Farm manure and bentonite clay amendments enhance the date palm morphology and yield

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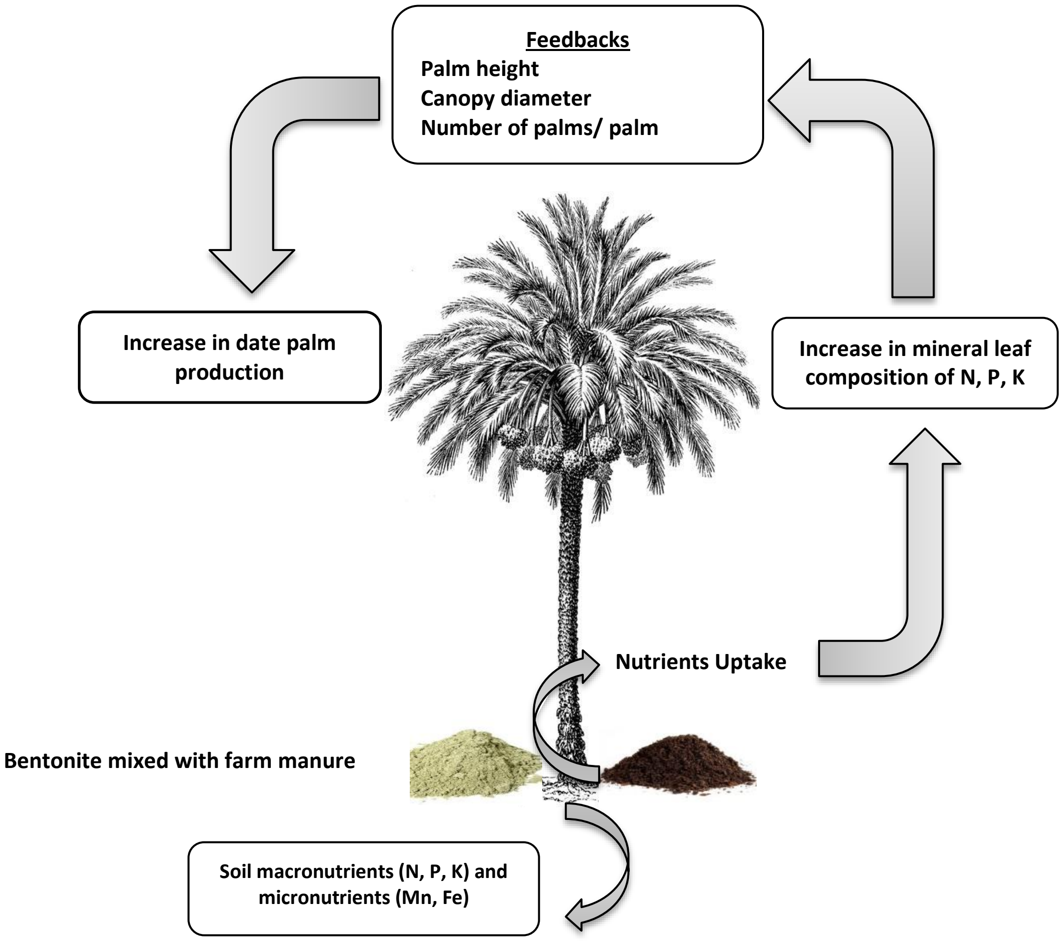
Graphical abstract



Abstract.

Date palm production contributes significantly to socio-economic development and food security in the dryland areas of Southern Tunisia. Soil degradation and nutrients depletion has dramatically increased in recent years. This is leading to a decline in date palm yields in these oases based production systems. Locally derived bentonite clay has been put identified as a new soil amendment to improve date morphological characteristics and date production. In this study, a three year field experimental study was carried out on 3 years old *Deglet Nour* date palms growing in sandy soil of a Tunisian oasis (Fatnassa, Southern Tunisia). The study aim was to compare the effect of two amendment types: (i) sand

(S) mixed with farm manure (M) and bentonite clay (B) (=BSM); and (ii) sand mixed with farm manure (SM) on the soil characteristics and morphological features of date palm. The results indicated that soil macro and micronutrient content were enhanced under BSM. Soil water retention in BSM also increased to 290±0.3 mm m^{-1} compared to 70±0.2 and 50±0.5 mm m^{-1} for an untreated (no amendment) and SM treatment, respectively. The amelioration of morphological characteristics was observed for the canopy diameter reaching 226±0.6 cm in BSM treatment compared to 172±0.6 cm in untreated palm trees. The height of the palms increased by 69±0.8 cm from 29±0.1cm in the control treatment, and leaf number increased from 40 leaves $palm^{-1}$ in BS to 60 leaves $palm^{-1}$ in BSM treatment. The leaf mineral content was significantly been improved in the third year, the leaf NPK contents were 220±0.6 mg kg^{-1}, 17±0.1 mg $kg^{-1,}$ and 200±0.04 mg kg^{-1} respectively, in BSM treatments. The effect of the farm manure and bentonite clay was noticeable for the yield production, the SM and BSM treatments offered yields of 70±0.9 kg $palm^{-1}$ and 80±0.5 kg $palm^{-1}$, respectively. It could partly ameliorate the alternate year bearing phenomenon of the Deglet Nour date variety. We conclude that, the joint application of farm manure and bentonite clay does represent an viable option to further improve the production and resilience of date palms in dryland areas.

Keywords: Deglet Nour; date palm; organic fertilizers; bentonite; manure; oasis; Tunisia.

1. Introduction

In arid and semi-arid areas, agriculture has been concentrated in regions where water is available. The oasis agro-systems is one of the important cultivation systems in these areas. Oases are mainly found near underground aquifers where water can reach the surface naturally and can be extracted through pumping (Mekki et al. 2013). For a long time, oasis agro-systems have played an important role in the development of the arid areas and the settlement of humans in these areas (Kadri and Van Ranst 2002; Tengberg 2012). They are seen as the opposite of desertification and land degradation, thus they have the potential to contribute to carbon sequestration in the arid areas (Lal 2004; Song and Zhang 2015). Date palm is the dominant crop in the oasis agro-system along with other crops such as fruit trees, cereals, and herbaceous plants (Tengberg 2012).

