Response of Washington Navel Orange Trees to Magnetized Irrigation Water and Different Levels of NPK Fertilization

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ABSTRACT

A field experiment was conducted to study the effect of two types of irrigation water i.e., saline water (EC=3.58 dSm^{-1}) and magnetized water, under three NPK fertilization levels (100, 80 and 60% of recommended dose), on the growth characteristics, nutritional status and productivity of Washington navel orange trees during the 2019 and 2020 seasons. Six treatments were arranged in a randomized complete block design as factorial experiment. Each treatment was replicated three times with three trees per replicate. Irrigation with magnetized water enhanced trees growth in terms of number of shoots per branch, shoot length, leaf area, canopy volume, root dry weight, overall nutritional status, yield, and fruit quality. Tree growth, leaf content of chlorophyll, total carbohydrates, and N, P, K, Ca, Mg, Fe, Mn, Zn, Cu, as well as fruit set, yield and fruit quality were significantly improved with increased levels of NPK fertilization, whereas Na, Cl, fruit drop were decreased but leaf proline content was not affected. The interaction effect of magnetic water and NPK fertilization significantly increased all the studied parameters, particularly at 80% NPK. This treatment improves tree growth, root growth, nutritional status, yield, and fruit quality. It could be recommended that the combined application of magnetized water and NPK fertilization (80%) effectively alleviates the adverse effects of saline water stress and improve tree growth, yield and fruit quality under sandy soil and drip irrigation conditions, in addition to saving about 20% of NPK fertilizers.

Key words: ascorbic acid, *Citrus sinensis,* firmness, magnetic field, root growth, TSS.

INTRODUCTION

Citrus plantation has widely increased in Egypt, especially in newly reclaimed sandy soils. The major problem of the new lands is the low fertility, water-holding capacity, and cation exchange capacity, in addition to irrigation with saline well water. Saline water is considered a limited factor for citrus growth and productivity, particularly orange (El-Dengawy et. al., 2019). Salinity drives to dysfunction in osmotic property of root cells, and hence affects water and nutrient uptakes by roots. It also causes imbalance in the nutrient levels, ion toxicity, accumulation of Na^+ and Cl^- and reduction in fruit yield (Abou-Baker et al., 2019).

Therefore, new strategies that mitigate salinity stress on citrus trees is required to for sustainable growth and productivity. In this respect, magnetic field technology is used for saline or brackish water management, where water is treated by a magnetic field or pass-through a magnetic device to be magnetized. Irrigation with magnetized water has led to accelerated water infiltration in soil and promoted salt leaching (Hozayn et al., 2017and Hamza et al., 2021).

Water subjected to magnetic field has shown small water molecules, which make both water and nutrients are more available to plant roots (Hilal et al., 2013) due to increased water permeability and the downward movement of salt ions such as Cl^-, Na^+ and HCO_3^-, from the root zone layers (Mostafazadeh-Fard et al., 2012). It was also found that when water passes through a magnetic field, its structure, density, salt holding capacity, and deposition ratio of solid particles are changed (Tai et al., 2008).

Magnetic treatment of water reduces the surface tension, which increases the solubility of water-soluble minerals such as N, K, Ca and Fe, which significantly improve plant growth, nutrient uptake and productivity (Osman et al., 2014; Ezz et al., 2017; Fanous et al., 2017 and Mohamed et al., 2017). In this respect, Aly et al., (2015) and Hamdy et al., (2015) concluded that fruit yield of Valencia orange, Balady and Fremont mandarins was positively increased with magnetized water compared to regular water. Also, fruit physiochemical characteristics were significantly improved in response to irrigation with magnetized saline water compared to the non-magnetized one. These findings were also confirmed by those of Fanous et al., (2017) on apricots, peaches and grapes.

Citrus tree nutritional status is a major factor affects growth, development, yield, and fruit quality (Esteves et al., 2021). The NPK mixture is required in relatively large amount due to its essential role in tree structure and metabolic processes (Sinha and Tandon, 2020). On the other hand, chemical fertilizers constitute around 40% of citrus production cost, in addition to their deleterious effects on soil, water and the surrounding environment (Ennab et al., 2019).
Therefore, the use of magnetized water through drip irrigation in combination with split weekly fertilizers doses were suggested to reduce the

overdoses of chemical fertilizers (Helaly, 2018; Selim, 2019 and Abdel Nabi et al., 2019).

