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RESEARCH ARTICLE

Effect of different soil amendments on irrigation and crop yields in the oases of southern Tunisia

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ABSTRACT

In the oasis agro-system, salinization and hydromorphy are the principal degradation factors that negatively affect the soils. These two processes are the result of the rise of the water table caused by the overdose of irrigations. To counteract soil degradation and restore field productivity, the oasis farmers turn to use sandy and manure amendments. Therefore, three treatments (Control (C), sandy amendment (T1) and combined amendments composed by sand and manure (T2)) has been applied in Nefzaoua oasis to evaluate the effect of different amendments on oasis soil fertility, irrigation parameters, and barley yield. Results showed that T2 enhanced yield parameter (3,07 t/ha) compared to control treatment (1.85 t/ha) thanks to the improvement in the total nitrogen concentration (1.38 g kg -1), soil organic carbon (28.74 g kg- 1) and therefore C/N ratio (20.78) for T2 treatment at the level of the 0-20 cm layer. The results revealed that sand + manure combination (T2) enhanced the irrigation dose that can be effectively applied for the barley plants (19.61 mm) compared to the control treatment (15.49 mm) and T1 treatment (12.26 mm). In addition, the combined treatment T2 declined significantly the oasis soil bulk density leading to rise the porosity of the top layers (0-20 cm). Our results obtained confirmed the effectiveness of the combined amendment composed of sand and manure in improving the fertility and productivity of the amended oasis soil.

Keywords: Soil amendments, irrigation, agro-system, soil degradation

INTRODUCTION

The Soil degradation and the decline of its quality represent a severe issue especially in the arid and Semi-arid regions (Li, Wu, and Qian 2016). The principal reason of this issue that threats agriculture land is salinization which happens over time and space (Haj-Amor et al. 2017).

Arable land loss caused by soil salinization and alkalization was projected to be 10 million hectares per year (Jalali 2007), with various nations affected including Australia, China, North and South America, India, Mediterranean countries, and Southeast Asia. The issue of soil salinization which is aggravated by climate change (Dhaouadi et al. 2021) reduces the availability of irrigation water, which restricts plant water absorption and inhibits plant development and production (Kijne, Barker, and Molden 2003).

Several studies on the effects of soil salinization on crop production have been conducted and the results showed that soil salinization is triggered by a number of factors, including the use of brackish water with poor management for irrigation, and insufficient drainage.

One of the arid regions most affected by salinization is the Nefzaoua oasis in southern Tunisia. Generally, the oasis's agricultural system divided into three levels, with the first level, mainly devoted to vegetable and fodder crops (mainly barley), the second to a fruit tree, and the third to date palm cultivation. In the oasis of Nefzaoua date palm (Phoenix dactyllifera) is the principal crop grown (Ahmed et al., 2022a,b), and it play an essential role in feeding the population and the local economy (Askri et al. 2014). In terms of fodder crops, barley is the primary agronomic resource most suited to the arid conditions of Tunisia's southern area, which are characterized by low rainfall amount and high evapotranspiration rate (Azaiez et al., 2020).

Due to inadequate irrigation water management and the unfavorable soil characteristics (sandy with high infiltration

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rate), the saline water table increased to a shallow level (\ 2 m), which resulted in soil salinization across the oasis (Dhaouadi et al. 2021).

Therefore, the crucial role of the irrigation water management to ensure sustainable agriculture in the oasis.

Irrigation in oases has been a major problem since ancient times because of water scarcity and the low irrigation frequency, especially during hot seasons. The use of the groundwater resources Intercalary Continental (IC) and Terminal Complex (TC) guarantees a sufficient permanent water supply during drying periods. Nevertheless, the continued use of these deep charged and non-renewable waters can affect the properties of the soil and agricultural production.

The irrigation method in the oases is the "water tower" defined as the time between two successive irrigations. The duration of the water tower in the oasis of Nefzaoua is long and poses water stress for the different crops especially during the hot seasons.

In order to reduce soil salinity, and replace the degraded soil by a healthy fertile soil with high water retention, different amendments in oases has become a common practice in southern Tunisia.