In Tunisia, date palm contributes significantly to the socio-economic development in the arid and desert areas of Southern Tunisia, the crop covers about 42,000 ha of agricultural land, with an annual production of nearly 241.000 metric tons (Mbaga et al. 2011). However, degradation is a growing threat to oases in Tunisia, mainly by soil salinization which stems from soil aridity and saline water resources used for irrigation. 50% of the irrigated lands are affected by soil salinity, while 25% are waterlogged and no longer suitable for cultivation (Besser et al. 2017). The depletion of soil organic matter is a noticeable phenomenon in these agro-systems as they do not support a thick vegetation cover that provide the organic matter input (Plaza et al. 2018). Additionally, natural challenges such as drought events and wind erosion coupled with mismanagement practices have contributed significantly to this loss in organic matter and soil infertility (Mlih et al. 2016). Traditionally, animal or plant sources of organic matter has been used as fertilizers in oasis agro-systems. Farmers use ca. 30 tonnes of sheep or goat manure per hectare every 3rd year to increase date palm production (Karbout et al. 2019). Manure is mixed with or buried under a sand layer near the palm trunks to slow down its decomposition and to attain the maximum benefit of nutrients release (Mlih et al. 2019). Using organic fertilizers secures the availability of nutrients for plant growth and helps maintain high moisture levels in the rooting zone of the date palms. Manure, for example, contains macro and micro mineral elements which are essential for crop growth (Fronning et al. 2008), it impacts soil physical properties namely soil bulk density, soil aeration, moisture retention, and water infiltration (Lehmann and Kleber 2015). Previous studies indicated that the application of organic amendments to soil affects positively crop growth and increases the yield (Anyanzwa et al. 2011; du Preez et al. 2011; Wood et al. 2018). The effect of applying organic fertilizers on date palm growth and production has been investigated in previous studies. Ibrahim et al. (2013) showed an increase in the number of leaves and number of bunches per date palm and an increase in fruit yield after applying sheep manure. The increase in yield and fruit quality has been reported in other studied (El Mardi et al. 2006; Marzouk and Kassem 2011).

Bentonite is a clay-generated material, it is used as a soil amendment to ameliorate sandy soils (Karbout et al. 2016; Karbout et al. 2015). It improves nutrient holding capacity, enhances soil structure, and helps provide a better home for soil microorganisms (Alghamdi et al. 2018; Pusch 2015). Previous studies reported high crop production when bentonite was used as a soil amendment (Datta et al. 2020; Mi et al. 2017).

The current study hypothesized that combining organic fertilizers with mineral fertilizers (i.e bentonite clay) will have a positive effect on soil chemical properties, morphological characteristics, and yield production. The study was achieved in a traditional oasis and traditional farming practices were applied throughout the study period.

2. Materials and methods

2.1. Site characteristics

This field study was carried out during three successive growing seasons of 2014; 2015 and 2016 on a Randomized, Complete Block Design (RCBD) that was implemented in a traditional oasis in Fatnassa (33.8° N; 8.7° E), in Kebili governorate, Southern Tunisia (Fig1).

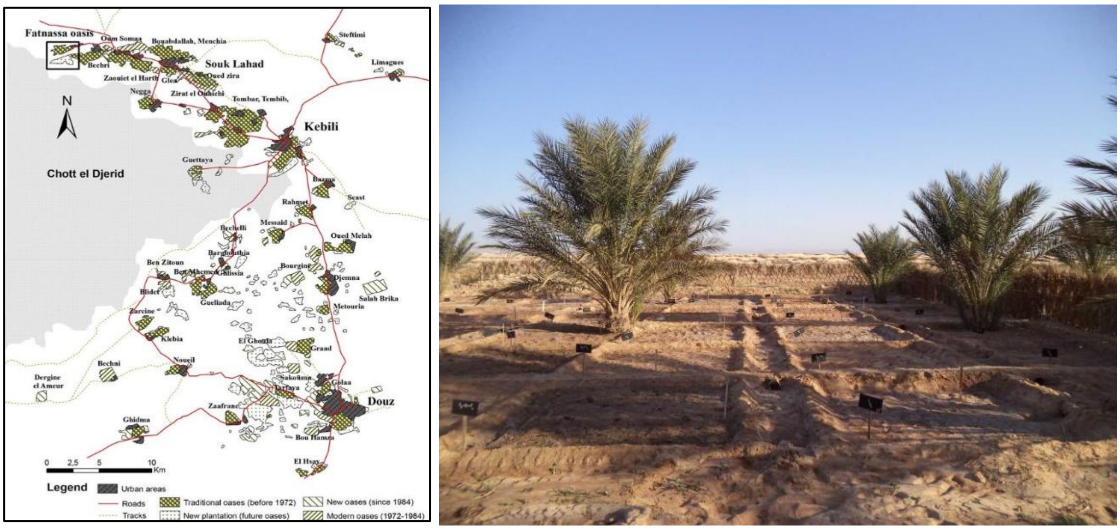


Figure 1. Left: Map of the Nefzawa oasian region adapted from Marini and Ongaro (1988).The study area is Fatnassa oasis in northwestern border of Nefzawa. Right: Plot design in the field for manure and bentonite amendments.

The mean annual rainfall in these areas is 40 mm and the evapotranspiration can be as high as 2000 mm per year. In the winter the temperatures drop to 1.9 °C whereas, in the summer period it can exceed 49 °C.