Few findings were reported on the role of magnetized water on fruit crops, and to evaluate its role in relation to fertilization to ensure a sustainable productivity and fruit quality. El Kholy et al., (2015) revealed that magnetized water and NPK fertilization at 80% enhanced vegetative growth, yield and fruit quality of banana plants. Moreover, magnetized saline water has produced healthy banana plants and good fruit quality, in addition to reduced demand of chemical fertilizers during the growth season. Mostafa et al., (2016) concluded that applying soil compost in combination with irrigation with magnetized water have resulted in improved vegetative growth, yield, and fruit quality of salt-stressed Washington navel orange trees. Similar results were also reported by El-Dengawy et al., (2019), and El-Khayat and Abd El-Wahd (2019).

The objectives of this study are to evaluate the role of magnetized water, particularly with reduced NPK fertilization levels on the growth and productivity of Washington navel orange trees under the conditions of sand soils and saline irrigation water of semi-arid Egypt.

MATERIALS AND METHODS

A field experiment was conducted during the 2019 and 2020 seasons in a private orchard at El-Noubaria, El-Bohaira, Egypt, on 14-year-old Washington navel orange trees (*Citrus sinensis,* Osbeck) budded on sour orange (*Citrus aurantium* L.) rootstocks, planted at 5 m × 5 m spacing in a sandy soil under drip irrigation system. Soil samples were randomly collected before the experiment, in addition to water samples before and after magnetizing effect, and analyzed according to Klute (1986) and Page et al., (1982), as shown in Table (1). Fifty-four trees uniform in growth, vigor and productivity, and subjected to the same cultural practices, were selected for the experiment and arranged in a randomized complete block design (RCBD) as a factorial experiment of two types of irrigation water i.e., saline water and magnetized water under three NPK fertilizer levels 100, 80 and 60% in six combination treatments, three replicates each. Each replicate was represented by three trees. Irrigation was applied using a saline well water (3.58 EC dSm^{-1}) with a total annual quantity of 3948 m^3/feddan; average of 23.5 m^3/ tree/year. Magnetic treatment of the water was performed by passing the water through a magnetic field using a magnetic device [2 inches diameter with a capacity of 14,500 Gauss]. Three levels of NPK fertilizers were applied (100% [control], 80% and 60% of the recommended doses). The used levels of the control treatment were represented by 100:34:84 units/feddan of NPK, respectively, as shown in Table 2. The fertigation technique was applied using ammonium sulphate (20.6 %) as two equal biweekly doses from mid-February until early October; potassium sulphate (48% K_2O) as two equal biweekly doses from mid-February until late April, and repeated from mid-July until late September; and phosphoric acid as a one weekly dose from mid-February until mid-October.

Four branches per each replicate (2 inches diameter) were selected from the four directions of the tree, and tagged for all physiochemical determinations.

Table 1: Soil and water analysis of the experimental site

Parameters	Soil analysis	Irrigation water before and after magnetizing effect	
		Before	After
Sand %	88.45	--	--
Silt %	9.37	--	--
Clay %	2.18	--	--
Texture	Sandy	--	--
pH 1:2.5	7.50	7.65	7.85
EC dSm^{-1} 1:5	2.12	3.58	3.55
O. M.%	0.44	--	--
K^+ meq/l	1.33	83.60	79.20
Ca^{++} meq/l	5.62	86.60	79.20
Mg^{++} meq/l	5.23	20.88	13.92
Na^+ meq/l	8.24	819.70	832.92
HCO_3^- meq/l	4.77	5.60	4.00
Cl^- meq/l	7.25	230.31	273.63
SO_4^{--}meq/l	8.40	1516.03	1536.77
CO_3^{--}	--	--	--
Total N, %	8.12	--	--
Available P, %	5.15	--	--
Available K, %	11.4	--	--

Table 2: NPK fertilization treatments (calculated based on 100:33.6:84 units /feddan/year; 600 g N:200 g P:500 g K/tree/year, respectively)

