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The Impact of Irrigation on *Citrullus colosynthis* using Clay Pots: A Case Study from Southern Iran

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Abstract: At present, land degradation is a major challenge in arid regions that cause serious environmental problems. This study seeks to provide an adaptive approach using water conservation practices (drought-tolerance plant establishment) for sustainable land management (SLM) in arid areas. The plant growth characteristics of *Citrullus colocynthis* under clay-pot and traditional irrigation methods have been analyzed and interpreted for their conservation effects over a three-year period, from 2019 to 2021. The results indicate that soil moisture levels under clay-pot irrigation increased by 49%, 39%, and 56% at depths of 10 cm, 30 cm, and 50 cm, respectively, compared to the traditional irrigation method. This led to a significant improvement in water use efficiency, which was 1.7 times greater, and a reduction in water consumption by threefold compared to the control treatment. Clay-pot irrigation led to a significant decrease in soil hydrogen potential, electrical conductivity, and sodium levels compared to the traditional irrigation method ($p \leq 0.05$). Field observations revealed that *C. colocynthis* had exceptional growth performance during prolonged drought seasons, and growth characteristics such as fruit yield and canopy cover significantly increased (2.02, 2.12 and 7.6, 8.3 times more than the first growth season, respectively). In addition, following plant establishment, organic carbon increased up to 19% and 38% compared to the first year respectively. Overall, the results of this study depicted that, water conservation techniques such as clay-pot irrigation and establishment of drought-tolerant plants (*C. colocynthis species*) has a positive effect on soil-water-plant relationships, and play a key role in sustainable land management in degraded farmlands.

Key words: Clay-pot irrigation, Water conservation strategies, Water use efficiency, Soil erosion, *Citrullus colocynthis*.

Land degradation has become a prominent environmental issue in arid regions (Prăvălie *et al.*, 2021; Haregeweyn *et al.*, 2023). This problem is primarily attributed to frequent droughts and soil erosion, which accelerate the land degradation process, especially in agricultural lands (Zhou *et al.*, 2016; Deng *et al.*, 2019; Borrelli *et al.*, 2020; Ye, 2021; Ebabu *et al.*, 2022).

The concerning effects of land degradation in arid zones manifest as soil salinization, decline in soil fertility, severe dust storm occurrence, and human health hazards, which threaten sustainable development targets. Therefore, there is an urgent need to implement effective efforts to prevent land degradation particularly, in fragile areas (Montanarella *et al.*, 2016; Haregeweyn *et al.*, 2017; Fenta *et al.*, 2018; Prăvălie *et al.*, 2021).

To mitigate the environmental impacts of land degradation and promote ecological functions and ecosystem services, Sustainable Land Management (SLM) is a crucial development strategy that provides insights into the management of land resources such as soils, water, and plants in arid areas (Robinson *et al.*, 2017; Ebabu *et al.*, 2019; Kebede *et al.*, 2020; Ziadat *et al.*, 2021). SLM practices refer to efficiently and employing appropriate technologies as well as approaches, which are adopted under different conditions for the effective conservation of land resources, and mainly focus on the combination of soil and water conservation practices (Nyssen *et al.*, 2010; Sultan *et al.*, 2017; Zhang *et al.*, 2018; IPCC, 2019; Jahanthigh and Jahanthigh, 2023; Haregeweyn *et al.*, 2023, Teshome *et al.*, 2023). Among the various strategies for sustainable land management (SLM), vegetation restoration stands out as an effective approach to combat land degradation. By promoting the conservation of soil and water resources, it plays a crucial role in controlling soil erosion, particularly in arid regions (Benabdellah *et al.*, 2011; Porensky *et al.*, 2014; Ramachandran and Radhapriya, 2016; Shao *et al.*, 2019; Wei *et al.*, 2021; Hu *et al.*, 2021; Wang *et al.*, 2022).

Numerous studies have proven that the success of vegetation restoration projects is profoundly affected by water conservation strategies incorporating native and drought-tolerant plant species which have high water use efficiency (Parsons *et al.*, 2006; Stanton-Clements *et al.*, 2013; Tang *et al.*, 2021; Shay *et al.*, 2021; Xu *et al.*, 2022; Zaviezo *et al.*, 2023). These species would ensure better survival and growth while also reducing the need for irrigation (Jaramillo-Díaz, 2023; Carabassa *et al.*, 2021; Cheng and Li, 2021; Martínez *et al.*, 2022). In this context, clay-pot irrigation (CPI) is recognized as an effective method for water-saving in hyper-arid regions (Bainbridge, 2002; Wolde-Georgis, 2010; Kefa *et al.*, 2013; Araya *et al.*, 2014; Adhikary and Pal, 2020; Mahata *et al.*, 2021; Carlos *et al.*, 2023). In this method, a clay pot retains water in its storage and utilizes capillary action to deliver moisture directly to the root zones of plants. This approach significantly reduces evaporation losses and minimizes overall water consumption (Siyal *et al.*, 2015). Additionally, the use of clay pots for irrigation is beneficial for minimizing salinity, making them valuable for utilizing saline water sources (Bhatt and Kanzariya, 2017). Besides that, taking native and drought-tolerant plants into account could increase the successful establishment of plants to restore vegetation (Shay *et al.*, 2021; Xu *et al.*, 2022; Zaviezo *et al.*, 2023). Some studies have reported that the survivability of different plant species in arid climates is different. Citrullus colocynthis is one such species that, due to its high tolerance to drought conditions, can be highly effective for vegetation restoration in desert regions (Ahmed *et al.*, 2016; Gogoi *et al.*, 2019; Midhat *et al.*, 2021). This species also possesses some medicinal properties besides significant growth potential in degraded soil (Magdy *et al.*, 2015; Menon *et al.*, 2016). Therefore, to mitigate the environmental effects of land degradation, employing native and drought-tolerant plant species, such as *Citrullus colocynthis*, along with clay pot irrigation, represents an effective strategy for addressing land degradation in arid regions.