The experimental design contains nine plots with an area of 9 m^2 each (Fig 1), the plots were planted with date palm of *Deglet Nour* variety only. The trees had the same vigor, height, and age (3 years old) at the beginning of the experiment. Each plot contained two palms, in total 18 palms were subjected to this research. Three treatments were conducted in three replicates as follows:

(i) untreated soil plots (U), (ii) sand mixed with farm manure and bentonite clay (BSM); (iii) and sand mixed with farm manure (SM).

The plots were subjected to traditional cultural practices as followed by local farmers thus,the amendments were incorporated manually using traditional farming tools. The manure was applied at a rate of 27 kg per plot (equivalent to 30 t ha^{-1}), the bentonite was applied at a rate of 8 t ha^{-1}. The sand was applied at a rate of 180 kg per plot. The application of sand material is used by farmers as it reduces the salinity of the soil and regenerate the soil (typically sandy soil) under date palm. The chemical and physical characteristics of the amendment materials are shown in Table 1.

Table 1. Chemical and physical characteristics for the amendments used for the treatments.

	Type of amendment*		
	Farm Manure	Bentonite	Sand dune
pH	6.2±0.0	7.2±0.0	8.7±0.0
EC ($dS.m^{-1}$)	11.9±0.0	8.3±0.0	2.6±0.0
Organic carbon (g kg^{-1})	468±0.0	0.0±0.0	<0.05±0.0
Total nitrogen (g kg^{-1})	62±0.0	2.2±0.0	<0.05±0.0
Extractable P (mg kg^{-1})	175±2.6	3.4±0.0	0.3±0.0
Exchangeable K (mg kg^{-1})	1230±0.2	65.0±2.6	4.0±0.0
Bulk density (g cm^{-3})	1.2±0.0	1.5±0.0	1.4±0.0
Permeability (cm ha^{-1})	45.2±0.2	22.1±1.3	67.4±2.3

*The applied farm manure (derived from goats and sheep) is traditionally used by farmers and the bentonite clay was derived from a geological source in Gabe's region.

2.2. Soil analysis

A sampling campaign had been carried in January 2014 to assess the changes in the physicochemical proprieties of the soil. Soil samples from the date palm rhizosphere zone have been collected at three different depths (0-20, 20-40, and 40-60 cm). The samples were oven-dried at 55°C before analysis.

The soil pH and the EC were measured using a pH meter (AD 3000) and (Jenway 3305) respectively. The total organic matter was evaluated according to the analytical procedure of the Walkley and Black rapid titration method (Black et al. 1965). The amount of nitrogen in the digested sample was determined using the Kjeldahl distillation and titration method (Bremner and Mulvaney 1982).

Manganese (Mn) and iron (Fe) contents were extracted by $CaCl_2$/ Diethylene triamine penta-acetic acid DTPA/ CAT acid containing 14.75 g $CaCl_2 .2H_2O$ and 7.88 g DTPA at a ratio of 1:10 (solid, liquid). The extracted solution was shaken for 1 hour in a horizontal shaking machine. The suspension was then filtered through a filter paper. The calcium acetate lactate method (CAL) was used to extract P and K (Hoffmann et al. 1991), from the collected samples, only 5 grams were used in the extraction solution of 50 mL, maintaining the ratio of soil-to- solution of 1:20. The extracted solution was prepared of 0.05 M calcium lactate (C6H10CaO6 x 5 H2O), 0.05 M calcium acetate ((CH3COO) 2 Ca x H2O), and 0.3 M acetic acid (CH3COOH). This solution was shaken for about two hours before being filtered. For the evaluation of useful water retention (UWR), the HYPROP® method (METER Group, München, Germany) was used according to the procedure described by Schindler et al. (2010), coupled with the WP4® Dewpoint Potentiometer (METER Group, WA, USA). Soil hydraulic conductivity was evaluated, however, independently via the constant head method.

2.3. Plant analyses

The canopy characteristics, the number of leaves per palm, and the palm trunk up to the meristem epic were evaluated every year. The canopy diameter was measured physically by using meter tape which was pulled up between the driplines of the palm crown. The number of the new emerged leaves were defrenciated from the old leaves as the latter were identified by special paint. The annual yield of fruit was recorded in November. After the harvesting, the mature fronds were dried, grounded, and digested using a mixture of perchloric and sulphuric acids to determine the contents of N, P, and K (Jones Jr et al. 1991).

2.4. Biennial bearing index

The biennial bearing index refers to the process where fruit trees shift between a year of high yield and the following year with no production or low yield (Fioravanço and Czermainski 2018). The index was used to estimate alternate bearing by the following equation, adapted from Hoblyn et al. (1937).

$$\text{Biennial bearing index} = \frac{\text{Absolute value of the difference between successive yields}}{\text{Sum of successive yields}} * 100$$

2.5. Statistical analyses

All reported data represent the mean for the three replicates of each soil sample. The statistical analyses were performed with SAS software 9.0. Differences between treatments 0-60 cm soil layer were analyzed using one-way analysis of variance (ANOVA) using GML procedure with Tukey’s Honestly Significant Difference (HSD) test ($p<0.05$). The significant differences between the treatments are marked by different letters, the homogenous groups (not significantly different) are symbolized by a common letter. A quantitative approach (i.e., averages, percentages, standard, ANOVA, etc.) was also used to determine the effect of independent factors (e.g., soil fertilization) on dependent ones of date palm production based on cultivated area, per tree, and applied amendment unit.

3. Results and discussion

3.1. Soil chemical and physical properties

Soils covering oasis lands have neutral pH values ranging from 7.5 to 7.6 (Table 2), indicating that the spatial distribution of bentonite and organic amendment across the study area has no significant impacts on the pH values of soils considering the buffering impacts all the soil depths. The pH values are in agreement with previous findings (Marlet et al., 2009; Mlih et al., 2019; Rejili et al., 2012). Higher EC values were observed in the upper layer (0-20 cm) with 8.8±0.6 ds/mL compared to the deep soil layers 6.0±0.2 ds mL^{-1}. The bentonite and organic amendment significantly decreased the EC in the soil to reach 5.74±0.2 ds mL^{-1} in the SM amendment. This decrease continued further with depth in the other treatments. The measured EC values of the sampled soils seem to be influenced by various factors namely the release of salts from gypsum crusts, use of water with high minerals contents for irrigation, and the raise of the shallow saline water table.