Most of the studies on salinization in the Tunisian oases has focused on the key causes and preventative strategies (Askri et al. 2014). However, few researches have studied the effects of different amendments on irrigation parameters and crop production in Nefzaoua oases. Consequently, the primary goal of this research is to study and understand how the organic and sandy amendments affects soil fertility, irrigation parameters and barley production.

MATERIEL AND METHODS

Field and climate conditions

This field study was established in the southeast of Tunisia, in the oasis of Negga (N 33° 43' 58.7712"; E 8° 50' 7.6848"), at an average altitude of 20 meters. It was conducted from November 2019 to November 2020. The research region is distinguished by a climate that is extremely arid climate, desert landscapes with sand dunes, and salt lakes.

The field region is characterized by long dry summer with high temperature that can exceed 55°C, and low amount of yearly precipitation (less than 100 mm). Additionally, the months between April and September are recognized for their water deficit. The annual evaporation exceeds 2000 mm. Sirocco winds bring sand and dust from the desert into the oasis in the spring and summer.

Experimental design and treatments

A randomized complete block design with three treatments and three replications (blocs) was used for this essay. Each bloc consisted of three plots of five meters long and four meters wide grown barley (*Hordeum vulgare* var. Ardhaoui). Barley seeds were sown by hand at a density of 200 seeds m^{-2} from November to May.

Three amendments treatments were applied in November 2019: sand (T1), sand combined with manure (T2) and control (C). The different amendments treatment were applied in the top layer of 0-20cm. The soils were then physically tilled in accordance with the standard farming practice. Manure (for goats and sheep) dose was equivalent to 30 ton ha^{1}, and sand dose was around 2000 m^3/ha (the same dose as traditionally use by farmers). Table 1 displays the physical and chemical characteristics of sand and manure.

Sampling and measurements

Soil organic carbon and total nitrogen

Soil samples form Negga oasis were collected after one month of amendment application according to 3 depths of soil layer (0-20 cm; 20-40 cm; and 40-60 cm). Soil organic carbon (SOC) was measured according to the following formula:

$$\text{SOC concentration (g kg-1)} = 4*((V-v)/V)*10$$

Where, V is controlled titration volume, and v represent the samples' titration volume.

Total nitrogen (TN) represents the total nitrogen content estimated by elemental analyzer and calculated as follows:

$$TN\ (g\ kg^{-1}) = 0,14 \times V_{HCl} \times 10$$

Where V_{HCl} represent the titration volume after distillation.

Irrigation dose

The irrigation dose (D) is considered as the theoretical dose of irrigation, it represents the useful soil reserve of water. Irrigation dose is computed in terms of 3 parameters: the water content at the field capacity (FC), the permanent wilting point (PWP) of the oasis soil, as well as the rooting depth according to the following formula:

$$D\left(m^3/ha\right) = \frac{\left(FC - PWP\right)}{100} Z \times 10$$

With:

FC: The volume water content of the soil at the field capacity (in percent)

PWP: The water content by volume of the soil at the wilting point (in percent)

Z: The rooting depth in mm.

Table 1: Chemical characteristic of the used amendment and physical characteristic of sand

Amendment type	Farm Manure	Sandy dune
pH	6.2±0.01	8.7±0.04
Organic carbon (g kg^{-1})	468±0.02	0.0±0.00
Extractable Phosphorus (g kg^{-1})	629±0.02	175±0.03
Total nitrogen (g kg^{-1})	2±0.05	0.01±0.03

Physical analysis of sand forms the oasis of Negga					
Glanunlomery			Electrical conductivity EC (ms/cm)	Bulk density BD (g/cm≥)	Porosity (%)
% Clay	% Lime	% Sandy			
5.13	6.23	88.64	4.57	1.52	42.64

The water tower

Determining the value of the irrigation dose used allows us to calculate the irrigation return period (Pi)

$$P\,(i) = \frac{D}{ETM}$$

With:
P (i) period between two successive irrigations in days
D: the irrigation dose in mm.
ETM: maximum evapotranspiration (need for culture).

Farmers will use the values thus calculated if the return period is suitable for the crops and if the duration of irrigation at the plot level is sufficient for easy handling of the irrigation.

Grain Yield

Plots (1m*1m) were hand-harvested to determine grain yield and thousand-kernel weight. Grains were obtained manually.