The Sistan Basin in southeast Iran is one of the active dust sources in southwestern Asia, which grapples with severe drought and wind erosion (Kaskaoutis *et al.*, 2019; Middleton, 2019; Jahanthigh and Jahanthigh, 2020). Currently, 75% of the total Sistan plainland is experiencing significant soil erosion, resulting in a decline in productivity, which poses a serious threat to livelihoods that predominantly rely on agricultural products (Jahanthigh *et al.*, 2022). Meanwhile, presence of gale winds during summer causes intense sand and dust storms, which accelerate the land degradation process over the Sistan basin (Alizadeh-Choobari *et al.*, 2014; Behrooz *et al.*, 2022). Hence, land degradation particularly in farmland has been identified as a common natural hazard causing many environmental problems in Sistan Plain.

The aim of this study was twofold: (1) to investigate the efficiency of clay pot irrigation

Table 1. physical characteristics of the experimental clay pots

Surface area (cm^2)	Thickness of clay-pot (cm)	Capacity of clay-pot (mL)	Seepage rate in soil (mL day^{-1})	Height (cm)	Shape of clay pot	Water tank stand height (m)
08 ± 7.2.876	2 ± 0.2.1	428 ± 5.1	387 ± 2.4	45 ± 1	bar-shaped	1

as a valuable water-saving technique compared to traditional irrigation methods on the growth characteristics of the *Citrullus colocynthis* plant and its effects on soil chemical properties; and (2) to assess the environmental impacts of *Citrullus colocynthis* on degraded farmland.

Materials and Methods

Location: The experiment was conducted at abandoned farmland located at Normohamad village (61°35´58 E longitude and 31°13´48 N latitude, 478 m above sea level) of Nimroz City in Sistan and Baluchestan province (Fig. 1). The region experiences a very harsh climate, with an average annual temperature of 32°C, which can rise to 43°C during June to August. The average annual precipitation is about 50 mm, while the average annual potential evaporation is approximately 5000 mm (Jahantigh *et al.*, 2022). The area has poor vegetation, with coverage ranging from 10% to 20%. Furthermore, soil salinity and alkalinity are significant constraints on plant growth in this region. Geologically, the area is primarily characterized by fine alluvial deposits and aeolian sand. During the summer, the presence of gale winds, particularly the 120-day wind, renders the region highly susceptible to wind erosion (Jahantigh and Jahantigh, 2020).

Water-saving technique: To evaluate the performance of the clay-pot system, an experiment was conducted in a laboratory by constructing a glass box, and the soil profile of the research area was replicated. Then, the clay pot was buried up to the neck such that the mouth, was located 4 cm above the soil surface, and using tubing and fittings (tee connecter and 16 mm pipe) was connected to a water storage tank with a 20 L capacity. The complete experimentation process and the data collected are illustrated in Fig. 2 and Table 1.

Experimental treatments and design: Field experiments were conducted from 2019

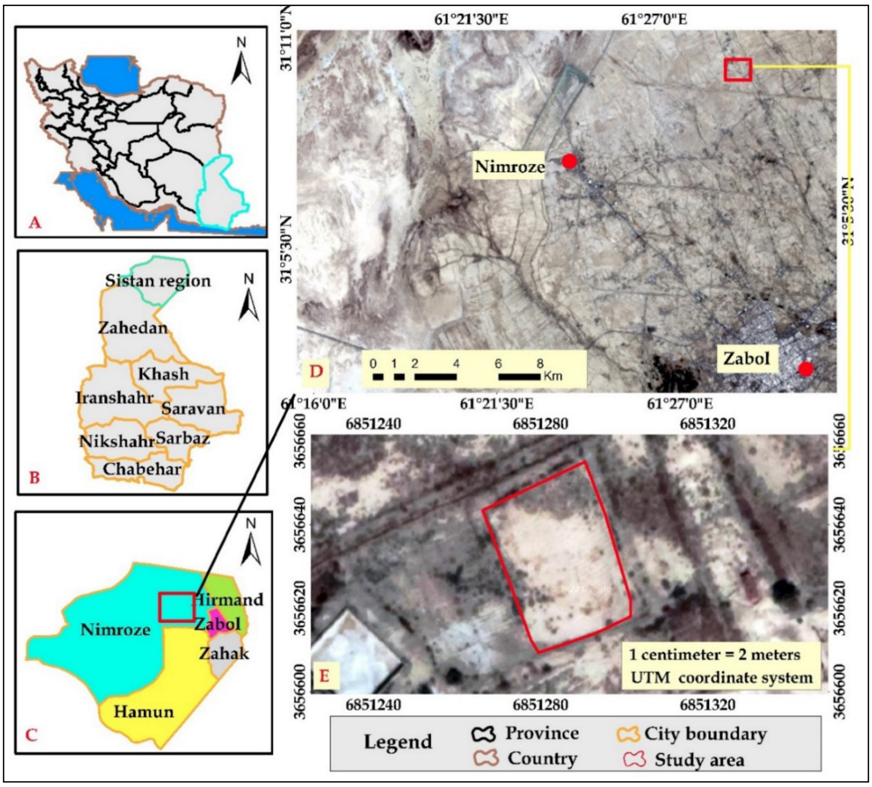

Fig. 1. Study location: A) map of Iran, B) the location of Sistan and Baluchestan Province in Iran, C) the location of the Nimroze in Sistan region, D) location of the Normohamad village in Nimroze city, E) location of the studied area in Normohamad village.