The upper soil layers are characterized by the highest TN and SOC contents (Table 2). The high SOC values,10.2±0.1 and 7.8±0.9 g kg^{-1} in BSM and SM respectively, indicated the relevant effects of soil management by frequent organic matter supply, and surface-added farm manure. These practices may have led to soil C accrual in the shallow soil depths (Kramer et al. 2017; Sollins and Gregg 2017). The highest TN values, 1.8±0.1 g kg^{-1}, were reported in the upper layers, of the soil and decreased significantly ($p<0.05$) at higher depths for all treatments (Gregory et al. 2016; Mayes et al. 2014). The previous trends were also observed for P which accumulated in the upper layers as a result of organic matter accumulation in these layers. The highest value for (4.7±0.4 mg kg^{-1}) was recorded for BSM treatment, while the untreated soil 0.7±0.6 mg kg^{-1} was accumulated in the soil, the accumulation of P was less pronounced at higher soil depths (Kimetu et al. 2008; Soinne et al. 2014). The exchangeable K increased with the addition of farm manure and bentonite to reach 826.4±0.5 mg kg^{-1} at 20-40 cm depth in BSM treatment, which means eight times higher compared to the untreated soil value (100±0.78 mg kg^{-1}). The increase in K values at all depths is attributed to the leaching effects (Cuadros et al. 2017; Wang and Huang 2001) (Table 2). The contents of both micronutrients, manganese, and iron (Mn, Fe), were higher in the surface layers (0-20 cm) and (20-40 cm) in BSM treatment with 6.2±0.1 mg kg^{-1} and 3.6±0.3 mg kg^{-1} respectively. It has been noticed that the micronutrients tended to be concentrated in the upper soil horizons and were not easily leached. The measured concentrations of Fe and Mn were within the permissible range for a large portion of the cultivated crops. The more availability of both micronutrients was observed in the BSM compared to the SM amendment. It can be seen that the application of manure along with bentonite has improved the status of the micronutrients in the soil (Shahid et al. 2016).

The use of bentonite clay and organic amendments has also improved useful water retention (UWR) of the oasis soil (Table 2). The UWR values increased from 70±0.2 mm m^{-1} in the untreated soil to 290±0.3 mm m^{-1} in the BSM treatment in the surface layer (0-20 cm). The increase in UWR in the treatments amended with bentonite is evidence of the effect of clay-based bentonite, increasing clay content in the soil profile has resulted in greater water retention (Tahir and Marschner 2017). However, the UWR decreased significantly in the SM treatment (50±0.5 mm m^{-1}), which can be explained by the missing effect of bentonite which binds sand particles and minimize high water flow (Saleth et al. 2009).

Table 2. Effects of bentonite clay and organic (manure) amendments on soil chemical characterisitics. U untreated, SM sand and farm manure, BSM sand, bentonite and farm manure.

Soil properties	EC (ds m^{-1})	pH	SOC (g kg^{-1})	TN (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	BD (g m^{-3})	Ks (cm h^{-1})	UWR (mm m^{-1})
					Soil depth 0-20 cm						
U	8.8±0.6c	7.6±0.3^{a}	4.1±0.1^{a}	1.0±0.1^{a}	0.7 ±0.6^{c}	100±0.8^{a}	3.7±0.4^{a}	2.2±0.1^{a}	1.5±0.6^{a}	9.5±0.6^{c}	70±0.2^{b}
SM	5.7±0.2^{a}	7.7±0.5^{a}	9.8±0.2^{c}	1.7±0.2^{b}	4.5±0.3^{a}	458±0.1^{b}	4.8±0.1^{b}	2.8±0.0^{a}	1.3±0.0^{ab}	33±0.2^{b}	50±0.5^{c}
BSM	8.5±0.4^{b}	7.5±0.4^{a}	10.2±0.1^{d}	1.8±0.1^{b}	4.7± 0.4^{b}	826± 0.5^{c}	6.2±0.1^{c}	3.6±0.3^{b}	1.4±0.3^{b}	10.7±2.0^{a}	290±0.3^{a}
					Soil depth 20-40 cm						
U	6.7±0.1^{a}	7.5±0.5^{a}	7.0±0.1^{a}	1.7±0.1^{a}	0.4±0.2^{a}	183.3±0.1^{a}	1.6±0.0^{a}	0.9±0.1^{a}	1.5±0.6^{a}	6.6±0.4^{d}	40±0.4^{a}
SM	5.0±0.5^{c}	7.5±0.2^{a}	6.6±0.1^{b}	1.3±0.2^{b}	3.8±0.6^{c}	600.0±0.1^{c}	4.0±0.2^{b}	2.7±0.2^{b}	1.4±0.6^{d}	27.0±0.2^{c}	40±0.6^{a}
BSM	7.8±0.7^{b}	7.8±0.9^{a}	7.1±0.2^{ab}	1.4±0.1^{b}	1.5±0.1^{b}	550.9±0.0^{b}	3.7±0.0^{c}	2.4±0.4^{b}	1.5±0.3^{c}	10.1±1.2^{b}	40±0.5^{a}
					Soil depth 40-60 cm						
U	6.0±0.2^{b}	7.6±0.5^{a}	2.9±0.1^{a}	0.7±0.1^{a}	0.4±0.7^{a}	150.0±0.7^{a}	1.5±0.3^{a}	1.4±0.1^{a}	1.6± 0.6^{d}	9.0±0.1^{a}	80±0.3^{a}
SM	5.5±0.4^{a}	7.7±0.3^{a}	1.8±0.1^{a}	0.4±0.1^{b}	1.5±0.5^{b}	150.0±0.9^{a}	3.9±0.1^{b}	2.9±0.3^{b}	1.6±0.6^{a}	09.7±0.0^{a}	80±0.7^{a}
BSM	8.3±0.6^{c}	7.6±0.7^{a}	1.8±0.1^{a}	0.4±0.1^{b}	1.5±0.8^{b}	150.0±0.2^{a}	4.5±0.4^{c}	4.3±0.1^{c}	1.5±0.3^{b}	09.2±0.5^{a}	60±0.5^{a}

