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Using moringa oleifera seed cake and compost as organic soil amendments for sustainable agriculture in Valencia orange orchard

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This work was conducted during two consecutive seasons, 2016/2017 and 2017/2018, at Experimental Research Station of National Research Centre at Nubaria, El Behiera governorate, Egypt. Twelve-year-old Valencia orange trees (*Citrus sinensis* L. Osbeck) budded on Volkamer lemon rootstock, grown in sandy soil under drip irrigation system were used as plant materials to study the effect of six organic soil amendment treatments on hydrophysical soil properties, soil water retention, soil water movement, water productivity, plant nutrient contents, yield and fruit quality. Treatments namely, moringa seed cake (MC) 100% (3 tons/fed), 1 moringa seed cake: 2 compost (COM), 1 moringa seed cake: 1 compost, 2 moringa seed cake: 1 compost, compost 100% (3 tons/fed) and control (none moringa seed cake and none compost). Results showed that the application of moringa seed cake combined with compost at 2:1 achieved the best results in terms of soil properties and water productivity of Valencia orange trees. This, in turn, improved nutritional status and increased the productivity of trees and fruit quality compared to the control.

1. Introduction

Oranges from the Valencia orange tree (*Citrus sinensis* L. Osbeck) are among the most consumed fruits because of their high Vitamin C content. Moreover, it is considered one of Egypt's main export fruits (Martí et al., 2009). Valencia orange trees are cultivated successfully in Egypt, but the trees planted in newly reclaimed soils face many challenges, including poor nutrient content and low soil organic matter and leaching nutrients, that affect tree growth and fruit quality. Such conditions require alternative agricultural practices to improve soil properties.

Recycling agricultural residues is crucial for augmenting soil organic amendments and achieving the best agricultural management; however, climate change valorises residues and participating in the circular economy and zero waste contributes to carbon sequestration (Almendro-Candel et al., 2018). Using organic fertilisers maintains soil components and productivity by increasing soil biological activity and overall soil stability with a positive correlation with microbial biomass. Also, it provides efficient use of nutrients and energy from traditionally managed soil. Organic fertilisation promotes primary metabolites, including soluble carbohydrates, chlorophyll pigments, carotenoids and secondary metabolites such as proteins, polyphenols and auxins (Saviozzi et al., 2002; Bejan and Vişoiu, 2010).

At present, agricultural production management techniques focus on a greater commitment to environmental sustainability. Organic farming is accepted by the European Union and FAO as an alternative to traditional agriculture and accepted as environmentally friendly (Martínez-Alcántara et al., 2016). In organic systems, soil management involves using mowed or tilled cover crops, animal manures, composts, and organic fertilisers that increase soil organic matter (SOM) whilst providing a steady release of nutrients to the crops as the organic matter breaks down. Exogenous organic matter applications improve soil chemical and physical properties and biological functions (Diacono and Montemurro, 2015).

Compost amendments are most frequently used to provide essential nutrients to rebuild soil physic-chemical properties and re-establish microbial populations and activities. Lakhdar et al. (2009); Hemdan (2014) elucidated that incorporating compost in the sandy soil improves soil's hydrophysical properties, including soil bulk density, void ratio, soil porosity and available water in the soil, hydraulic conductivity, and mean diameter of soil pores. The positive effects of compost on aggregate stability, bulk density, porosity, infiltration rates and total water holding capacity of soils can also be improved. In some studies, the effect of applied compost on soil water retention was evaluated, and results showed that compost amendment increased plant available water (Cogger, 2005; Carter, 2007; Mylavarapu and Zinati, 2009).

Synthetic fertilisers as sources of plant nutrients are associated with land and soil degradation and environmental pollution besides their high cost. Moringa oleifera is promoted as a safe, natural alternative, being investigated to ascertain its effect on the growth and yield of crops (Phiri, 2010). Different parts of this plant contain a profile of important minerals, proteins, vitamins, β carotene, amino acids and various phenolic that provide a rich and rare combination of zeatin with several flavonoid pigments (Nagar et al., 1982; Siddhuraju and Becker, 2003; Anwar et al., 2007). Nitrogen availability is considered the critical factor affecting the yield of organic production systems (Clark et al., 1999). Organic fertilisers are slow-release sources for nitrogen resulting in a deficiency in crop yield (Pang and Letey, 2000). Soil fertilisation by Moringa oleifera seed cake leads to plant growth enhancement within a short period of its application compared to other organic matters from animal dung and plant compost, which require long periods for decomposition and use of caution (Villablanca, 2007). Moringa oleifera is an edible and extremely safe cultivated variety of the genus moringa belonging to the Moringaceae family (Mahmood et al., 2010). It offers many benefits in food supplements, medicine, nutrition, water treatment, green manure, and natural fertiliser (Fatma et al., 2020), in soil and water conservation and to decrease greenhouse gas mission (Daba, 2016).

Moringa seed cake is ready after the extraction of moringa oil from the seeds, and it is obtained from a cold-pressing method. Moringa cake is rich in protein content, about 60% and as a powder contains all the essential amino acids; phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, leucine, and lysine. Additionally, cysteine (or sulphur-containing amino acids), tyrosine (or aromatic amino acids), histidine and arginine (Jahn, 1988). Moringa oleifera seed cakes have been shown to increase the mineral content of soil and increase the yield of maize crops compared to the control (Emmanuel et al., 2011).

Organic fertilisers derived from moringa oleifera seed processed with the proper procedure can increase the soil aeration and richness of indigenous invertebrates, specialised endangered soil species, beneficial arthropods, earthworms, symbionts and microbes (FAO, 2010). Stricevic et al. (2011) mentioned that the AquaCrop model could be used with a high degree of reliability in practical management, the simulations of biomass, yield, and water demand. Therefore, the purpose of this study was to test the performance of two organic fertilisers, moringa seed cake and compost, alone or mixed, on soil properties, nutrient uptake, yield and fruit quality, and water productivity Valencia orange.

2. Materials and Methods

2.1. Experimental conditions and plant material

The study was carried out through two successive seasons, 2016/2017 and 2017/2018, on 12-year-old "Valencia" orange trees (*Citrus sinensis* L. Osbeck) budded on Volkamer lemon rootstock, planted at 3 x 4 m (350 trees fed $^{-1}$), grown in sandy soil under drip irrigation system at Experimental Research Station of National Research Centre at Nubaria, El Behera governorate Egypt. The chemical and mechanical properties of soil are presented in Table (1), and the water irrigation analysis is shown in Table (2). Trees were selected at random as uniform in their vigour growth as possible and received the same horticultural practices, except for the purpose of this study. The experiment followed a complete randomised block design on 24 trees as six treatments were applied. Each tree was considered a replicate; four replicates trees per each treatment.