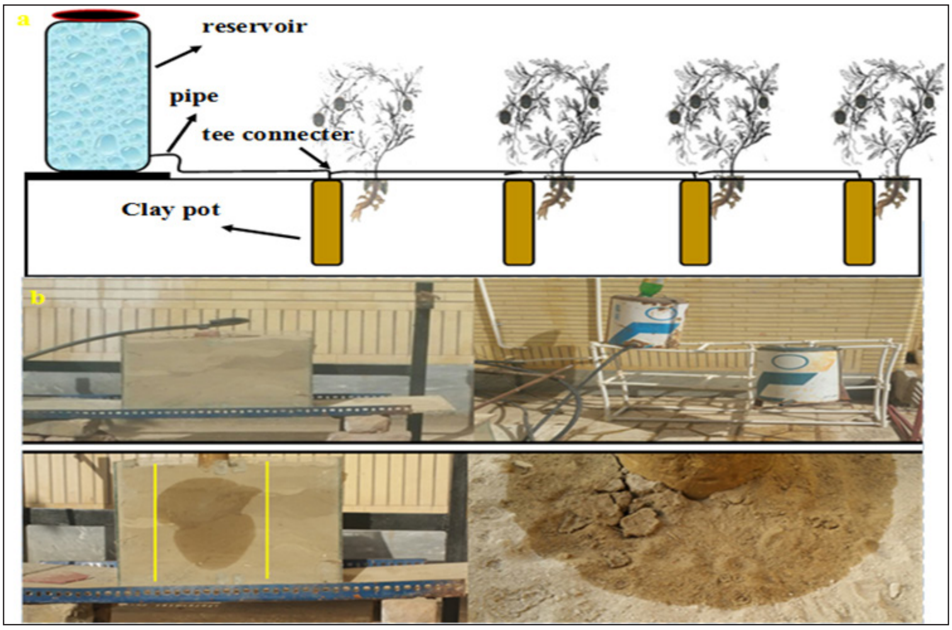

Fig. 2. View of the clay-pot irrigation system (a) and measuring the water seepage (b).

to 2021 in the degraded farmland of Nor-Mohamad village. The experimental design was structured as a randomized complete block design, consisting of 7 replications to ensure reliable and statistically significant results. Each treatment included clay-pot and traditional irrigation. A total of 14 experimental plots were prepared each measuring 3 m × 3 m (9 m²). To establish clay pot irrigation circular pits 60 cm deep and 45 cm in diameter were excavated in the center of seven plots (Fig 3a). In rest seven plots hand watering was adopted as traditional method of irrigation. Each plot contained one plant with a 0.5 m buffer zone between each sampling plot (Fig. 3). The primary tillage (by hand) was carried out in each plot and seeds of the plant were sown on 25 January 2019.

Observations Recorded: Plant characteristics such as length, canopy, and litter vegetation were recorded (using a ruler) monthly for 3 years (2019-2021). Also, at the end of the growing season, the number of branches per plant, fruits per plant, seeds per fruit, and

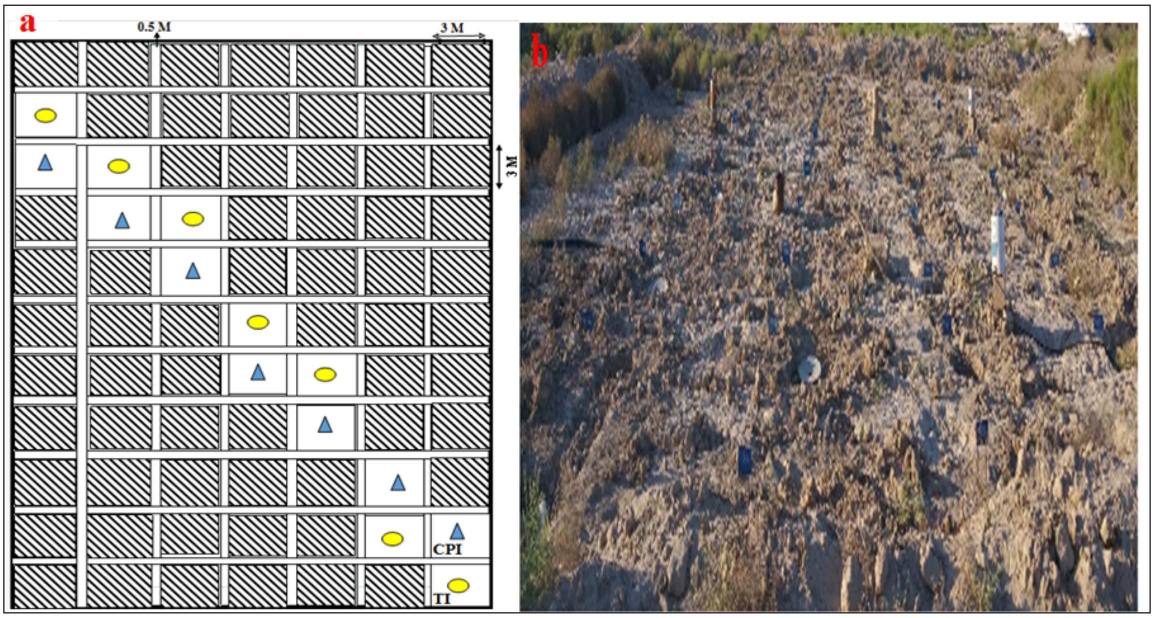

Fig. 3. a) Layout of the experimental plots, b) View of Treatments in degraded farmland of Nor-Mohamad village.