3.2. Organic and bentonite amendment effects on date palm morphological characteristics

3.2.1. Date-palm canopy

The application of the amendment did not affect the date palm canopy in the first year (Table 3). The date-palm canopy increased significantly ($p<0.05$) in the second year (2015). The diameter of the palm canopy reached 190±0.9 cm and 195±0.5 cm in SM and BSM treatments, respectively. The effect of this combination was more pronounced in the third year (2016) as the diameter of the canopy reached 226±0.6 cm in BSM treatment. The amendments had a smaller effect on SM treatment compared to that of BSM and untreated palm trees (172±0.6 cm). The results indicated that combining bentonite with organic amendments has more effect on the diameter of the palm canopy compared to farm manure and sand amendments only.

The amelioration of palm tree canopy reduces the evaporation rates by shading effect, and keep keeps the soil wet under the canopy (D'Odorico et al. 2007).

3.2.2. Number of leaves per palm

The number of leaves per palm in the first year of amendment application has shown no significant variation. While in 2015, the number of leaves per palm increased significantly ($p<0.05$) from 40 leaves palm^{-1} in the untreated soil to 50 leaves palm^{-1} and 54 leaves palm^{-1} for the SM and BSM, respectively. In the third year of amendment, the number of leaves continued to increase to reach a maximum of 60 leaves palm^{-1} in the BSM treatment.

The findings give concrete evidence of the impact of bentonite mixed with organic amendments on leaf reproduction. The increase of the leaves' number per palm means an increase in the leaves mass which is essential for biological processes such as plant growth and reproduction (Wang et al. 2019). In a previous study on date palm, palm Barje et al. (2016) found that applying farm manure has improved the leaf length and areas. In sunny areas, large leaves for example play an important role in regulating the microclimate and thus avoiding overheat (Wright et al. 2017). Additionally, the leaves of palms can be used as windbreaks to reduce the effect of wind erosion and help the farmers to produce compost from the waste of date palms (Abid et al. 2020; Mohamed et al. 2020).

3.2.3. Height of palm tree

No effect on the length of palm in the first season was recorded (Table 3), however, in 2015, a significant ($p<0.05$) increase by 65±0.2 cm in the palm length in the BSM treatment was observed, and an increase by 60±0.5 cm in SM treatment. The increase in length per palm continued in the third season (2016), to reach 69±0.8 cm in the BSM treatment.

The amelioration in palm length improves its resilience against the strong wind blown especially in the spring season in this region according to the local farmers' experience.

Table 3. Effect of organic amendments farm manure (FM) with and without the addition of bentonite (B) on the morphological characteristics of the date palm. U untreated, SM sand and farm manure, BSM sand, bentonite and farm manure.

Treatments	**Date-palm canopy (cm)**			**Number of leaves per palm**			**Palm height (cm)**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
U	172 ± 0.2^{a}	172 ± 0.5^{c}	172 ± 1.2^{b}	40^{a}	40^{b}	42^{d}	32 ± 0.1^{a}	33 ± 0.2^{b}	29 ± 0.1^{a}
SM	189 ± 0.9^{a}	190 ± 0.9^{a}	192 ± 1.0^{a}	45^{a}	50^{a}	54^{a}	37 ± 0.2^{a}	60 ± 0.5^{a}	59 ± 0.3^{c}
BSM	180 ± 0.8^{a}	195 ± 0.5^{b}	226 ± 0.6^{a}	41^{a}	54^{b}	60^{b}	34 ± 0.5^{a}	65 ± 0.2^{a}	69 ± 0.8^{c}

3.2.4. Leaf mineral content

The amendments' effect on NPK contents of date palm leaf was not significant in the first and second seasons (Fig 2). However, the N contents recorded in the date palm leaves during the third season were 160±0.9 mg kg^{-1} and 220±0.6 mg kg^{-1} for SM and BSM, respectively. P and K contents were also high and recorded 16 mg kg^{-1} and 17 mg kg^{-1} for P, and 120 mg kg^{-1} and 200 mg kg^{-1} for K in SM and BSM treatments, respectively.

The high contents of N, P, and K in the leaves indicate that application of organic and mineral amendment has secured sufficient quantities of the most essential nutrients for palm growth. The findings are in agreement with Barje et al. (2016) findings after applying organic amendments for