2.2. Treatments

Six organic amendment treatments were used:

1. Moringa seed cake 100% (3 tons/fed)
2. 1 Moringa seed cake: 2 Compost
3. 1 Moringa seed cake: 1 Compost
4. 2 Moringa seed cake: 1 Compost
5. Compost 100% (3 tons/fed)
6. Control (3 tons/ fed farmyard manure)

Farmyard manure, compost and moringa seed cake were added in December during both seasons in trenches close to the root system under the tree canopy after being mixed with part of the surface soil and followed by irrigation. The physical and chemical properties of farmyard manure, compost and moringa seed cake are shown in Tables (3, 4 and 5). Moreover, 50% of recommended doses of synthetic fertilisers by the Ministry of Agriculture and Land Reclamation in Egypt for the sandy soils of nitrogen (60 kg N /fed/year), phosphorus (30 kg P_2O_5 /fed/year) and potassium fertilisers (50 kg K_2O /fed/ year) were applied in different rates during both seasons.

Table 1. Analytical data of the studied soil of orchards farm (before studied treatments application)

Mechanical analysis (%)						
Sand	**Silt**		**Clay**	**Texture**		
84.2	11.8		4.0	Loamy sand		
Chemical soil characteristics						
pH	**EC dSm^{-1}**		**$CaCO_3$ %**	**O.M. %**		
7.79	1.6		2.0	3.54		
Available macronutrients (%)				**Available micronutrients (ppm)**		
N	P		K	Fe	Zn	Mn
0.78	0.32		0.46	8.8	4.2	3.2
Soluble cations (me/l of soil past extract)				**Soluble anions (me/l of soil past extract)**		
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}+HCO_3^{-}	Cl^{-}	So_4^{--}
8.7	4.0	2.3	1.0	0.52	11.48	4.0
Hydro-physical analysis						
Bulk density g cm^{-3}	Total porosity %	Saturation %	Field capacity %	Wilting percentage %	Available water %	Hydraulic conductivity m day^{-1}
1.6	39.62	27	15.7	7.2	8.5	11.2

Table 2. Analysis of irrigation water.

Properties	**pH**	**EC dSm^{-1}**	**K^{+}**	**Na^{+}**	**Mg^{+2}**	**Ca^{+}**	**SO4^{-2}**	**HCO^{-3}**	**CO3^{-2}**	**Cl^{-}**
Value	7.88	0.54	0.45	0.3	2.25	2.3	0.41	1.7	-	3.2

Table 3. Physical and chemical properties of the farmyard manure

Properties	Values
Moisture content (%)	29.5
pH (1:10)	6
EC (1:20) dS/m	1.4
Organic matter (%)	25.5
Macro element (%)	
Total Nitrogen	0.85
Phosphorus	0.14
Potassium	0.22
Magnesium	0.25
Micro element (ppm)	

Table 4. Physical and chemical properties of the compost

Properties	Values
Moisture content (%)	25-30
pH(1-10)	7.5
EC (1-10) (dS/m)	1.5
Organic matter (%)	57
Organic carbon (%)	50
C/N ratio	18:01
Macro element (%)	
Total nitrogen	1.4
Phosphorus	2.82
Potassium	0.3
Magnesium	0.47
Micro element (ppm)	
Zinc	378.8
Iron	26
Manganese	30

Table 5. Physical and chemical properties of moringa seed cake

Properties	Values
Moisture content (%)	4.9
pH	4.8
EC (dS/m)	3.20
Organic matter (%)	79.8
Carbohydrate (%)	16
Protein (%)	24
C/N ratio	12.14
Macro element (%)	
Total Nitrogen	3.8
Phosphorus	0.61
Potassium	0.7
Magnesium	0.31
Micro element (ppm)	
Zinc	18.8
Iron	12.5
Manganese	40

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2.3. Measurements

2.3.1. Leaf mineral contents

Twenty leaves were taken in late August from ten shoots of the current spring growth cycle randomly distributed around the tree/ replicate. Samples were dried at 70°C till constant weight and finely ground and digested in a mixture of perchloric: sulphuric acid (1:3 v/v) for determination of the following nutrient elements: total nitrogen (%) using the modified micro – Kjeldahl method as outlined by Cottenie et al. (1982), phosphorus (%) was estimated as described by Chapman and Pratt (1961), potassium was measured photometrically using flame photometer outlined by Cottenie et al. (1982). Iron, zinc, and manganese as ppm were spectrophotometrically determined using atomic absorption spectrophotometer (PerkinEl-mer 100 B).

2.3.2. Total carbohydrates content

Total carbohydrates content in leaves powder was determined as a percentage according to Dubois et al. (1956).

2.3.3. Yield (kg/tree)

At harvest time, the yield was calculated as kg/tree by multiplication number of fruits/tree x average fruit weight.

2.3.4. Fruit quality

At harvest, ten fruits from each replicate were randomly selected to determine fruit quality as follows:
• Percentage of juice: Fresh fruits were ground in an electric juice extractor for freshly prepared juice, then juice weight and percentage of juice was evaluated.
• Percentage of total solids solid (TSS %): It was expressed using Digital refractometer PR32 (0.32% Atago Palete ATago. CO. LTD. Japan).
• Percentage of total acidity content (TA %): It was determined by titrating 10 ml juice from each sample using NaOH (0.1N) phenolphthalein (ph. th) as an indicator. The acidity was expressed as g of citric acid/100ml juice according to (AOAC, 2000) and then calculated TSS/ TA ratio.
• Ascorbic acid (vitamin C): It was determined by using 2.6 dichlorophenolindophenoldye and 2% oxalic. Vitamin C content was calculated as mg /100 ml juice (AOAC, 2000).
2.3.5. Determination of studied soil hydrophysical properties
• Soil bulk density and total porosity were determined according to Dewis and Freitas (1970).
• Soil water retention values were carried out using the pressure membrane apparatus (Loveday, 1974). The moisture content of the soil was determined gravimetrically.
• Soil water transmission properties: Saturated hydraulic conductivity was determined under constant parameter head (m day^{-1}) as described by Singh (1980).

$$K= HAT/QL$$

• Where; K: hydraulic conductivity coefficient, Q: volume of water being passed through the soil column at time (T), L: length of soil column, H: hydraulic head, A: cross-section area. Mean diameter of soil pores (µm): Mean diameter of soil pores was calculated using the equation described by Dielman and De Ridder (1972) as follows:

$$d = (6.177637\sqrt{K} \qquad \text{(for water at 20°C)}$$

Where d: soil mean pore diameter in microns, K: hydraulic conductivity in m day^{-1}.

2.3.6. Irrigation water requirements

The investigation was conducted out under the drip irrigation system as 4 emitters per tree, emitter charge is 4 litre/hour, reference evapotranspiration (ETo) was calculated using meteorological data at El-Behira in Egypt according to Penman-Monteith equation (Allen et al., 1998) for both seasons 2016/2017and 2017/2018.

The irrigation water applied 3200 m^3/ fed was calculated according to the following equation (Doorenbos, 1992):

$$IW= ((ET_o*K_C*K_r*I)/Ea* (1-LR)) *4.2$$

Where; IW is Irrigation water requirement m^3 / fed, ET_o is Reference evapotranspiration, K_c is Crop coefficient with No weed control= 0.85, K_r is Reduction factor= 0.75, I = Irrigation interval, Ea is Irrigation efficiency = 90%, LR is Leaching requirement = 10% of the total water amount.