Table 2. Effect of irrigation methods on water consumption and irrigations events

Treatment	Irrigation events	Water consumption (L $plot^{-1}$)	Rainfall (mm)	Interval between two consecutive irrigations (Day)
Clay pot irrigation	27	210 (6.6 ±)	8	8
Traditional	48	810 (8.1 ±)	8	3

fruit yield were recorded. To estimate canopy and litter area within the plots, the longest dimensions (width and length) were measured during study period.

Soil moisture, Water consumption and WUE: To calculate the water use efficiency (WUE) the empirical formula (1) was used.

$$\text{WUE} = \frac{\text{Crop yield}}{\text{I}} \qquad \ldots 1$$

where, WUE = Water use efficiency (kg ha^{-1} mm^{-1}), crop yield = as grain, seed or total dry matter (kg ha^{-1}) and I = water used for irrigation (mm). To obtain the total amount of water consumed, we computed the quantity of water applied during each irrigation event, taking into account the effective rainfall during the growth periods. After harvesting the fruit yield, WUE (kg m^3) was determined by dividing fruit yield by total water consumption. Equation (2) Was used to determine the amount of required water for each irrigation event. The TDR method was used to measure soil moisture before each irrigation event at 3 different depths 10 cm, 30 cm, and 50 cm.

$$\text{I} = \frac{(\theta f - \theta) \times D}{100} \qquad \ldots 2$$

where, θ = Soil moisture before irrigation (volume percentage), θf = Volumetric soil moisture at field capacity (volume percentage), D = Effective depth of root (m) and I = Irrigation water depth (m).

Analysis of Soil Chemical Properties: Soil sampling was performed at the end of each growth season from depths of 0-25 and 25-50 cm and a total of 72 Soil samples were collected. Samples were analysed for some chemical properties of the soil such as pH, EC, Na^+, K^+, P^+, and Organic carbon (OC). Soil pH was determined using the saturation method and pH meter, EC with Conductometric method, and absorbable phosphorus was measured using sodium bicarbonate and spectrophotometric readings (Monaci *et al.*, 2017). Na^+ and K^+ were determined photometrically and Organic carbon was measured by the Walkley and Black titration method (Richards, 1954; Moghimi *et al.*, 2013). For estimating evaporation, the pan evaporation method was employed. Class A evaporation pan was installed within the study area for calculating evaporation (Chu *et al.*, 2010).

Statistical analysis: Statistical analyses were performed using Analysis of variance (ANOVA) to evaluate the effects of the treatments on growth indexes, water consumption, WUE index, and soil Chemical Properties. The least significant differences method (LSD) was used to compare the means of various treatments (at $p<0.05$) using the MSTAT-C and SPSS 23 software (Wu *et al.*, 2023).

Results and Discussion

Water consumption and Soil moisture

Comparing the water consumption (Table 2) implied that, clay pot irrigation (about 270 L $plot^{-1}$) led to 1.8 times water saving compared to traditional method (about 480 L $plot^{-1}$). Woldu (2015) reported that clay pot as one of the important sub-surface irrigation methods causes water consumed to be directly transferred to the soil profile, resulting in decreased evaporation loss compared to traditional method. The finding indicated that the average volumetric soil moisture under clay pot irrigation was relatively greater than that under the traditional method (Fig. 4a). Also, monitoring the dynamics of soil moisture at different depths revealed that under traditional method the soil moisture content was 17.2% (10 cm), 18.3% (30 cm), and 15.8% (50 cm) cm, while under clay pot irrigation comparable values were 19.5%, 23.3% and 29.2% respectively after one day of irrigation (Fig. 4b). Further, comparison of soil moisture at different depths illustrated, distribution uniformity of moisture under clay pot has greater by 49%, 39%, and 56% at 10, 30, and 50 cm depth respectively than the traditional method (Fig. 4c). As a consequence, the interval between two consecutive irrigation events through clay pot irrigation was 2.7 time longer than under traditional method (Table 2). This observation is also supported by the results of Araya *et al.* (2014) and Lucieta *et al.* (2018).