Statistical analysis

SPSS (16.0) software was used to analyze the data. The significance of the factor was determined according to p-values. Student test ($p < 0.05$) was used for the comparison of samples means. The figures were performed using GraphPad Prism 8 program.

RESULTS AND DISCUSSION

Effects of treatments on SOC, TN and C/N ratio

SOC and TN contents in untreated soil (C) were significantly ($p < 0.05$) lower than the amended plots. When organic matter (manure) was added, SOC and TN concentrations improved significantly ($p < 0.05$). In fact, the highest SOC and TN concentrations were observed under T2 (sand + manure) where reached 28.74 g kg^{-1} and 1.38 g kg^{-1} respectively (Table 2). Similarly, T2 enhanced meaningly ($p < 0.05$) C/N ratio in the soil to reach 20.78.

The highest TN, SOC and C/N were observed in the upper layer, which suggest that these part of soils received more organic matter from manure application (Mlih et al. 2019). The great improvement of TN and SOC concentration in the upper layer (0-20 cm) of soil treated with organic matter (combined amendments: sand + manure) can be explained by the rapid mineralization of manure rich in carbon and nitrogen. The treatment with organic amendments significantly enhanced SOC concentration and its stock (Yazdanpanah, Mahmoodabadi, and Cerdà 2016). In addition, climatic conditions in the oasis system can improve soil mineralization when organic matter is applied to the soil (Kravchenko and Thelen 2007). Our results explicitly show that the rate of organic matter mineralization is substantially higher on the surface than in the deep layer, where organic matter seems to be very weakly mineralized (Brahim et al. 2021).

Effect of amendments on field capacity (FC) and permanent wilting point (PWP)

Fig. 1 shows the findings of the mean volumetric water contents of the field capacity (FC) and the permanent wilting point (PWP) under different treatments and soil layers.

The water contents (the field capacity and the permanent wilting point) were enhanced under T2, while they were reduced under T1 compared to the untreated plots (Control). These differences were detected mainly in the superior layer (0-20 cm), and no significant difference between treatment was noted in lower layers (20-40 cm, and 40-60 cm).

The effect of T1 amendment is probably caused by the applied sandy texture, which is distinguished by a coarser grain size than the original soil (Dougherty and Chan 2014), resulting in the increase of soil macro pores, therefore the decrease of water retention. While when applying T2 composed of sand and manure the capillary forces being stronger in soil pores, therefore the increase of in soil water content.

Our results showed that FC and PWP values were increased due to the presence of organic matter. The increase of FC values in the 0-20 cm layer is more evident than

Table 2: Organic carbon (OC), total nitrogen (TN) concentration and C: N ratio's for 0-60 cm depth in the oasis soil under various amendment treatments

	Depth (cm)	Control	T1	T2
SOC Concentration g kg-1	0-20	15.12±2.01b	17.28±2.3b	28.74±1.16a
	20-40	3.91±1.4c	4.10±1.1c	4.11±1.87c
	40-60	2.7±0.74d	2.59±1.6d	2.48±1.26d
TN concentration g kg-1	0-20	1.21±0.7b	0.99±0.4bc	1.38±0.3a
	20-40	0.78±0.41c	0.71±0.21c	0.76±0.8c
	40-60	0.46±0.22d	0.5±0.17d	0.51±0.8d
C: N ratio	0-20	12,5±1.31c	17.45±1.4b	20.78±2.1a
	20-40	5.01±0.39d	5.73±0.2d	5.36±0.1d
	40-60	5.89±0.42d	5.18±0.3d	4.83±0.1d