2.3.7. Water productivity

Water productivity was calculated by Aquacrop model version 6, FAO paper 66 (Steduto et al., 2012) as follows:

$$WP= (B/\Sigma(Tr/ET^{o}))\ (CO_2)$$

Where, B is the biomass produced cumulatively (kg per m^2) for most crops, Tr is the crop transpiration (either mm or m^3 / unit surface), with the summation over the period in which the biomass is produced, and WP is the water productivity parameter kg of biomass per m^3 of water transpired. The WP parameter is based on the atmospheric evaporative demand and the atmospheric CO_2 concentration to simulate future climate scenarios. Conservative and non-conservative crop parameters for orange obtained from various sources are shown in (Table 6).

2. 4. Statistical Analysis

Treatments were arranged as experiments in a complete randomised block design. The obtained data of both seasons were subjected to analysis of variance (one way ANOVA test) using CoStat - Statistics Software Computer program. Least significant difference (LSD) was used to compare between means of treatments according to Duncan (1955) at a probability of 5 %.

Table 6. Conservative and non-conservative crop parameters for orange obtained from various sources

Non-conservative parameters	**Orange**
Base temperature (°C) below which crop development does not progress	8.0
Upper temperature (°C) above which crop development no longer increases with an increase in temperature	40.0
Number of trees per hectare	600.0
Maximum effective rooting depth (m)	2.0
Harvest Index (HIo) (%)	90.0
Conservative parameters	
Water Productivity normalized for ETo and CO_2 (WP*) (gram/m^2)	17.0
Water Productivity normalized for ETo and CO_2 during yield formation (as % WP*)	100.0
Minimum air temperature below which pollination starts to fail (cold stress) (°C)	8.0
Maximum air temperature above which pollination starts to fail (heat stress) (°C)	40.0
Excess of potential fruits (%)	60.0
Canopy growth coefficient (CGC): Increase in canopy cover (fraction soil cover per day)	0.104
Maximum canopy cover (CCx) in fraction soil cover	0.900
Canopy decline coefficient (CDC): Decrease in canopy cover (in fraction per day)	0.080
Crop coefficient when canopy is complete but prior to senescence (Kcb,x)	0.150
Maximum root water extraction (m^3water/m^3soil.day) in top quarter of root zone	0.024
Maximum root water extraction (m^3water/m^3soil.day) in bottom quarter of root zone	0.006
Effect of canopy cover in reducing soil evaporation in late season stage	60.0
Soil water depletion factor for canopy expansion (p-exp) - Upper threshold	0.50
Shape factor for water stress coefficient for canopy expansion (0.0 = straight line)	3.0

Source: AquaCrop model as described by ((Raes et al., 2009; Steduto et al., 2009).

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3. Results

Macro-element leaf contents

Results in Table (7), revealed that the application of fertilisation with moringa seed cake and compost improved N, P, K and Mg leaf contents of Valencia orange trees compared to control.

Nitrogen leaf content: Adding moringa seed cake in combination with compost at 2:1 reflected the highest nitrogen leaf content (2.80 & 2.83 %) compared with other treatments in both seasons, respectively. Also, use moringa seed cake + compost at 1: 1 was not significantly different from using moringa seed cake alone in the first season. In the second season, there were no significant differences between applying moringa seed cake and compost at 1: 2 or 1: 1 of them whereas, control gave the lowest value of nitrogen leaf content (2.21 & 2.55 %) during both seasons under the study.

Phosphorus leaf content: In the first season, moringa seed cake in combination with compost at 2:1 recorded the highest phosphorus leaf content followed by combination with moringa seed cake and compost at 1: 1 followed by combination with moringa seed cake and compost at 1: 2. Where applying either moringa seed cake alone or compost alone were non-significant differences. In the second season, also moringa seed cake in combination with compost at 2:1 recorded the highest phosphorus leaf content followed by compost alone then moringa seed cake + compost at 1: 1. Meanwhile, there was no significant difference between applying moringa seed cake + compost at 1: 2 or moringa seed cake alone or control.

Potassium leaf content: In the first season, moringa seed cake + compost at 2:1 and compost alone gave the maximum values (1.58 %) of potassium leaf content with the same statistical level, meanwhile there were no significant differences between using moringa seed cake alone and control. In the second season, moringa seed cake + compost at 2:1 resulted in maximum values (1.88 %) of potassium leaf content. Whereas, application with moringa seed cake + compost at 1: 1 gave the minimum values (1.25 & 1.66 %) of potassium leaf content during the two seasons, respectively.

Magnesium leaf content: In the first season, application with moringa seed cake + compost at 2: 1 gave the highest value (0.49 %) of magnesium leaf content. In the second season, moringa seed cake alone or moringa seed cake + compost at 2:1 or 1: 2 resulted in no significant differences between them. There were also no significant effects among compost alone and moringa seed cake + compost at 1:1. The control gave the lowest value of magnesium leaf content during both seasons under the study.

Table 7. Effect of organic fertilization with moringa seed cake and compost on leaves macro-element contents of Valencia orange trees.

Treatment	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Magnesium (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
100% MC	2.76b	2.78b	0.12d	0.12d	1.48ab	1.77c	0.44d	0.48a
1 MC: 2 COM	2.75c	2.77c	0.13c	0.12d	1.38bc	1.81b	0.45c	0.48a
1 MC : 1 COM	2.76b	2.77c	0.14b	0.13c	1.25c	1.66f	0.46b	0.47b
2 MC :1 COM	2.80a	2.83a	0.17a	0.18a	1.58a	1.88a	0.49a	0.48a
100% COM	2.21d	2.62d	0.12d	0.17b	1.58a	1.72d	0.43e	0.47b
Control	2.21d	2.55e	0.11e	0.12d	1.45ab	1.68e	0.42f	0.45c

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

Micro-element leaf contents

Results in Table (8), showed that compost or moringa seed cake application each alone or together significantly increased leaf micro-element contents than control. The highest values were recorded by using moringa seed cake in combination with compost at 2:1. Meanwhile, the lowest values were recorded by control in the first and second seasons.

Percentage of total carbohydrates

Table (8) shows that in the first season, using moringa seed cake in combination with compost at 2:1 recorded the highest percentage of total carbohydrates in leaves (47.57 %) followed by application of moringa seed cake in combination with compost at 1:1 then 1:2, However, no significant differences were found in the application of moringa seed cake alone and compost alone. The observation in the second season reveals that applying moringa seed cake + compost at 1:2 gave the highest value of for percentage of total carbohydrates (48.26 %) followed by treatments moringa seed cake in combination with compost at 1:1, moringa seed cake in combination with compost at 2:1, moringa seed cake alone and compost alone without significance. On the other hand, the lowest percentage of total carbohydrates value (40.19 & 40.41 %) was recorded by control in both seasons, respectively.

Yield

Results in photos (1& 2), Table (9) show that applying moringa seed cake in combination with compost had a significant effect on tree yield and total yield per fed (Fig.1) compared with the control. In this respect, application of moringa seed cake in combination with compost at 2:1 gave the highest significant value in both studied seasons (98.33 & 98.67 kg/tree) followed by application of moringa seed cake + compost at 1:1 (88 & 91.67 kg/tree), while no significant differences were recorded by application of moringa seed cake + compost at 1:2 or moringa seed cake alone or compost alone in the first season and among seed cake alone or compost alone in the second seasons. Meanwhile, the lowest significant value (76.67 & 77.67 kg/tree) was recorded by control in both seasons, respectively.