Weather characteristics and irrigation events

During the irrigation period (first growth season) the amount of water consumption under traditional irrigation in the beginning of the year was 60 L plot^{-1} which due to synergistic effects of temperature, wind speed, and evaporation increased up to 90 L plot^{-1} in

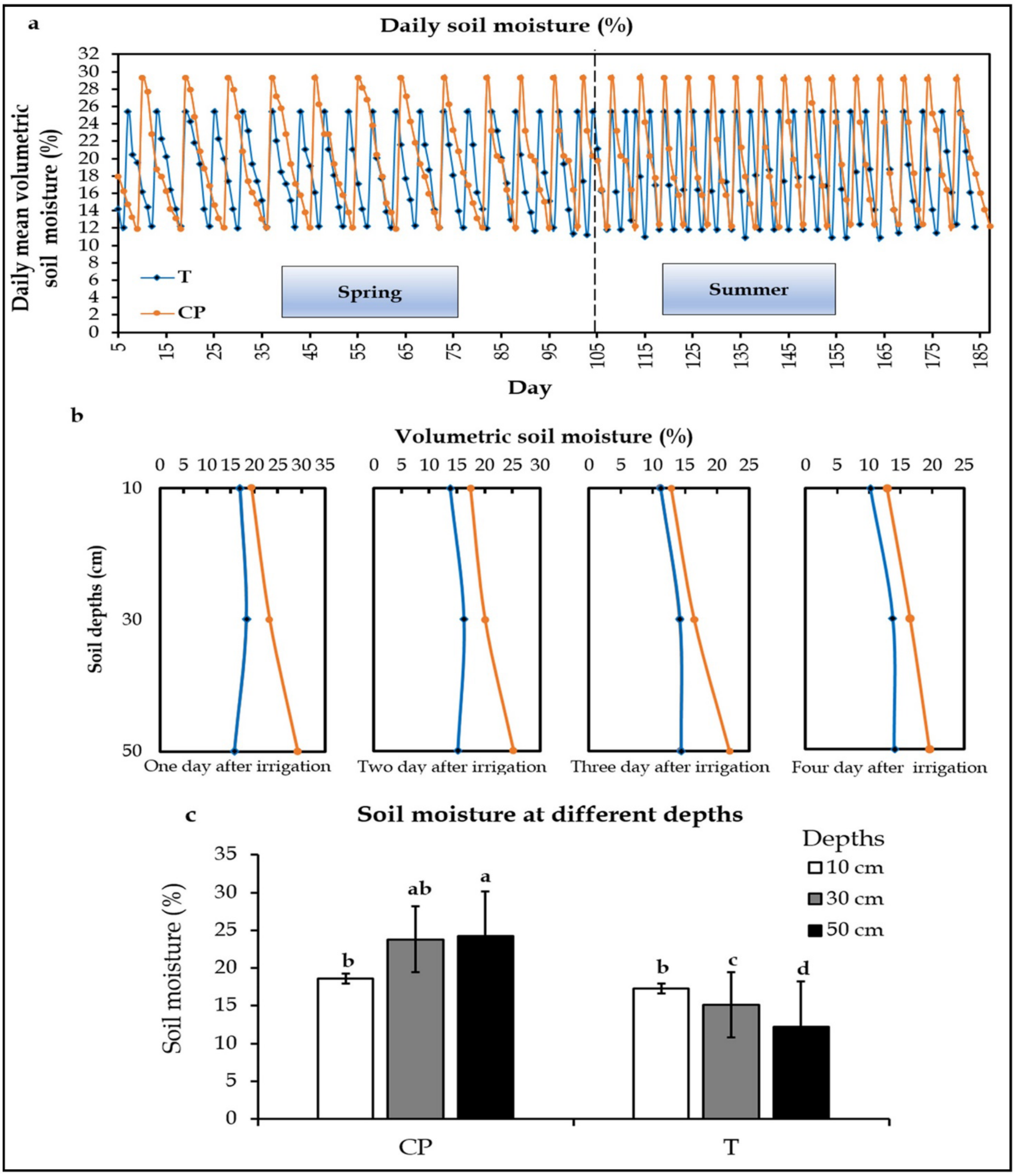

Fig. 4 a) Daily means of volumetric soil moisture (%) In treatments (CPI and TI) during irrigation periods (first growth season), b) variation of volumetric soil moisture at soil depths four days after irrigation, and c) mean comparison of soil moisture at soil depths under ICP and IT irrigation methods (The means with different superscripts in each column are significantly different based on LSD's post hoc test at p≤0.05).

Table 3. Effect of irrigation methods and growing season on growth index

Treatment	Shrub length (cm)	No. of branches per plant	No. of seeds per fruit	No. of Fruits per plant	Dry fruit weight (g)	Fruit yield (kg ha^{-1})	WUE index (kg m^{-3})
Clay pot irrigation	206.7^{a}	194.6^{a}	257.25^{a}	22.8^{a}	25.2^{a}	1796.2^{a}	20.11^{a}
Traditional irrigation	96.9^{b}	148.5^{b}	212.1^{b}	15.7^{b}	20.2^{b}	1072.04^{b}	11.15^{b}
2019	111.6^{c}	38.9^{b}	227.6^{b}	12.5^{c}	19.65^{b}	904.85^{b}	2.18^{b}
2020	210.9^{b}	229.6^{a}	236.7^{a}	22.6^{b}	22.3^{a}	1830.1^{a}	22.87^{a}
2021	233.3^{a}	246.2^{a}	238.5^{a}	32.2^{a}	23.1^{a}	1921.26^{a}	24.01^{a}
			Irrigation x yield				
Clay pot irrigation 2019	126.4^{d}	47.3^{c}	249.25^{a}	14.9^{cb}	21.1^{b}	1047.97^{cb}	6.11^{c}
Traditional irrigation 2019	96.9^{e}	30.4^{c}	206.1^{b}	10.1^{c}	18.2^{c}	612.74^{c}	0.93^{c}
Clay pot irrigation 2020	235.25^{ab}	265.3^{a}	261.25^{a}	26.4^{a}	24.1^{a}	2118.39^{a}	26.47^{a}
Traditional irrigation 2020	186.7^{c}	193.9^{b}	216.1^{b}	17.8^{b}	20.6^{b}	1218.833^{b}	15.22^{b}
Clay pot irrigation 2021	258.3^{a}	271.3^{a}	261.4^{a}	27.2^{a}	24.5^{a}	2222.15^{a}	27.77^{a}
Traditional irrigation 202	208.2^{b}	221.2^{b}	217.1^{b}	19.2^{b}	21.6^{b}	1384.56^{b}	17.31^{b}
			P-values				
Irrigation	*	**	**	**	**	**	*
Yield	**	**	**	**	**	*	**
Yield x irrigation	**	**	ns	ns	ns	ns	ns