Fertilizer types	Fertilization levels		
	100 % NPK	80% NPK	60% NPK
Ammonium sulphate	489.3	391.4	293.5
20.6 % N kg/feddan	(2.91 kg /tree)	(2.32kg /tree)	(1.74 kg /tree)
Phosphoric acid	62.2	49.7	37.3
54% P_2O_5 liter/feddan	(370 ml/tree)	(295 ml/tree)	(220 ml /tree)
Potassium sulphate	175.0	140.0	105.0
48% K_2O kg/feddan	(1.04 kg /tree)	(0.83 kg/tree)	(0.73 kg /tree)

1. Vegetive growth:

Number of shoots per branch was counted. Shoot length (cm) was measured using a regular ruler. Leaf area (cm^2) was measured using a leaf area meter Model Li 3100 area – meter. Canopy volume (m^3) was estimated according to the following equation:

Canopy volume = 0.528 x H x D^2, where H is the tree height and D is the tree diameter (Castle, 1983)

2. Root growth:

Soil samples were collected using an auger [10 cm diameter and 30 cm length] in a distance of 50–100 cm from the tree trunk and depth of 30, 60 and 90 cm. Samples were washed using a 1 mm-mesh cloths to separate the fibrous roots from the soil. Root samples were dried at 70 °C to a constant weight, and then the dries weight of the fibrous roots (≤ 2mm) was determined as g/auger according to Morgan et al., (2007).

3. Nutritional status:

By the second week of August, twenty mature leaves were collected from each replicate to determine the contents of proline, chlorophyll, total carbohydrates, and macro- and micronutrients. Leaf proline (µ mole/g fw) was determined in 0.5 g of fully mature leaves, according to the method of Bates et al., (1973). Chlorophyll a, b and total (µg/cm^2) were determined using N, N dimethyl formamide, according to Moran (1982). The remaining leaves were dried at 70 °C until a constant weight, and then 0.5 g of the powder was taken to determine total carbohydrates, according to Doubis et al., (1956). Dried leaves were grounded and homogenized with H_2SO_4 and H_2O_2 according to Evenhuis and DeWaard (1980). The solution was used to determine N, P, K, Ca, Na, Mg, Fe, Mn, Zn and Cu. Nitrogen was determined by micro-Kjeldahl method (A.O.A.C., 1990). Potassium by flame photometer, P by using spectrophotometer (A.O.A.C., 1990). The atomic absorption spectrophotometer (Unican SP 1900) was used to determine Ca, Na, Mg, Mn, Fe, Zn and Cu according to Chapman and Pratt (1978). Chloride was determined by the silver nitrate method (Brown and Jackson, 1955).

4. Fruit set and drop percentages:

Number of flowers, fruitlets at initial set (15 days after full bloom), and number of fruits at harvest were counted on the selected main branches in four directions of the tree to evaluate the final fruit set (%) and fruit drop (%) using the following equations:

$$\text{Fruit set} = \frac{\text{Number of fruitlets}}{\text{Number of perfect flowers}} \times 100$$

$$\text{Fruit drop} = \frac{\text{Number of fruitlets at initial set} - \text{Number of harvested fruits}}{\text{Number of fruitlets at initial set}} \times 100$$

5. Yield and fruit quality:

Fruit harvest was conducted in December 21^{th} and 19^{th} of the 2019 and 2020 seasons, respectively. Total fruit yield per tree (kg/tree) and per the harvested area (ton/feddan) was calculated. Twenty fruits were randomly collected from each tree to evaluate fruit quality according to A.O.A.C., (1990). Fruit weight (g), volume (ml) and firmness (kg/cm^2), peel thickness (mm), and juice content (%). Also, total soluble solid (TSS) (%) was determined using a hand-held refractometer. Titratable acidity % was determined as citric acid, and TSS/acid ratio was calculated. Ascorbic acid (mg/100 ml juice) was determined using 2, 6 dichlorophenol indophenol, according to Rangana, (1977).

Statistical analysis:

The statistical analysis was performed using SAS software package, version 9.1in a two-way ANOVA, and the least significant differences (LSD) at $p \leq 5\%$ was used for mean comparisons (Snedecor and Cochran, 1990).