Table 8. Effect of organic fertilization with moringa seed cake and compost on leaves micro-element contents and total carbohydrates of Valencia orange trees

Treatment	Iron (ppm)		Zinc (ppm)		Manganese (ppm)		Total carbohydrates (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
100% MC	70d	78d	71e	45.39d	45.39d	66b	45.39d	45.39d
1 MC: 2 COM	67e	80c	85c	46.67c	46.67c	58d	46.67c	46.67c
1 MC : 1 COM	73c	85b	92b	47.25b	47.25b	65c	47.25b	47.25b
2 MC :1 COM	77a	88a	100a	47.57a	47.57a	72a	47.57a	47.57a
100% COM	75b	77d	80d	45.37e	45.37e	56e	45.37e	45.37e
Control	70d	75e	25f	40.19f	40.19f	53f	40.19f	40.19f

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

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Figure 1. Photos of Valencia orange trees in December 2016 before using moringa seed cake and compost.

Figure 2. Photos of Valencia orange trees in March 2018 showing the productivity after using moringa seed cake and compost.

Fruit quality

As for fruit weight, presented in Table (9), treatment with moringa seed cake + compost at 2:1 gave the heaviest fruits (311 & 370 g) in both seasons, respectively while the lightest fruit weight was recorded by the control (276 & 280 g) in the first and second seasons, respectively.

Regarding the percentage of juice, the obtained results show that use of moringa seed cake in combination with compost at 2:1 recorded the highest significant value compared with other treatments (75.57 & 76.86 %) in both seasons, respectively followed by application of moringa seed cake + compost at 1:1 (71.46%) in the first season and moringa seed cake alone (74.36%) in the second season. Meanwhile, control

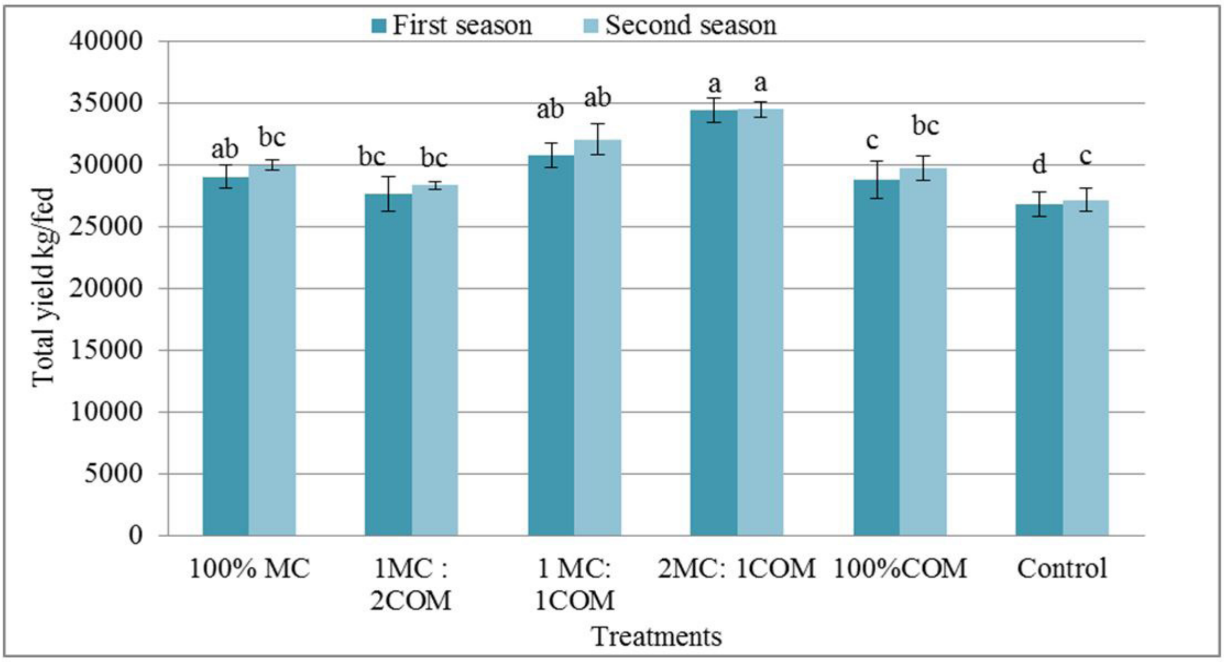

Fig. 3. Effect of organic fertilisation with moringa seed cake and compost on total yield/fed of Valencia orange with standard errors. Where: COM (Compost) and MC (Moringa seed cake). Different letters in a figure show significant differences according to LSD test (P= 0.05).

recorded the lowest values (50.31& 51.45%) in both seasons, respectively.

Ascorbic acid (vitamin C) content (also shown in Table 9) was highest in the application of moringa seed cake in combination with compost at 2:1 (34.55 & 34.46 mg/100 ml) followed by application of moringa seed cake in combination with compost at 1:1 (33.89 & 33.58 mg/100 ml) in the two seasons of the study, respectively. The lowest vitamin C value was recorded by control (29.19 & 30.44 mg/100 ml) in the first and second seasons, respectively.

Regarding total soluble solids in juice (TSS), in the first season treatment with compost alone gave the highest TSS value (12.7 %) (Table 10), while in the second season application of moringa seed cake in combination with compost at 1:2 gave the highest value followed by moringa seed cake in combination with compost at 2:1 (13.33 & 13.17 %), respectively and without significance. The lowest value of TSS was recorded by control treatments (11.13 & 12 %) in the first and second seasons, respectively. Total acidity percentage (TA) was lowest in treatments with moringa seed cake + compost at 2:1 (1.04 %) and in moringa seed cake + compost at 2:1 and 1:2 without significance (1.01%) in both studied seasons, while the highest acidity content was obtained with control (1.07%) in the first and second seasons. Concerning TSS/TA ratio (Table 10) the highest ratio was recorded by treatment with moringa seed cake + compost at 2:1 in the first season and by treatment with moringa seed cake + compost at 1:2 followed by 2:1 without significance in the second season. The lowest TSS/ TA ratio was recorded by control treatment in the first and second seasons.

Soil hydrophysical properties

Incorporating moringa seed cake with compost improved the hydrophysical properties of sand soil, soil water transmission and soil water retention in the studied area during both seasons. Applying moringa seed cake in combination with compost at 2:1 achieved the lowest value of soil bulk density, highest values of total porosity and void ratio (Table 11 and Fig. 4). The decrease percentages of soil bulk density was (22.66 and 23.33%), the increase percentages of total porosity were (29.02 and 30.65 %), and void ratio were (66.23 and 72%) over the soil not treated with moringa seed cake or compost during the first and the second seasons respectively. However, the control gave the highest value of bulk density and the lowest

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values of total porosity and void ratio during both seasons under the study.