Control: Untreated soil; T1: Sand dune; T2: Sand dune+manure

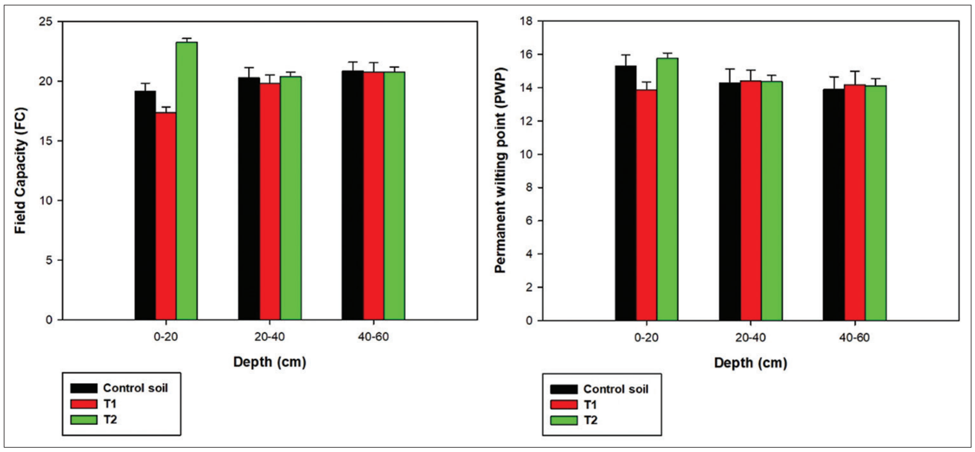

Fig 1. The mean volumetric water contents of the field capacity and at the permanent wilting point under different treatments (control, T1 and T2) and soil layers (0-20cm, 20-40cm and 40-50cm) in Negga oases.

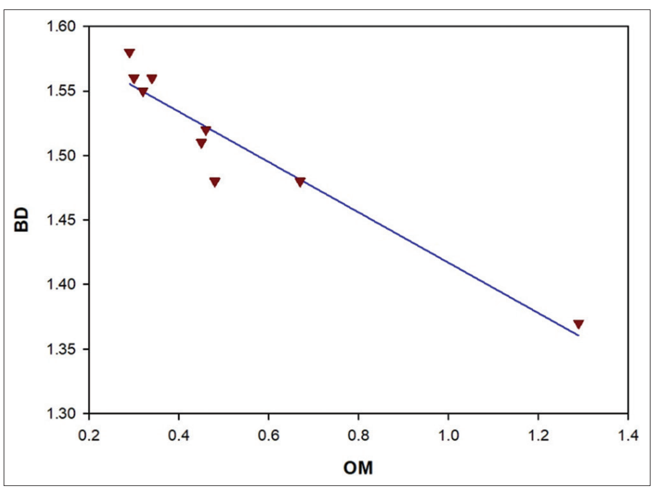

Fig 2. Correlation between Organic Matter Content in soil and bulk density.

PWP. Available Water Capacity (AWC), which measure the disparities between FC and PWP, increased with the increase of organic matter. In other words, soils with greater organic matter (OM) retain more water and present higher AWC because of the higher FC. Soil amended with organic matter retain more water at PWP. However, because the rise in moisture at FC is noticeably bigger, the consequence does not correspond to lower AWC values (Ankenbauer and Loheide 2017).

The increase of SOM decreases bulk density and enhances the soil structure through the formation of aggregate and the contribution to its stability (Fig. 2), which increase the soil porosity and improves water retention (Haynes and Beare 2020).

Effect of the amendments on the soil physical state

After the application of the amendment, the bulk density and the total porosity was determined to evaluate the physical properties of the amended soil. The results are collected in the Table 3.

Our results proved that T2 (Sand + manure) enhanced significantly the soil porosity and bulk density compared to T1. Indeed, this combined amendment (T2) improved the soil structure evidently in the superior layer (0-20 cm).

The bulk density of the 0-20 cm layer varied between 1.52 ± 0.58 g. cm^3 in the control soil and 1.37 ± 0.08g. cm^3 in T2 treatment, affecting soil porosity to reach 42.42 ± 0.56% in the control soil, 48.1 ± 0.08% under T2. This improvement is due to the replacement of a compact soil (initial soil) by a more friable layer (T2). Several researches proved the beneficial effect of organic matter on soil structural (Athira, Jagadeeswaran, and Kumaraperumal 2019). Globally the bulk density increased significantly ($p < 0.05$) while passing from the surface layer to the underlying layers, (Table 3). In fact, bulk density was around 1.55 g. cm^3, 1.51 g. cm^3, 1.48 g. cm^3 in the 20-40 cm layer, and 1.58g. cm^3, 1.56 g. cm^3, 1.56 g. cm^3 in the 40-60 layer of the control soil, T1 and T2 respectively. Further, the soil total porosity decreased significantly ($p < 0.05$) while passing from the surface to the underlying layers, it was around 41.28, 42.8 and 43.93 in the 20-40 cm layer, and 40.15, 40.9 and 40.9 in the 40-60 cm layer, for the control soil, T1 and T2. This change in porosity and bulk density in the soil layers is due to the susceptibility of the initial soil particle size to compaction.