RESULTS AND DISCUSSION

1. Vegetative growth:

The obtained results indicated that all treatments had positively affected all vegetative growth parameters of Washington navel orange trees, compared to the control (Table 3). Trees irrigated with magnetic water recorded the highest number of shoots per branch, shoot length, leaf area and canopy volume in both seasons. These results are in consistent with the previous reports of Aly et al., (2015) and Mohamed et al., (2017). El-Dengawy et al., (2019) reported that magnetic water improved the canopy size, number of shoots per branch, shoot length and leaf area of 'Washington' navel orange trees. Also Mahmoud et al., (2019) reported that irrigation with magnetized water in saline soils effectively improved the vegetative growth of Washington orange.

The number of shoots per branch, shoot length, leaf area and canopy volume were also significantly improved with the increased rates of NPK fertigation from 60 to 100% during both seasons (Table 3). Trees subjected to 80 and 100% NPK recorded the highest values of vegetative growth characteristics compared to those subjected to 60% NPK in both seasons. Similar results were reported on sweet orange (Ramana et al., 2014). Nirgude et al., (2016) concluded that overall vegetative growth of *Citrus sinensis* Osbeck cv. Mosambi was positively related to the amount of NPK applied through dripper. Ismaiel and Habasy (2021) found that the application of 500:250:250 units/feddan NPK stimulated shoot length, leaf area and number of leaves per shoot of 'Balady' lime budded on Macrophylla rootstocks.

The combined application of magnetized water and NPK was significantly effective on the vegetative growth characteristics of Washington navel orange trees during both seasons (Table 3). Trees subjected to magnetized water and NPK either at 80% or 100% showed the maximum number of shoots per branch, shoot length, leaf area and canopy volume, whereas the lowest values were recorded with non-magnetized water and 60% NPK treatment in both seasons. The current findings are in consistent with those of Ezz et al., (2016) and El-Khayat and Abd El-Wahd (2019). Mostafa et al., (2016) indicated that the application of magnetized water (3685.5 m^3/feddan) and compost (4kg) per tree resulted in the utmost shoot length and thickness, number of leaves per shoot, and leaf area of Washington navel orange trees. El Kholy et al., (2015) stated that irrigation with magnetized water in combination with 80% NPK improved the pseudo stem height and circumference, number of green leaves, and leaf area at bunch shooting stage in 'Williams' banana.

In generally, results indicated that the most pronounced effect was referred to the combined application of magnetized water and NPK, particularly at 80%. This is indicating that irrigation with magnetized water has reduced the amount of NPK fertilizers used by 20%. Magnetized water positively reduced soil pH, slightly dissolved soil soluble components, and led to increased nutrient mobility and enhanced macro- and micronutrient uptakes, which enhanced efficiency of NPK fertilizers (Mostafazadeh-Fard et al., 2012, Hilal et al., 2013 and Sarraf et al., 2020). Magnetic field reduced water surface tension, increased minerals dissolvability, which provides adequate nutrients for plant growth and development (Cai et al., 2008; Lee et al., 2013). The improvement of plant growth could also be related to the improvement in photosynthesis enzyme activities, and synthesis of phytohormones such as auxins, gibberellins and cytokinin with reduction in abscisic acid (Dhawi, 2014).