Soil water retention

As a result of enhancing the hydrophysical soil characteristics, the increments in soil available water, field capacity and saturation per cent, as shown in Fig. (5) and Table (12), were detected by adding each of moringa seed cake and compost either alone or mixing them compared to the control. Moringa seed cake riches with compost at ratio 2:1 achieved the highest values of soil available water, field capacity and saturation per cent. The increase percentages were (66.28 and 70.45%), (66.2 and 70.44%) and (66.25 and 70.43 %) in soil available water, field capacity and saturation per cent over the soil that received neither of moringa in where the lowest values were recorded during both of the seasons, respectively.

Table 9. Effect of organic fertilization with moringa seed cake and compost on yield and fruit weight, juice% and Ascorbic acid of Valencia orange

Treatment	Yield (kg/tree)		Fruit weight (g)		Juice (%)		Ascorbic acid (mg/100 ml)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
100% MC	83.00bc	85.67bc	281d	312c	65.42d	74.36b	31.43c	31.11e
1 MC: 2 COM	79.00bc	81.00cd	288c	355b	66.39c	68.80c	32.57b	32.91c
1 MC : 1 COM	88.00ab	91.67ab	300b	282e	71.46b	60.14d	33.89b	33.58b
2 MC :1 COM	98.33a	98.67a	311a	370a	75.57a	76.86a	34.55a	34.46a
100% COM	82.33bc	85.00bc	280d	295d	57.64e	58.39e	30.75d	32.16d
Control	76.67c	77.67d	276e	280f	50.31f	51.45f	29.19e	30.44f

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

Table 10. Effect of organic fertilization with moringa seed cake and compost on TSS %, TA% and TSS /TA ratio of Valencia orange

Treatment	TSS (%)		TA (%)		TSS /TA ratio	
	1st	2nd	1st	2nd	1st	2nd
100% MC	12.47d	13.03ab	1.06b	1.03c	11.76bc	12.65ab
1 MC: 2 COM	12.57b	13.33a	1.06b	1.01e	11.86c	13.20a
1 MC : 1 COM	11.93e	12.80ab	1.05c	1.05b	11.36bc	12.19b
2 MC :1 COM	12.50c	13.17a	1.04d	1.01a	12.02a	13.04a
100% COM	17.70a	12.40bc	1.06b	1.02d	11.98ab	12.16b
Control	11.13f	12.00c	1.07a	1.07a	10.40d	11.21c

Where: COM (Compost) and MC (Moringa seed cake).The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

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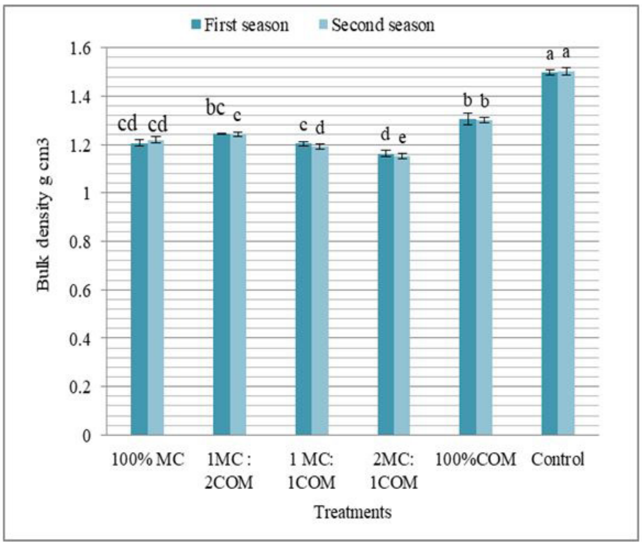
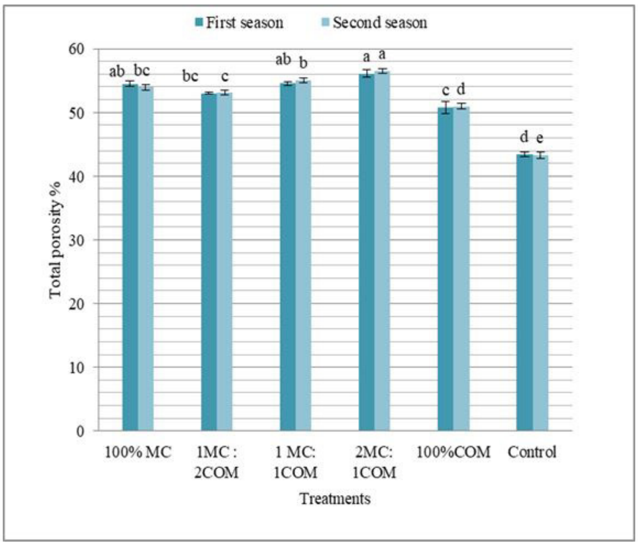
Table 11. Effect of organic fertilization with moringa seed cake and compost on soil hydrophsical properties

Treatment	Bulk density (g/ cm³)		Total porosity (%)		Void ratio	
	1st	2nd	1st	2nd	1st	2nd
100% MC	1.21cd	1.22cd	54.46ab	53.95bc	1.20ab	1.17c
1MC: 2COM	1.24bc	1.24c	53.04bc	53.09c	1.13bc	1.13c
1 MC: 1COM	1.20cd	1.19d	54.55ab	55.04b	1.20ab	1.22b
2MC: 1COM	1.16d	1.15e	56.11a	56.52a	1.28a	1.3a
100% COM	1.30b	1.3b	50.77c	50.93d	1.03c	1.04d
Control	1.50a	1.5a	43.49d	43.26e	1.20ab	1.17c

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).



a)



b)

Figure. 4. (a & b) Effect of organic fertilization with moringa seed cake and compost on soil bulk density and total porosity % with standard errors. Where: COM (Compost) and MC (Moringa seed cake). Different letters in a figure show significant differences according to LSD test (P= 0.05).

Soil water transmission properties

Results in Fig. (6) reveal that compost or moringa seed cake application either alone or together significantly decreased hydraulic conductivity than the control; the decline percentages in hydraulic conductivity were (52.48 and 71.88%) over the control during the first and second seasons, in the sequence. The lowest values were recorded by using moringa seed cake in combination with compost at 1:1 followed by the combination at 2:1. Meanwhile, the highest values were recorded by control in the first and second seasons. Also, the mean diameter of soil pore decreased more than control at the rate of (31.5 and 47.02%) in the two seasons, respectively (Table 12).