Note: a, b, c means in the same column with different superscripts are significantly different based on LSD's post hoc test at p≤0.05, CP = Clay pot, T = Traditional irrigation, ** = P<0.01, * = P<0.05, ^{ns}: Not significant.

May, June, and July respectively. Corresponding values of water consumption under clay pot irrigation was 30 and 50 L plot^{-1} (Fig. 5). This process highlights the performance of clay pot irrigation in harsh climatic conditions. Results showed that clay pot method during critical

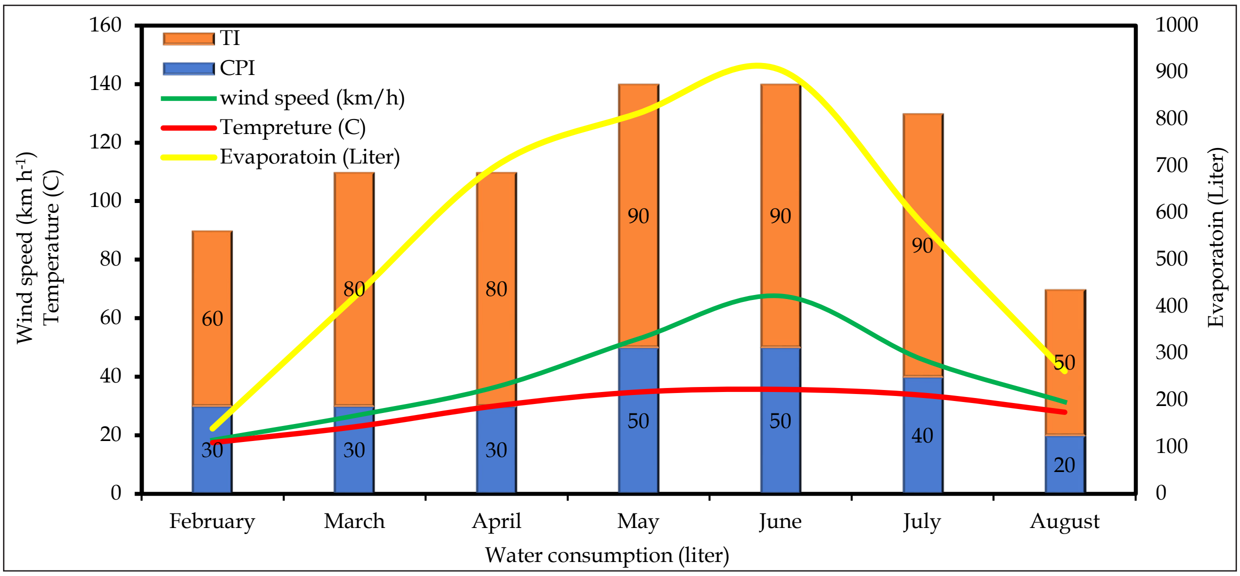

Fig. 5. Graph illustrating the temporal variation of water consumption in relation to fluctuations in temperature, wind speed, and evaporation during irrigation periods.

Table 4. Effect of irrigation methods and growing season on canopy changes

Treatment	The area of dried litter on the soil surface (m^2)	Canopy surface (m^2)
Clay pot irrigation	0.69^{a}	2.7^{a}
Traditional Irrigation	0.48^{b}	1.92^{b}
2019	0^{c}	0.41^{b}
2020	0.23^{b}	3.1^{a}
2021	1.49^{a}	3.41^{a}
	Irrigation x yield	
Clay pot irrigation 2019	0^{d}	0.51^{c}
Traditional irrigation 2019	0^{d}	0.32^{c}
Clay pot irrigation 2020	0.29^{c}	3.73^{a}
Traditional irrigation 2020	0.18^{c}	2.48^{b}
Clay pot irrigation 2021	1.7^{a}	3.87^{a}
Traditional irrigation 2021	1.2^{b}	2.95^{b}
	P-values	
Irrigation	*	*
Yield	**	**
Yield x irrigation	^{ns}	^{ns}

Note: a, b, c means in the same column with different superscripts are significantly different based on LSD's post hoc test at $p \leq 0.05$, CP = Clay pot, T = Traditional irrigation, ** = P<0.01, * = P<0.05, ^{ns}: Not significant.

months (February, March, April, May, June, July, and August), resulted in 3.5, 3, 4, 3.7, 4.7, and 4.5 times saving of water compared to the traditional method.