Table 3: Effect of magnetized water and NPK fertilization on number of shoots per branch, shoot length (cm), leaf area (cm^2) and canopy volume (cm^3) of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Number of shoots per branch		Shoot length (cm)		Leaf area (cm^2)		Canopy volume (m^3)	
	2019	2020	2019	2020	2019	2020	2019	2020
NMW	15.93	16.66	13.36	15.22	21.85	24.61	19.23	21.86
MW	17.74	18.75	14.39	16.37	25.79	27.78	22.48	26.73
L.S.D. ($p \leq 5\%$)	0.24	0.21	0.15	0.06	0.16	0.09	0.61	0.53
100% NPK	17.63	18.86	14.33	15.98	27.27	26.95	22.25	27.09
80% NPK	17.62	18.46	14.58	16.83	24.84	28.76	21.50	25.12
60% NPK	14.86	15.80	12.72	14.57	19.35	22.88	18.82	20.68
L.S.D. ($p \leq 5\%$)	0.29	0.26	0.19	0.08	0.20	0.12	0.75	0.65
NMW+100% NPK	17.00	17.95	13.57	15.42	25.22	25.19	20.80	24.48
NMW+80% NPK	16.83	17.47	14.32	16.46	22.51	27.30	20.51	23.25
NMW+60% NPK	13.97	14.56	12.20	13.79	17.82	21.36	16.40	17.85
MW+100% NPK	18.27	19.77	15.09	16.54	29.33	28.71	23.70	29.70
MW+80% NPK	18.41	19.45	14.84	17.21	27.18	30.23	22.50	27.00
MW+60% NPK	15.75	17.04	13.24	15.36	20.88	24.41	21.24	23.51
L.S.D. ($p \leq 5\%$)	0.42	0.37	0.27	0.11	0.29	0.17	1.06	0.92

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

2. Root growth:

Both magnetized water and NPK treatments were effective on fibrous root growth during both seasons (Table 4). Magnetized water effectively increased root dry weight either at 50 or 100 cm away from the trunk, as well as at 30, 60 and 90 cm depth. These results support the previous findings on Murcott mandarin (Abou-Baker et al., 2019). It was reported that magnetized water effectively enhanced the root growth of four citrus rootstocks (Mohamed et al., 2017). It was effective on root weight, length, and size of Washington navel orange seedlings; however, the increase in these parameters was less on fibrous roots that grow between 50 and 100 cm away from the main stem, as well as with increased depth from 30 to 90 cm (Mahmoud et al., 2019). Similar results were also reported by Morgan et al. (2007). This could be attributed to adequate distribution of soil moisture in root zone with irrigation of saline magnetized water, compared to non-magnetized water (Zabady, 2017), which reflected on enhanced tree growth (Mostafa, 2020).

The highest values of root dry weight were recorded with NPK fertilization at 100%, followed by 80% (Table 4) with a significant difference among all fertilization levels in both seasons. These results support the previous report of Tarai and Ghosh (2016) who revealed that maximum root growth of sweet orange was observed at 200:75:150 NPK g/tree/year. Table 4 has also indicated that root dry weight decreased, as the distance from tree trunk increased from 50 to 100 cm, as well as with increased soil depth from 30 to 90 cm.

Maximum root growth was also noticed with the combined application of magnetized water and NPK fertilization at 100%, followed by that at 80% in both seasons (Table 4). The lowest root growth was recorded with the combined application of non-magnetized water and NPK at 60%, as previously reported by Abdel-Nabi et al., (2019) and Selim (2019). These treatments were also less effective as the distance from tree trunk increased, as well as with increased soil depth. The positive effect of the treatment could be referred to the reduction in water amount in root zone, increased levels of nutrient solubility and availability to the plant, and decreased levels of toxic ions mainly Na^+ and Cl^- (Osman et. Al., 2014 and Fanous et.al., 2017).

3. Nutritional status:

3.1. Leaf total carbohydrate, chlorophyll, and proline contents

Data in Table 5 showed that irrigation with magnetized water was positively affected leaf contents of carbohydrate and chlorophyll, whereas proline content was the lowest compared to the control (EC = 3.58 dSm^{-1}) during both seasons. Ferreira-Silva et al., (2008) stated that leaf proline content tended to increase as salinity levels increased.