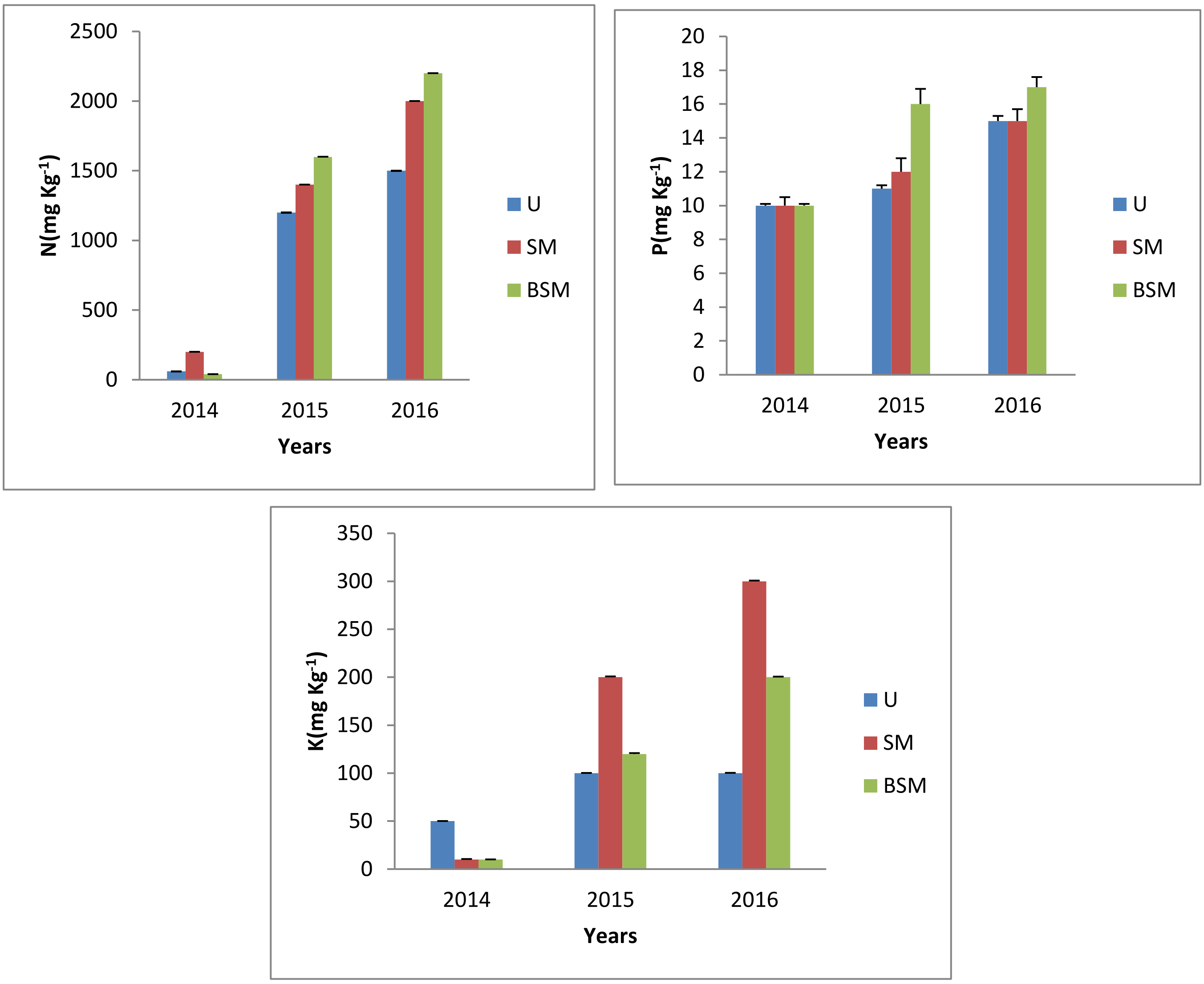


Figure 2. Effects of organic amendments of farm manure (FM) and bentonite (B) on the mineral content of the leaf of *Deglet Nour* date palms. U untreated, SM sand and farm manure, BSM sand, bentonite and farm manure.

3.2.5. Fruit yield and biennial bearing index

The first season of the study (2014) was considered an off-year as it exhibited no significant correlation with organic and mineral amendments application (Table 4). Despite the amelioration that occurred on the soil physical and chemical characteristics, the annual production hardly exceeds 5.0±0.3 kg palm^{-1}. The influence of bentonite clay mixed with organic fertilizers required time to show a visible effect on fruit yield (Abdul Baki and Aslan 2005; Ibrahim et al. 2013).

The impacts of the application of the fertilizer were pronounced in the next year (2015). The SM and BSM treatments offered yields of 70±0.9 kg palm^{-1} and 80±0.5 kg palm^{-1}, respectively. The findings are in agreement with Almadini et al. (2020) who attained an average production of 81.4 kg palm^{-1} in a traditional oasis and 54.6 kg palm^{-1} in a new oasis after application of farm manure.

Table 4. Effect of organic amendments farm manure (FM) with and without the addition of bentonite (B) on fruit yield and bearing index. U untreated, SM sand and farm manure, BSM sand, bentonite and farm manure.

Treatments	Date palm yield production palm^{-1} (kg)			Biennial bearing index	
	2014	2015	2016	2014-2015	2015-2016
U	5.0±0.3^{a}	5.0±0.6^{c}	3.2±1.2^{b}	0.8	0.0
SM	4.8±1.0^{a}	70±0.9^{a}	40±9.0^{a}	0.9	0.3
BSM	2.0±0.8^{a}	80±0.5^{b}	45±0.6^{a}	1.0	0.3

The yield has significantly dropped in the third year due to the lack of nutrient replenishment and the continuous depletion of soil nutrients by plant uptake. The assessment of fruit production for this year indicates the inadequacy of the applied amendments to overcome the biennial bearing of palm plantations (Marzouk and Kassem 2011).

The previous findings were confirmed by calculating the biennial bearing index using the data for fruit yield per palm (Table 4). The results indicate lower values in 2016 compared to 2015, explained mainly due to the yield reduction mentioned above. The highest and lowest decline were recorded in SM and BSM treatments, respectively. The obtained data highlights the requirement of a balanced application of organic and mineral fertilizers to meet the requirement of the date palm tree.

4. Conclusions

The BSM application, i.e. sand (S) mixed with farm manure (M) and bentonite clay (B), improved soil fertility (enhancing macro- and micronutrients) and date palm morphological characteristics. It significantly increased palm leaf number, date canopy diameter, tree length, fruit yield production and leaf mineral content. Furthermore, it could partly ameliorate the alternate year bearing phenomenon of the *Deglet Nour* date variety. More assessments for the amendments applied ratios and timing are however needed to fully overcome the biennial bearing issue. BSM had a positive effect on soil water retention when compared to BS and unamended (U) soils. The latter finding highlights that BSM thus can contribute to solutions for remediation strategies for water scarcity more globally in dryland oasis agro-systems.