Growth characteristics of plant: The results showed that growth characteristics (shrub length, number of branches, fruits plant^{-1}, number of seeds fruit^{-1}, and dry weight) were higher under clay pot irrigation compared to the traditional irrigation ($p \leq 0.05$). Moreover, the increment of fruit yield (1796.2 kg ha^{-1}) and WUE (20.11 kg m^{-3}) was perceptible under CPI (Table 3). As elucidated, irrigation under clay pot has resulted in uniform distribution of moisture at each depths of soil. Lucieta *et al.* (2018) report that this mechanism cause water consumed directly transferred to the root zone. In other words, installing clay pot with a cylinder shape causes the pot located parallel to the root plants and meets plant-water requirements properly (Bhatt and Kanzariya, 2017). This mechanism has an effective role in plant growth that has the tap-root system by improving the distribution of moisture in soil depths. The *C. colocynthis* specie is one of the plants that has very delicate, fleshy, and long tap roots (Dhakad *et al.*, 2017; Kapoor *et al.*, 2022). Hence, proper irrigation under CPI helps develop the root system, facilitating plant growth during prolonged drought seasons. Meanwhile, analysis of growth parameters over the three growing seasons manifested that, the growth characteristic of this species irrigated using clay pot, during second and third seasons (under non-irrigation) significantly increased compared to TI ($p \leq 0.05$).

Effect of plant establishment on land cover

Results showed that irrigation methods and growth seasons affected the vegetation canopy over the study period (Table 4). So, the largest significant value of vegetation canopy (2.7 m^2) was obtained under CPI (1.4 times more than TI). Also, the growing season greatly influenced vegetation canopy ($p \leq 0.05$) and the order of canopy peak over study period was third growing seasons (3.41 m^2) > second growing seasons (3.1 m^2) > first growing seasons (0.41 m^2). Similarly, the main factors affected vegetation litter during study period ($p \leq 0.05$). Besides that result indicated, the peak period of *C. colocynthis* growth is synchronous with harsh climate conditions, and due to perceptible increase of canopy and litter of vegetation, caused a relatively resistant layer (about 4-5 cm thickness), which covers soil surface during prolonged drought seasons. The study area is an abandoned farmland because of severe drought, and limited access to water resources has not been cultivated for a decade and is currently exposed to wind erosion (Jahantigh

Table 5. Effect of irrigation methods, growing season and depths on soil characteristic

Factors		pH	Ec (dS m^{-1})	Na^+ (meq L^{-1})	OC (%)	K^+ (meq L^{-1})	P (ppm)
Clay pot irrigation		7.65^b	2.78^b	25.2^b	0.201^a	60.73^a	4.9^a
Traditional irrigation		8^a	3.1^a	27.9^a	0.192^a	59.4^a	4.8^a
Depth	0-25 cm	7.51^b	2.63^b	24.95^b	0.22^b	60.05^a	5^a
	25-50 cm	8.10^a	3.28^a	28.5^a	0.17^a	61.06^a	4.82^a
2019		7.95^a	3.10^a	28.35^a	0.157^c	60.20^a	4.87^a
2020		7.67^b	2.87^b	26.65^b	0.197^b	60.62^a	4.90^a
2021		7.61^b	2.81^b	26.31^b	0.24^a	61^a	4.92^a
				P-values			
Irrigation		*	*	*	ns	ns	ns
Depth		*	*	*	*	ns	ns
Year		ns	ns	ns	**	ns	ns
Irrigation x depth		*	**	**	ns	ns	ns
Year x depth		ns	ns	ns	*	ns	ns
Irrigation x year x depth		ns	ns	ns	ns	ns	ns

Note: a, b, c means in the same column with different superscripts are significantly different based on LSD's post hoc test at p≤0.05, CP = Clay pot, T = Traditional irrigation, ** = P<0.01, * = P<0.05, [ns]: Not significant.

and Jahantigh 2023). However, as clarified the studied species has a good ability to adapt to desert areas. Ahmed *et al.* (2016) and Gogoi *et al*. (2019) reported that *C. colocynthis* species due to its unique properties such as drought tolerance and high adaptation to harsh climatic areas is a suitable plant for vegetation restoration, controlling wind erosion and desertification in arid zone.

Soil characteristic: Obtained results declare that, the implementation of water conservation strategies had a substantial impact on soil characteristics (Table 5, Fig. 6). So that, the implementation of clay pot irrigation led to lower pH, Ec, and Na than traditional irrigation. Similar results were reported by Siya *et al.* (2015) and Bhatt and Kanzariya (2017). They stated that clay pot irrigation by improve the moisture distribution uniformity causes, the root-zone salt accumulates at the outer fringes of the soil mass wetted by clay pot, and consequently affects the soil solute. Comparing the soil chemical properties at depths of 0-25 cm and 25-50 cm showed that the highest pH, Ec, and Na were related to deeper layers (25-50 cm), which were significantly different from the surface layer (0-25 cm). Boduroglu and Rashid (2022) underscore that the solute transport substantially influences the soil chemical properties. In this context, Jahantigh and Jahantigh (2020) pointed out that due to high groundwater level and evaporation rate, water and solute transport to surface layers increases rapidly, which accelerate the soil salinization process in Sistan area.As discussed, the increment of pH, Ec, and Na at deeper layers, were strongly attributed to upward movement of solutes through capillary force in the soil profile. However, Wang *et al.* (2018) reported that vegetation cover due to altering the radiation allocations in soil, has significant influences on soil evaporation and consequently, the capillary force in the soil profile. Hence, the increment of canopy coverage and litter of vegetation during the second and third growing seasons can partly mitigate the capillary force and upward movement of solutes to the surface layer (depth of 0-25 cm). The result showed that the highest amount of pH, Ec, and Na has measured in the order of the first growing seasons > second growing seasons > third growing seasons. Besides that, establishment of C. colocynthis specie showed positive effect on soil organic carbon. As result presented, the soil organic carbon increased up to 19 % and 38% after two and three years compared to the first year, respectively. It is generally accepted that, deep-rooted perennial plants play a crucial role in the stock of soil organic carbon (Peixoto *et al.* 2022; Benslama *et al.,* 2024; Pace *et al.,* 2024). Also, decomposition of accumulated litter leads to improving the OC concentration (Xiong *et al.*, 2020). Based on these results, one could therefore hypothesize that, the synergistic effect of the root system

