute of Food Security in Drylands, United Arab Emirates University and all the associates who gave the help in conducting this research.

## Author contributions

Conceptualization: Elke GABRIEL-NEUMANN; Methodology: Ayesha ALAM; Formal Analysis: Ayesha ALAM; Writing- original draft preparation: Ayesha ALAM; Writing - review and editing: Ayesha ALAM; Funding acquisition: Elke GABRIEL-NEUMANN; Resources: Elke GABRIEL-NEUMANN; Supervision: Elke GABRIEL-NEUMANN. All authors approved the manuscript.

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