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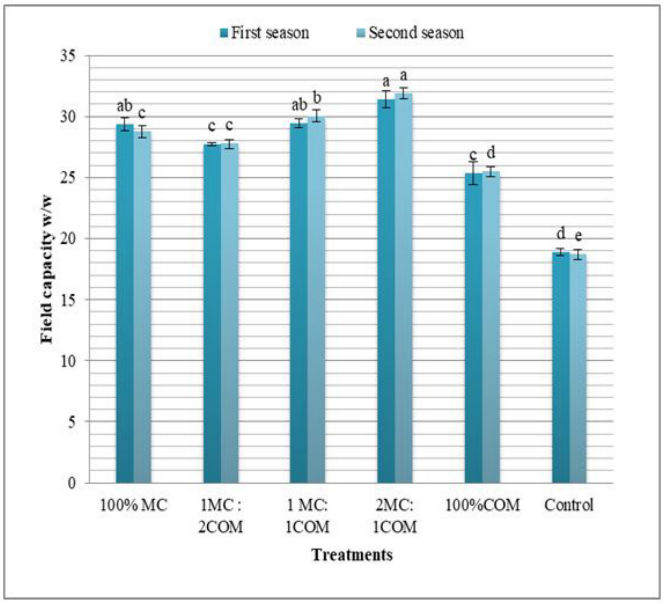
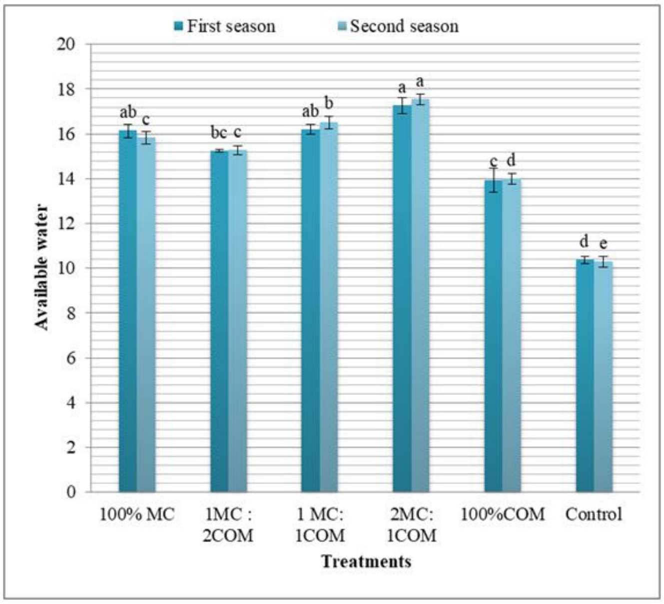


a)



b)

Figure. 5. (a & b) Effect of organic fertilization with moringa seed cake and compost on field capacity and available water of studied soil with standard errors Where: COM (Compost) and MC (Moringa seed cake). Different letters in a figure show significant differences according to LSD test (P= 0.05).

Table 12. Effect of organic fertilization with moringa seed cake and compost on soil water retention

Treatment	Soil available water		Field capacity (w/w)		Saturation (%)		Mean diameter of pore (µm)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
100% MC	16.14ab	15.81c	29.34ab	28.75c	45.14ab	44.23c	18.43b	15.13c
1MC: 2COM	15.24bc	15.27c	27.71c	27.76c	42.63bc	42.71c	17.34c	15.92b
1 MC: 1COM	16.19ab	16.52b	29.44ab	30.03b	45.29ab	46.2b	13.27d	9.68e
2MC: 1COM	17.26a	17.54a	31.38a	31.89a	48.28a	49.05a	15.08a	14.31d
100% COM	13.93c	14.01d	25.33c	25.47d	38.98c	39.18d	18.04b	15.19c
Control	10.38d	10.29e	18.88d	18.71e	29.04d	44.23c	19.38a	15.13c

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

Water productivity

Water productivity was calculated by Aquacrop program sourced by FAO Paper 66. Results in Table (13) and Fig. (7) display that moringa seed cake and compost either alone or mixed increased the measured Valencia orange water productivity. Incorporating moringa seed cake with compost at 2:1 is superior to other treatments, where the measured water productivity values attained (10.75 and 10.79 Kg/m^3) during the first and the second seasons, respectively and the simulated water productivity achieved (11.26 and 11.30 Kg/m^3), in the same sequence. Meanwhile, the lowest significant values of measured water productivity and simulated water productivity (8.38 & 8.49 and 8.78 & 8.89 Kg/m^3) were recorded by control in both seasons, respectively.

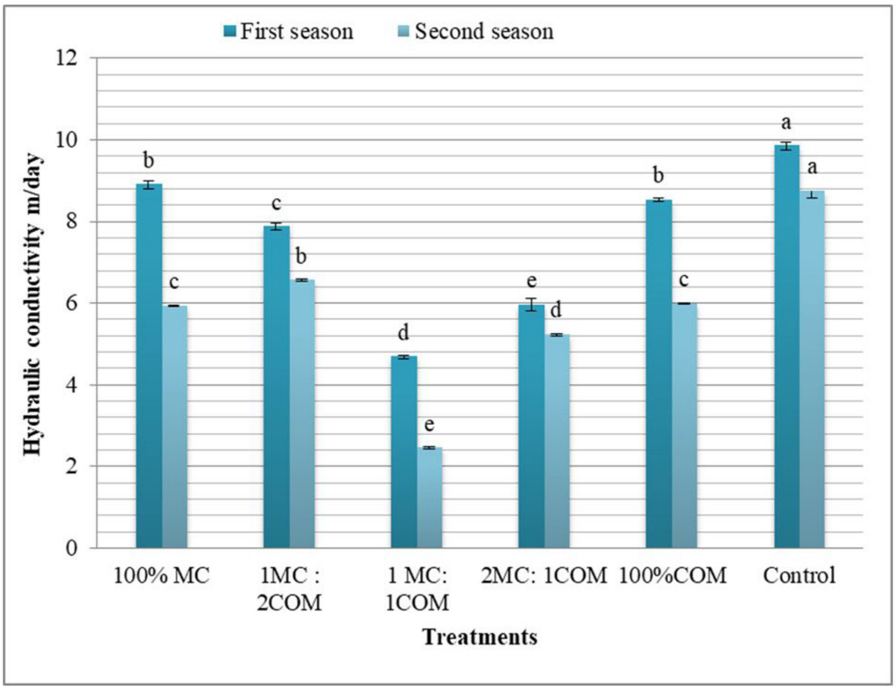


Figure.6. Effect of organic fertilisation with moringa seed cake and compost on hydraulic conductivity of studied soil with standard errors. Where: COM (Compost) and MC (Moringa seed cake). Different letters in a figure show significant differences according to LSD test (P= 0.05).

Table13. Effect of organic fertilization with moringa seed cake and compost on water productivity of Valencia orange

Treatment	Water requirement (m^3/fed)	Yield (kg/fed)		Measured water productivity (Kg/m^3)		Simulated water productivity (Kg/m^3)	
		1st	2nd	1st	2nd	1st	2nd
100% MC	3200	29050ab	29983.33bc	9.08ab	9.37bc	9.51ab	9.81bc
1MC: 2COM	3200	27650b	28350bc	8.64b	8.86bc	9.05b	9.28bc
1 MC: 1 COM	3200	30800ab	32083.33ab	9.62ab	10.03ab	10.08ab	10.50ab
2MC: 1 COM	3200	34416.67a	34533.33a	10.75a	10.79a	11.26a	11.30a
100% COM	3200	28816.67ab	29750bc	9.01ab	9.29bc	9.43ab	9.74bc
Control	3200	26833.33b	27183.33c	8.38b	8.49c	8.78b	8.89c

Where: COM (Compost) and MC (Moringa seed cake). The same letter within each row indicates no significant differences according to LSD test (P= 0.05).