References

Abdul Baki A, Aslan S (2005) Management of soil and water in date palm orchards of Coachella Valley, California. International Center for Agricultural Research in Dry Areas.

Abid W, Mahmoud IB, Masmoudi S, Triki MA, Mounier S, Ammar E (2020) Physico-chemical and spectroscopic quality assessment of compost from date palm (Phoenix dactylifera L.) waste valorization. J Environ Manage 264:110492. doi:10.1016/j.jenvman.2020.110492

Alghamdi AG, Aly AA, Al-Omran AM, Alkhasha A (2018) Impact of biochar, bentonite, and compost on physical and chemical characteristics of a sandy soil. Arab J Geosci 11:670. doi:10.1007/s12517-018-3939-y

Almadini AM, Ismail AIH, Ameen FA (2020) Assessment of farmers practices to date palm soil fertilization and its impact on productivity at Al-Hassa oasis of KSA. Saudi J Biol Sci. doi:https://doi.org/10.1016/j.sjbs.2020.11.084

Anyanzwa H, Okalebo JR, Othieno CO, Bationo A, Waswa BS, Kihara J Effects of Conservation Tillage, Crop Residue and Cropping Systems on Changes in Soil Organic Matter and Maize–Legume Production: A Case Study in Teso District. In: Bationo A, Waswa B, Okeyo JM, Maina F, Kihara JM (eds) Innovations as Key to the Green Revolution in Africa, Dordrecht, 2011// 2011. Springer Netherlands, pp 205-213

Barje F, Meddich A, El Hajjouji H, El Asli A, Ait Baddi G, El Faiz A, Hafidi M (2016) Growth of Date Palm (Phoenix dactylifera L.) in Composts of Olive Oil Mill Waste with Organic Household Refuse. Compost Sci Util 24:273-280. doi:10.1080/1065657X.2016.1171738

Besser H et al. (2017) GIS-based evaluation of groundwater quality and estimation of soil salinization and land degradation risks in an arid Mediterranean site (SW Tunisia). Arab J Geosci 10:350. doi:http://doi.org/10.1007/s12517-017-3148-0

Black C, Evans D, Dinauer R (1965) Methods of soil analysis J Am Soc Agron 9:653-708.

Bremner J, Mulvaney C (1982) Nitrogen-Total 1. Methods of soil analysis. Part 2. Chemical and microbiological properties,(methodsofsoilan2). Madison, Wisconsin: American Society of Agronomy,

Cuadros J, Andrade G, Ferreira TO, de Moya Partiti CS, Cohen R, Vidal-Torrado P (2017) The mangrove reactor: Fast clay transformation and potassium sink. Appl Clay Sci 140:50-58. doi:https://doi.org/10.1016/j.clay.2017.01.022

D'Odorico P, Caylor K, Okin GS, Scanlon TM (2007) On soil moisture–vegetation feedbacks and their possible effects on the dynamics of dryland ecosystems. J Geophys Res Biogeosci 112. doi:https://doi.org/10.1029/2006JG000379

Datta R et al. (2020) Bentonite-Based Organic Amendment Enriches Microbial Activity in Agricultural Soils. Land 9:258.

du Preez CC, van Huyssteen CW, Mnkeni PNS (2011) Land use and soil organic matter in South Africa 2: a review on the influence of arable crop production. S Afr J Sci 107:35-42.

El Mardi MO, Al Julanda Al Said F, Bakheit Sakit C, Al Kharusi LM, Al Rahbi IN, Al Mahrazi K Effect of pollination method, fertilizer and mulch treatments on the physical and chemical characteristics of date palm (Phoenix dactylifera) fruit I: physical characteristics. In: III International Date Palm Conference 736, 2006. pp 317-328

Fioravanço JC, Czermainski ABC (2018) Biennial bearing in apple cultivars. Revista Ceres 65:144-149.

Fronning BE, Thelen KD, Min D-H (2008) Use of Manure, Compost, and Cover Crops to Supplant Crop Residue Carbon in Corn Stover Removed Cropping Systems. Agron J 100:1703-1710. doi:https://doi.org/10.2134/agronj2008.0052

Gregory AS, Dungait JAJ, Watts CW, Bol R, Dixon ER, White RP, Whitmore AP (2016) Long-term management changes topsoil and subsoil organic carbon and nitrogen dynamics in a temperate agricultural system. Eur J Soil Sci 67:421-430. doi:https://doi.org/10.1111/ejss.12359

Hoblyn T, Grubb N, Painter A, Wates B (1937) Studies in Biennial Bearing.—I. J Pomol Hort Sci 14:39-76.

Hoffmann G, Thun R, Deller B (1991) Die Untersuchung von Böden. VDLUFA-Verlag, Darmstadt

Ibrahim MM, El-Beshbeshy RT, Kamh NR, Abou-Amer AI (2013) Effect of NPK and biofertilizer on date palm trees grown in Siwa Oasis, Egypt. Soil Use Manag 29:315-321. doi:https://doi.org/10.1111/sum.12042

Jones Jr JB, Wolf B, Mills HA (1991) Plant analysis handbook. A practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Publishing, Inc.,

Kadri A, Van Ranst E (2002) Contraintes de la production oasienne et stratégies pour un développement durable. Cas des oasis de Nefzaoua (Sud tunisien), [Limitations of oasis production and strategies for sustainable development, South Tunisia]. Science et changements planétaires / Sécheresse 13:5-12.

Karbout N, Dhaouidi L, Boughdiri A, Jaoued M, Moussa M, Bousnina H (2019) Qualitative analysis of the indicators of degradation of the Nefzaoui oases and quantitative study of their impacts on the socio-economic level of the region farmers. Analyse qualitative des indicateurs de dégradation des oasis de Nefzaoui et étude quantitative de leurs impacts sur le niveau. J New Sci 65:4114-4124.

Karbout N, Gasmi I, Moussa M, Bousnina H (2016) Effect of clay amendment on the conservation of moisture in sandy soils of South East Tunisia. J Res Environ Earth Sci 4:125-131.