Many studies investigated the relation between organic matter and soil bulk density and revealed a considerable correlation between both.

Curtis and Post (1964), Sakin et colleagues (2011) proved a strong negative relationship between organic matter and bulk density. Among the data obtained from the study findings, discovered the greatest association between bulk densities and organic matter. In accordance with those results, our data showed a strong negative correlation (r = - 0.92) between organic matter and bulk density. In fact, the increase of organic matter decreases the bulk density in soil (Fig. 3) which is essential for an appropriate plant growth. contrary to our results Asanopoulos et al. (2021) indicated that soil organic matter has a positive relationship with bulk density.

Table 3: The effect of different treatments on soil Bulk density (DA) and total porosity (PT)

Traitement	Depth (cm)	BD ($g.cm^3$)	Total porosity (%)
Control	0-20	1.52±0.58 c	42.42±0.56 bc
	20-40	1.55±0.65 b	41.28±0.65 c
	40-60	1.58±0.65 a	40.15±0.65 c
T1	0-20	1.48±0.39 d	43.93±0.39 b
	20-40	1.51±0.65 c	42.8±0.65 bc
	40-60	1.56±0.28 b	40.9±0.28 c
T2	0-20	1.37±0.08 e	48.1±0.08 a
	20-40	1.48±0.28 d	43.93±0.2 b
	40-60	1.56±0.65 b	40.9±0.65 c

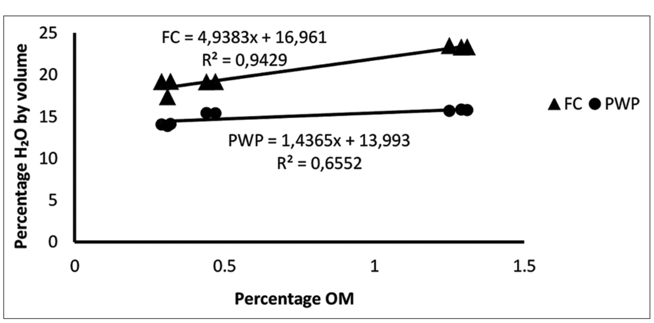

Fig 3. Correlation between organic matter and H_2O to obtain FC and PWP.

Effect on the irrigation parameters of oasis crops

Effect on the irrigation dose for oasis crop

Based on the water parameters acquired previously (Fig. 4) for the non-amended and amended (T1 and T2) soil, an average irrigation dosage was calculated for an annual crop (barley).

The variations in irrigation dosages across treatments are attributable to the changes caused by the applied amendments to the surface layers (0-20 cm and 20-40 cm). For a barley crop, the irrigation dose to be applied is respectively 15.49 mm, 12.26 and 19.61 mm for a control soil, soil amended by T1 and soil amended by T2.

The gypsum sand amendment (T1) reduced the irrigation dosage to be applied compared to control soil and the soil treated with gypsum sand and manure (T2). Organic matter promotes soil water retention by virtue of its low bulk density and high porosity. The increase in soil organic matter content leads to an increase in FC and PWP (Lal 2020).

The structure-forming effect of organic matter has less effect on water retention capacity when the water content is close to the wilting point than when it is close to the field capacity.

The proportion of textural components and the quantity of organic carbon in the soil affect the soil organic carbon content of available water content (AWC). Eden, Gerke, and Houot (2017) indicated that a rise in carbon content causes a rise in AWC in coarse soils.