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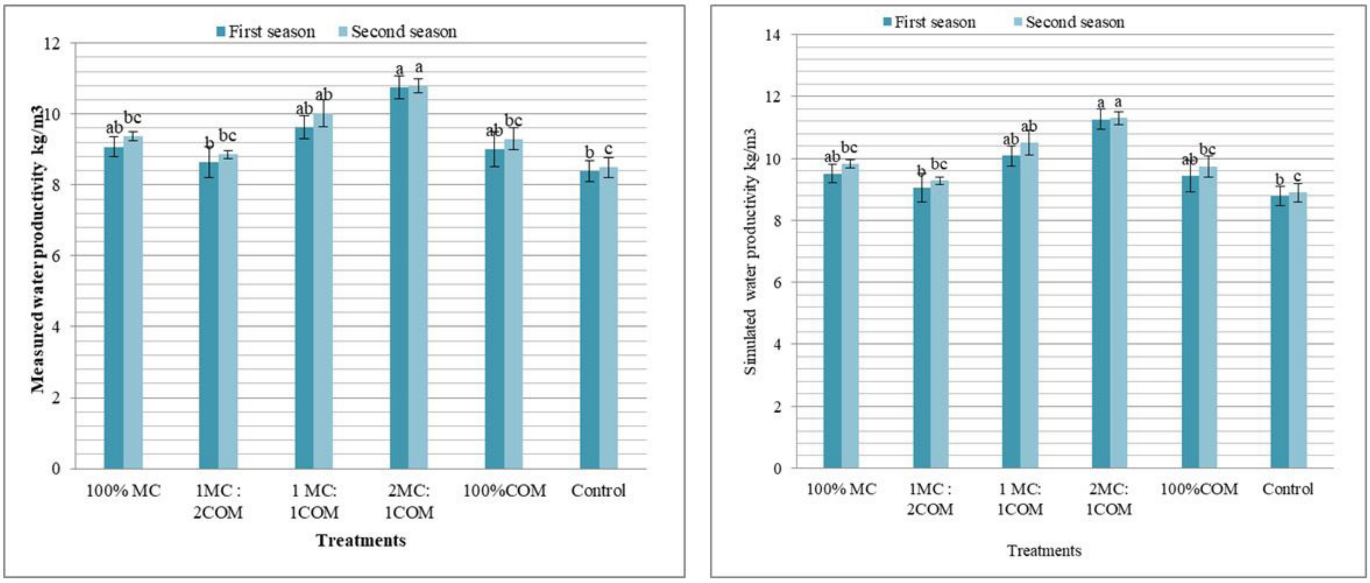

b) a)

Figure 7. (a & b) Effect of organic fertilisation with moringa seed cake and compost on measured and simulated water productivity of Valencia orange with standard errors. Where: COM (Compost) and MC (Moringa seed cake). Different letters in a figure show significant differences according to LSD test (P= 0.05).

4. Discussion

Due to the scarcity of alternative organic amendments in developing countries, crop residue can achieve positive effects on soil quality, soil organic matter, and soil moisture retention, enhanced nutrient cycling, and decreased soil loss, among other environmental and soil health benefits (Turmel et al., 2015). Cautious organic amendments use for sustainable agriculture is essential to enhance soil properties and simultaneously reduce harmful environmental impacts (Masunga et al., 2016).

Compost is a readily available amendment with beneficial effects on the physical, chemical, biochemical and biological properties of the soils. Moreover, compost-based treatments can exert protective effects against plant diseases occurrence and/or stimulate an enhanced plant physiological status with improvements in quantity and quality of crop productions. It increases not only organic matter in the soil, but also the available phosphorus and the exchangeable potassium, calcium, and the other micro-elements, and affects soil pH, encourages the proliferation of soil microorganisms, increases microbial population and activity of microbial enzymes (Liguori et al., 2015).

Moringa oleifera flowers, immature pods, seeds and leaves are rich sources of vitamins, minerals, proteins and other important phytochemicals. The leaves and seeds contain proteins and essential amino acids, which are important for human nutrition. Seeds provide protein electrolytes that can be used in water purification (James and Zikankuba, 2017).

Therefore, this investigation was carried out on sandy soil under a drip irrigation system to evaluate using moringa oleifera seed cake and compost as organic soil amendments for sustainable agriculture in Valencia orange orchard. Moringa oleifera seed cake has a low value of C/N ratio, and it was not applied during the composting process but mixed after compost maturity. Using organic residues with a low value of C/N ratio for obtaining compost can lead to nitrogen loss to the atmosphere through the volatilisation of ammonia during the recycling process (Azim et al., 2018).

Testezlaf et al. (2007) found that the root system distribution of Valencia orange trees by dry weight of the roots had diameters equal to or less than 1.5 mm. The soil layer from (0.0–0.4 m) showed a larger percentage of root, with a reduction of root concentration from the end of the tree canopy to between rows for all evaluated trees. Also, the soil layer from (0.0-0.3 m) showed a larger percentage of roots and until 2 m horizontal distance from the trunk (Júnior et al., 2012). There are studies confirming that most root water depletion takes place at 0.6 m soil depth (Obreza and Boman, 2002; Hemdan, 2003). So, soil amendment treatments were incorporated in the 0.0-0.4 m soil layer * 1 m horizontal distance from the trunk of the Valencia orange tree.

Soil properties

The results as compared to the control in Table (11) indicate an increase in the hydrophysical properties of the soil which in turn improved the Valencia orange yield. In detail, incorporating moringa seed cake with compost improved the hydrophysical properties of sand soil, soil water transmission and soil water retention in the studied area, this observation is in agreement with the findings of Hemdan (2014) and Jain and Kalamdhad (2020). This may be due to the use of moringa seed cake compared with compost and farmyard manure amendments as shown in Tables (3, 4 and 5) which led to the increase in organic matter and organic nitrogen and the decrease in organic carbon thus decrease in soil bulk density.

Bauer and Black (1981) confirmed that soil bulk density adversely relies on soil organic matter content and significantly impacts water penetration or root growth. The smallest soil bulk density values and the greatest total soil porosity were observed in the soil treated with moringa seed cake in combination with compost at 2:1 ratio. Incorporating agriculture residues in the soil as sustainable practice has improved soil properties (e.g. bulk density, porosity, and saturated hydraulic conductivity) and attains zero waste in agriculture production and thus better soils management (Almendro-Candel et al., 2018).

With respect to soil water retention, the increments in soil available water, field capacity and saturation per cent detected improved when adding each moringa seed cake and compost either alone or mixed compared to the control. This finding agrees with Santibáñez and Varnero (2014). Soil moisture content is the most effective factor of root zone on plant roots growth (Obreza and Boman, 2002; Júnior et al., 2012). Compost encourages the microbial activity of microbial enzymes in the soil (Liguori et al., 2015), thus increases soil water retention by enriching moringa seed cake with compost.

These results are in agreement with Pandey and Shukla (2006); Carter (2007); Hemdan (2014); Jain and Kalamdhad (2020) who showed that compost increased soil water retention (field capacity and soil available water) in sandy soil nevertheless declined the hydraulic conductivity of sandy soil and mean diameter of soil pores. Accordingly mixing compost with moringa seed cake enriched the organic matter and led to improving soil water retention and transmission.