Karbout N, Moussa M, Gasmi I, Bousnina H (2015) Effect of clay amendment on physical and chemical characteristics of sandy soil in arid areas: the case of ground south-eastern Tunisian. Appl Sci Reports 11:43-48.

Kimetu JM et al. (2008) Reversibility of Soil Productivity Decline with Organic Matter of Differing Quality Along a Degradation Gradient. Ecosystems 11:726. doi:10.1007/s10021-008-9154-z

Kramer MG, Lajtha K, Aufdenkampe AK (2017) Depth trends of soil organic matter C:N and 15N natural abundance controlled by association with minerals. Biogeochemistry 136:237-248. doi:10.1007/s10533-017-0378-x

Lal R (2004) Carbon sequestration in dryland ecosystems. Environ Manage 33:528-544.

Lehmann J, Kleber M (2015) The contentious nature of soil organic matter. Nature 528:60-68. doi:https://doi.org/10.1038/nature16069

Marini C, Ongaro L (1988) La carta delle oasi del Nefzaoua, un esempio di analisi digitale di immagini da satellite. Rivista di Agricoltura Subtropicale e Tropicale 62:91-102.

Marzouk H, Kassem H (2011) Improving fruit quality, nutritional value and yield of Zaghloul dates by the application of organic and/or mineral fertilizers. Scientia Horticulturae 127:249-254.

Mayes M, Marin-Spiotta E, Szymanski L, Akif Erdoğan M, Ozdoğan M, Clayton M (2014) Soil type mediates effects of land use on soil carbon and nitrogen in the Konya Basin, Turkey. Geoderma 232-234:517-527. doi:https://doi.org/10.1016/j.geoderma.2014.06.002

Mbaga M, Suleiman Rashid Al-Shabibi M, Boughanmi H, Mohamed Zekri S (2011) A comparative study of dates export supply chain performance: the case of Oman and Tunisia. Benchmarking: An International Journal 18:386-408. doi:https://doi.org/10.1108/14635771111137778

Mekki I, Jacob F, Marlet S, Ghazouani W (2013) Management of groundwater resources in relation to oasis sustainability: The case of the Nefzawa region in Tunisia. J Environ Manage 121:142-151. doi:https://doi.org/10.1016/j.jenvman.2013.02.041

Mi J, Gregorich EG, Xu S, McLaughlin NB, Ma B, Liu J (2017) Effect of bentonite amendment on soil hydraulic parameters and millet crop performance in a semi-arid region. Field Crops Res 212:107-114. doi:https://doi.org/10.1016/j.fcr.2017.07.009

Mlih R, Bol R, Amelung W, Brahim N (2016) Soil organic matter amendments in date palm groves of the Middle Eastern and North African region: a mini-review. J Arid Land 8:77-92. doi:https://doi.org/10.1007/s40333-015-0054-8

Mlih RK, Gocke MI, Bol R, Berns AE, Fuhrmann I, Brahim N (2019) Soil Organic Matter Composition in Coastal and Continental Date Palm Systems: Insights from Tunisian Oases. Pedosphere 29:444-456. doi:https://doi.org/10.1016/S1002-0160(19)60814-3

Mohamed OZ, Yassine B, Hilali Rania E, El Hassan A, Abdellatif H, Rachid B (2020) Evaluation of compost quality and bioprotection potential against Fusarium wilt of date palm. Waste Manag 113:12-19. doi:10.1016/j.wasman.2020.05.035

Plaza C et al. (2018) Soil resources and element stocks in drylands to face global issues. Sci Rep 8:1-8.

Pusch R (2015) Bentonite clay: environmental properties and applications. CRC Press,

Schindler U, Durner W, von Unold G, Müller L (2010) Evaporation Method for Measuring Unsaturated Hydraulic Properties of Soils: Extending the Measurement Range. Soil Sci Soc Am J 74:1071-1083. doi:https://doi.org/10.2136/sssaj2008.0358

Shahid M et al. (2016) Micronutrients (Fe, Mn, Zn and Cu) balance under long-term application of fertilizer and manure in a tropical rice-rice system. J Soils Sed 16:737-747.

Soinne H, Hovi J, Tammeorg P, Turtola E (2014) Effect of biochar on phosphorus sorption and clay soil aggregate stability. Geoderma 219-220:162-167. doi:https://doi.org/10.1016/j.geoderma.2013.12.022

Sollins P, Gregg JW (2017) Soil organic matter accumulation in relation to changing soil volume, mass, and structure: Concepts and calculations. Geoderma 301:60-71. doi:https://doi.org/10.1016/j.geoderma.2017.04.013

Song W, Zhang Y (2015) Expansion of agricultural oasis in the Heihe River Basin of China: Patterns, reasons and policy implications. Physics and Chemistry of the Earth, Parts A/B/C 89-90:46-55. doi:https://doi.org/10.1016/j.pce.2015.08.006

Tengberg M (2012) Beginnings and early history of date palm garden cultivation in the Middle East. J Arid Environ 86:139-147. doi:https://doi.org/10.1016/j.jaridenv.2011.11.022

Wang C et al. (2019) The Smaller the Leaf Is, the Faster the Leaf Water Loses in a Temperate Forest. Front Plant Sci 10. doi:10.3389/fpls.2019.00058

Wang FL, Huang PM (2001) Effects of organic matter on the rate of potassium adsorption by soils. Can J Soil Sci 81:325-330. doi:10.4141/s00-069

Wood SA, Tirfessa D, Baudron F (2018) Soil organic matter underlies crop nutritional quality and productivity in smallholder agriculture. Agric, Ecosyst Environ 266:100-108. doi:https://doi.org/10.1016/j.agee.2018.07.025

Wright IJ et al. (2017) Global climatic drivers of leaf size. Science 357:917-921. doi:http://doi.org/10.1126/science.aal4760