The water tower

Based on the needs of the considered barley crop for irrigation water in winter and summer and taking into

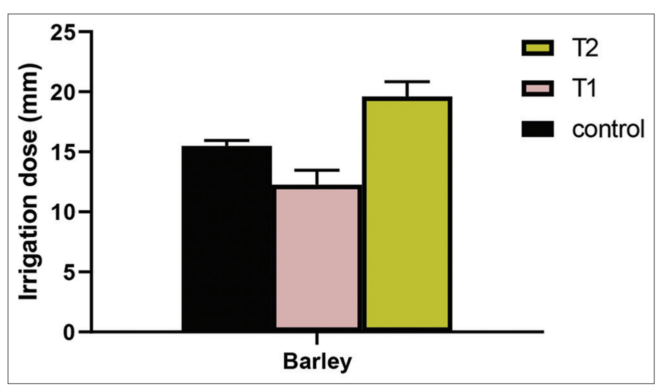

Fig 4. Irrigation dose calculated for barley in terms of applied amendments (Control, T1 and T2).

account the irrigation doses calculated for the three treatments (control, T1 and T2), it is possible to determine the period between the two successive irrigations (Table 4). The irrigation period is the time taken from a crop to deplete the usable water reserve (RU) in its root zone. This period is therefore calculated by relating the irrigation dose to the ETM of the crop at the corresponding vegetative stage (Development stage).

Table 3 gives the irrigation periods in winter and in summer for growing barley depending on the soil amendments applied. It appears that the average irrigation period for a barley crop in the pedoclimatic conditions of the oasis of Negga differs depending on the organic amendment practiced. Applying a single irrigation period for the unamended soil, then for the same soil after its amendment using sand and organic matter leads to water stress conditions for barley growing.

From the examination of this table, it emerges that both in winter and in summer, the applied water turn is precisely below the required irrigation period. This results in putting the existing barley crop under water stress leading to their wilting and death. It is this insufficiency of the turn (period between two very distant irrigations) which forced the farmers to abandon herbaceous crops. Only farmers with another source of water continue to grow these crops.

Irrigation in oases has been a major problem since antiquity because of the low frequency of water towers especially during hot seasons. Types of crops due to the poor distribution of water distribution during the seasons of the year (Ghazouani et al. 2019).

Grain yield

Treatments influenced grain yield variability. In fact, grain yield ranged between 1.45 (t/ha) for T1, to 3.07 (t/ha) for T2, while the control soil showed 1.85 (t/ha). Overall, the application of combined amendments (sand and manure) increased grain yield compared to unamended soil (Fig. 5).

This study indicated that applying organic matter combined with sand (T2) improved barley growth and production. In addition, it has been proved that the application of organic matter combined with sand reduces soil salinity (Zriba et al. 2020) and therefore enhance production.

The positive correlation between organic matter and the water quantity stored in the root zone (Fig. 3) proved that organic matter in T2 increased water storage, which in turn improved the plant status and production. Based on the finding that T1 (sand) reduce the easily usable water reserve, our results highlighted the relationship between grain yield and the easily usable water reserve.

As a result of the organic amendments treatment, barley growth and yield were greatly improved. In fact, organic matter is vital for the soil ecology because it offers substrates for decomposing bacteria (which provide minerals to plants), and enhances soil structure and water retention. This improvement could be explained by the high nutrient availability, particularly nitrogen release patterns and mineralization kinetics (Rekaby et al. 2020).

Thousand-kernel weight (TKW)

TKW ranged widely across the treatment: from 31.90 g for T1, to 41.86 g for T2, while control soil showed 36.32 g. Globally, application of the combined amendment (sand and manure) enhanced grain weight compared to unamended soil (Fig. 6).

The positive effects of T2 treatment were manifested in the development and production of barley, which explicates the considerable increase in grain weight. These findings are consistent with recent findings concerning increased plant production in dry and semi-arid soils amended with different organic matter (Mbarki et al. 2020) and (Achiba et al. 2016). These improvements can be due to the nutrient content of T2 treatments. Indeed, several researchers emphasize the critical role of macronutrients

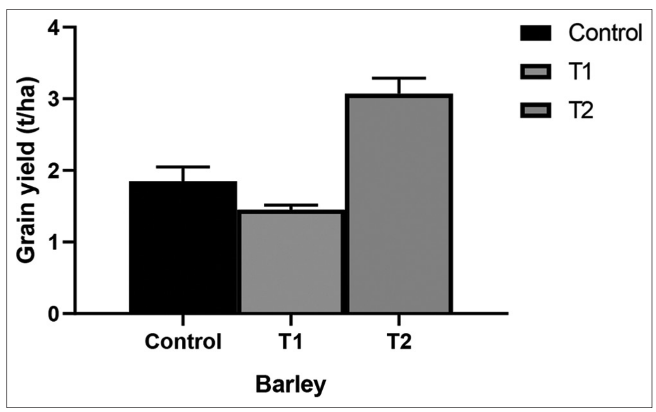

Fig 5. Grain yield (t / ha) in the three treatments (Control, T1 and T2).