Water productivity

Applying moringa seed cake and compost either alone or mixing both of them increased measured Valencia orange water productivity. This may have been associated with soil water retention (field capacity and available water) improvement as abovementioned by adding soil organic amendments (compost and moringa seed cake). Similar patterns were observed by (Cogger, 2005; Carter, 2007; Calzolari et al., 2009; Mylavarapu and Zinati, 2009; Hemdan, 2014; Mansour et al., 2019; Jain and Kalamdhad, 2020). These results are in agreement with (Stricevic et al., 2011; Mansour et al., 2019; Mansour et al., 2020). Steduto et al. (2012) reported that the Aquacrop simulation model is dependent on many influences such as climate, soil, irrigation water, etc., stimulates vegetative growth, biomass, yield and water productivity. Calibration results showed closed matching between values measured and those simulated by the Aquacrop model.

Application of the combinations of moringa seed cake with other organic soil amendments on varied crop types in the moringa plant ecosystem could be suggested. This may lead to attaining safe soil management for best crop yield and water productivity.

Some nutrient contents of Valencia Orange leaves

Nitrogen, phosphorus, potassium, magnesium leaf contents were observed as higher as compared to control for single compost application. Other researchers observed similar patterns (Farahzety et al., 2013; Hemdan, 2014; Sharma et al., 2017), single moringa seed cake application (Emmanuel et al., 2011; Sinha et

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al., 2011; Lee et al., 2018) or together at different ratios. The combination of moringa seed cake with compost at a ratio of 2:1 showed the highest nitrogen, phosphorus, potassium, magnesium leaf contents during both seasons as compared to other combination treatments where moringa seed cake was added alone or along with other ratios. This study agrees with the findings of (Emmanuel et al., 2011) on the application of moringa seed cake conducted on maize farms. This may be due to the application of moringa seed cake with compost and the improved soil chemical and hydrophysical properties because the cake organic matter contains high macro and micronutrients. (Emmanuel et al., 2011; Baiano and Morra, 2017; James and Zikankuba, 2017; Jain and Kalamdhad, 2020) showed the significant increments in porosity suppressed the leaching of the nutrients, observed the higher amount of total nitrogen and available phosphorus concentration in the soil.

According to Hartz et al. (2000), the nitrogen mineralisation rate of manures and composts was relatively low. N recovery averaged 11%, 6%, and 2% of total amendment N for manure, manure compost, and plant residue compost, respectively. The rate of mineralisation of amendment C had almost reduced to the soil organic C level in 4 and 16 weeks for compost and manure in the same sequence. Also, Azeez and Van Averbeke, (2010) showed that increasing the N rates of manures will improve their potential as plant nutrient sources. Complementing the manures with N fertilisers will increase its quality and influence and achieve integrated nutrient management.

On the other hand, Moringa seeds cake quickly dissolves in the same applied period (Emmanuel and Emmanuel, 2011). The low C/N ratio of moringa seed cake indicates that this would be an effective source of nutrients through rapid mineralisation reactions. It contains a high protein content of up to 68.6 % (Martín et al., 2010), and mixing with compost enhances the essential microbial activity for its decomposition, which positively affects the cultivated crop.

Incorporation of varied organic amendment combinations in the soil positively influenced soil physicochemical properties; hydrolases of C and N, microbial biomass carbon, mineralisation of the important organic elements have been promoted by soil enzymatic and biological activity. So, soil fertility and plant nutrient uptake have been improved (Frankenberger and Dick, 1983; Tejada et al., 2008; Elnasikh et al., 2011; Emmanuel et al., 2011; Sinha et al., 2011; Yuan et al., 2020).

Compost or moringa seed cake application either alone or together significantly increased leaf micro-element contents than the control. The highest values were recorded by using moringa seed cake in combination with compost at 2:1, as the moringa seed cake has supported the microbial activity of soil and hence enhanced the soil properties and simultaneously increased the macro and micronutrients availability in the soil to be consumed by the plant (Emmanuel et al., 2011).

Total yield and fruit quality

All applied treatments, either sole compost or moringa seed cake applications or mixed, significantly affected the yield of Valencia orange trees compared with the control; similar patterns were detected by others (Emmanuel and Emmanuel, 2011; Sinha et al., 2011; Iren et al., 2015; Lee et al., 2018). One important finding implied in this study is that despite a lower application percentage of compost (33.3%) in combination with a higher percentage of moringa seed cake (66.6 %), it showed the highest increment of total yield per feddan (Fig.1). Moringa is a good source of essential minerals and sulphur-containing amino acids. Ngigi and Muraguri (2019) analysed moringa oleifera seeds by inductively coupled plasma optical emission spectroscopy and observed the highest amounts of K and Mg with values of 15,930.5 and 2229.3 mg kg^{-1}, respectively. Elnasikh et al. (2011), Mohammed et al. (2014), and Lee et al. (2018) detected that applying neem seed cake as soil amendment significantly increased electrical conductivity, acidifying capacity, exchangeable calcium, iron, zinc, manganese and copper availability. In addition, soil microbial biomass and soil enzymatic activities and plant nutrient uptake have been enhanced by the combination of soil amendments, and this was consequently reflected on Valencia orange yield (Sinha et al., 2011; Scotti et al., 2015; Lee et al., 2018; Scotti et al., 2018). In contrast, Sinha et al. (2011) found that the amendment combination consistently positively affected all soil fertility and plant growth parameters. However, Lee et al. (2018) noticed

that incorporating beef cattle manure compost at 30 ton ha^{-1} and mixed oilseed cake applications at 3 ton ha^{-1} increased onion bulb yield.
Moringa seed cake in combination with compost at 2:1 recorded the highest percentage of total carbohydrates in leaves, fruit weight, percentage of juice, Ascorbic acid (vitamin C) content, total soluble solids in juice (TSS), TSS/TA ratio and lowest total acidity percentage followed by application of moringa seed cake in combination with compost at 1:1. The results agreed with Liguori et al. (2015), who reported that compost has improved watermelon yield quality. Yassin and Ismail (1994) and others revealed that cotton and sunflower seed cakes increased cowpea plant growth in sandy, sandy loam and clay-loam soils, respectively. In addition, oilseed cakes positively affected plant health by suppressing parasitic nematodes in soil rootzone. Scotti et al. (2018) observed that defatted seed cakes have different chemical analyses and positive effects on soil microbiota. As the result of assessing seed cakes as a soil amendment, it can be permitted to invest the by-products of seed oil extraction as the coproducts for sustainable agriculture. Such research should be applied to varied crop types in different ecosystems to attain the best soil management for optimum crop water productivity.

5. Conclusion

This study demonstrated that incorporating moringa seed cake with compost improved the hydrophysical properties of soil, soil water retention, and transmission, reflecting the vegetative growth and nutritional status of trees. This, in turn, improved the productivity of Valencia orange and fruit quality compared to the control. Therefore, the study recommends applying moringa seed cake combined with compost at a 2:1 ratio to maximise growth, yield and quality of Valencia orange grown under new-reclaimed lands (sandy soils). This approach also provides a natural organic fertiliser that improves the soil's physical properties and can partially replace various synthetic soil fertilisers. In addition, the results using the Aquacrop model indicate an opportunity to increase the yield potential and simulated crop water productivity under climate change scenarios.

Conflict of interest

The authors hereby declare that there is no conflict of interest.

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