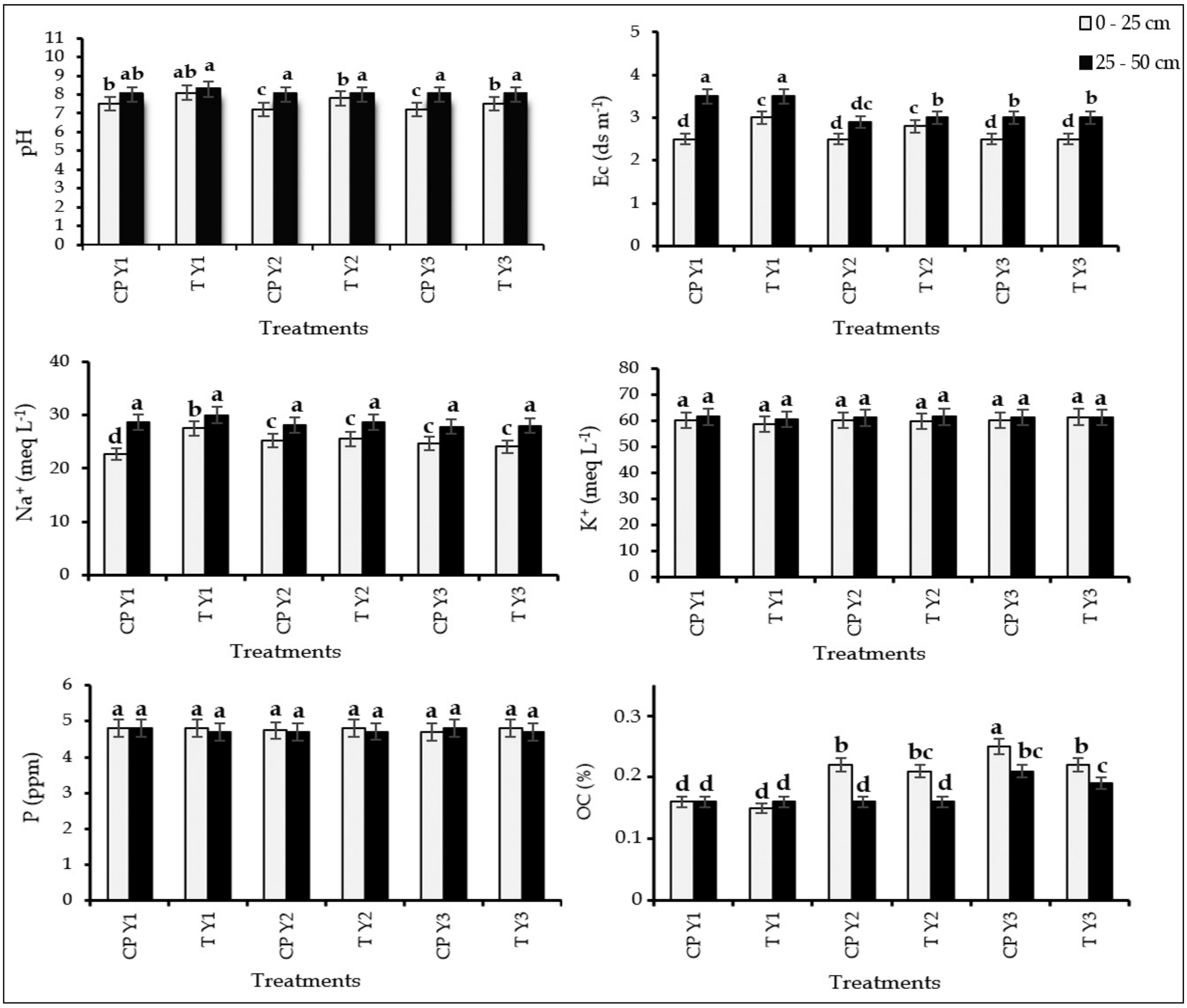

Fig. 6. Comparison the effect of treatments (irrigation methods, growing season and depths) on soil characteristic (The means with different superscripts are significantly different based on LSD test at p <0.05).

and decomposition of litter biomass profoundly influenced the C accumulation in the soil.

Conclusion

Results showed that CPI as one of the important water-saving techniques triggered a significant increase in water-saving and WUE in comparison to traditional irrigation (3 and 1.7 times respectively). *C. colocynthis* has considerable potential to adapt to extreme arid conditions and restore vegetation in degraded farmland. Water conservation strategies resulted in positive effects on Soil-Water-Plant relationships. Therefore, implementing CPI and establishing *C. colocynthis* are ideal strategies to restore vegetation for SLM in degraded farmland. However, future research is essential to make smart choices of WCS for SLM in arid areas, and the results of this study can be used as valuable information to gain better insights to expanding WCS and restoring vegetation in fragile areas.

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