Table 4: Theoretical irrigation periods and irrigation periods practiced by farmers for barley cultivation in the oases of Negga

Traitements	Dose (mm)	ETM (mm/days)		Theoretical water tower (days)		Practical water tower (days)	
		Summer	Winter	Summer	Winter	Summer	Winter
Control	15,49	8.2	3.5	2	4	30	21
T1	12,26	8.2	3.5	1	3		
T2	19,61	8.2	3.5	2	6		

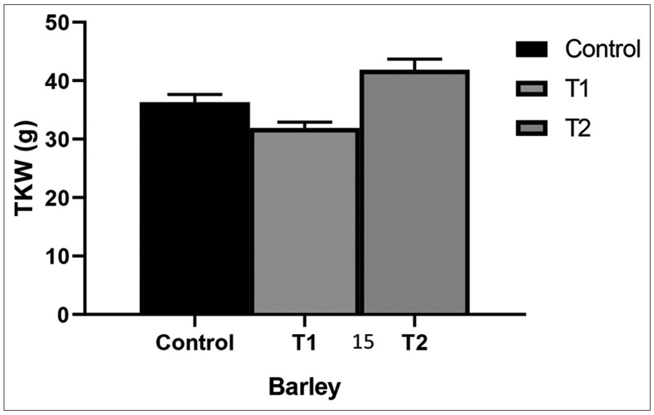

Fig 6. Thousand-kernel weight (TKW) in the three treatments (Control, T1 and T2).

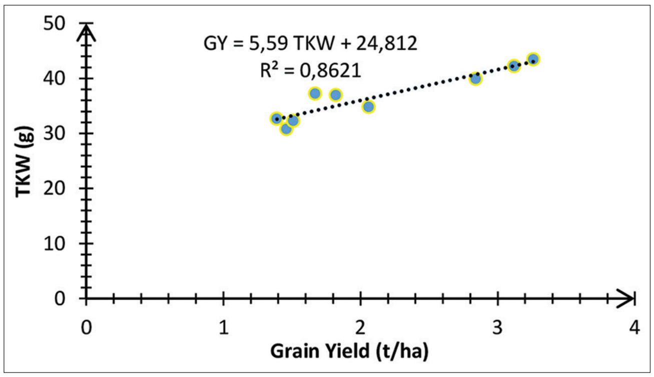

Fig 7. Correlation between GY and TKW.

and micronutrients given by organic matter in activating metabolic processes, enhancing development and metabolite production in plant tissues (El Mahdi 2008).

To study the relationship between grain yield (GY) and TKW, correlation analysis was established by compiling the three treatment data. Results showed that TKW is a main component determining GY (Fig. 7). In fact, there was a strong correlation between GY and TKW ($R^2 = 0.86$).

CONCLUSION

The soils of the oases are subject to various degradation processes, in particular hydromorphy and salinization, resulting in a decline in their fertility and their production potential.

The use of sandy and organic amendments is among the cultivation operations that oasis farmers frequently practice in order to preserve the soils and maintain their productivity.

The combined amendments (sand + manure) increased the concentration of TN and SOC in the superior layer (0-20 cm); this is explained by the rapid mineralization of manure rich in carbon and nitrogen. In addition, the combined amendment (sand + manure) is accompanied by an increase in water content at field capacity and at the permanent wilting point compared to unamended depth layers and compared to unamended plots. Indeed, the contribution of organic matter to the soils favored a greater effect on water retention in coarse-textured soils.

Our findings revealed a positive relationship between organic matter and the quantity of water stored in the root zone, which boosted barley crop yield in soils amended with sand and manure.

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