Table 4: Effect of magnetized water and NPK fertilization on fibrous root dry weight (g/auger*) of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	2019						2020					
	50 cm-distance from tree trunk			100 cm-distance from tree trunk			50 cm-distance from tree trunk			100 cm-distance from tree trunk		
	Soil depth (cm)						Soil depth (cm)					
	30	60	90	30	60	90	30	60	90	30	60	90
NMW	0.89	0.84	0.32	0.89	0.90	0.20	1.22	1.21	0.43	1.22	1.25	0.27
MW	1.02	1.01	0.45	1.30	1.08	0.31	1.41	1.37	0.61	1.81	1.38	0.42
L.S.D. ($p \leq 5\%$)	0.07	0.08	0.06	0.11	0.08	0.05	0.11	0.06	0.06	0.11	0.05	0.06
100% NPK	1.03	1.09	0.51	1.54	1.17	0.31	1.40	1.59	0.69	2.11	1.54	0.43
80% NPK	1.02	1.02	0.40	1.15	1.09	0.29	1.41	1.38	0.55	1.61	1.42	0.39
60% NPK	0.83	0.67	0.24	0.61	0.72	0.17	1.14	0.90	0.32	0.82	0.99	0.23
L.S.D. ($p \leq 5\%$)	0.09	0.09	0.08	0.14	0.10	0.07	0.14	0.08	0.08	0.14	0.07	0.08
NMW+100% NPK	0.97	1.00	0.47	1.40	1.07	0.26	1.30	1.57	0.63	1.92	1.51	0.35
NMW+80% NPK	0.95	0.90	0.25	0.69	0.94	0.20	1.30	1.23	0.35	0.94	1.29	0.27
NMW+60% NPK	0.77	0.62	0.24	0.60	0.70	0.16	1.07	0.84	0.32	0.81	0.95	0.21
MW+100% NPK	1.10	1.18	0.56	1.69	1.27	0.37	1.50	1.61	0.76	2.31	1.57	0.51
MW+80% NPK	1.09	1.14	0.55	1.61	1.24	0.38	1.52	1.53	0.76	2.28	1.56	0.51
MW+60% NPK	0.89	0.72	0.25	0.62	0.75	0.19	1.22	0.97	0.33	0.84	1.03	0.26
L.S.D. ($p \leq 5\%$)	0.12	0.14	0.11	0.19	0.14	0.09	0.20	0.11	0.11	0.20	0.09	0.11

*auger = 2357 cm^3 soil, NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

The increase in proline could be attributed to the increase in protein hydrolysis under salinity conditions. Murkute et al., (2005) found that the adverse effects of salinity resulted in accumulation of free amino acids, and proline in particular. Mahmoud et al., (2019) and El-Khayat and Abdel-Wahd (2019) reported that irrigation with magnetized water led to improved contents of chlorophyll a, b, carotenoids, and decreased proline and increased total carbohydrate contents of navel and Valencia oranges. Similar results were also recorded on four citrus rootstocks treated with magnetized water and magnetic iron (Mohamed et al., 2017). Abou-Baker et al., (2019) reported that magnetized water positively affects photosynthetic pigments, total carbohydrates, and proline contents of Murcott mandarin trees.

Results have also indicated that total carbohydrate and chlorophyll (a, b, total) contents were significantly increased with increasing levels of NPK fertigation from 60 to 100%, with significant differences among all three fertilization levels in both seasons. NPK fertilization was found ineffective on leaf proline content during both seasons. Khalil et al., (2015) reported that total carbohydrates, photosynthetic pigments and proline contents were significantly improved with NPK fertilization at 200:50:200 kg/feddan. The application of NPK and Mg fertilizers at 990:203:800 g/tree/year and 5g/tree/year, respectively were the best tool to improve chlorophyll contents in navel orange trees (Zaghloul and Knany, 2012). Application of 80% NPK was found effective improving total carbohydrate contents and C/N ratio of Balady mandarin trees (El-Salhy et al., 2010). Also, the application of 500:250:250 units/feddan NPK enhanced leaf total carbohydrates and chlorophyll contents of Balady lime trees (Ismaiel and Habasy, 2021).

The contends of carbohydrate and chlorophyll were positively enhanced with the combined application of magnetized water and NPK at 100%, followed by 80% with significant differences between all these two treatments in both seasons. On the other hand, proline content was the highest in trees subjected to non-magnetized water and 60% NPK (Table 5). Low proline content was reported with the combined application of magnetized water and humic acid (El-Dengawy et al., 2019). Magnetized water and humic acid & microorganisms improved carbohydrate and chlorophyll, and decreased proline contents in Valencia orange trees (El-Khayat and Abd El-Wahd, 2019). The positive effect of the magnetized water and NPK fertilization could be due to the increase in nutrient uptake, particularly N, K, Ca, Fe and Mn required for activity of the enzymes responsible of chlorophyll biosynthesis (Sarraf et al., 2020), which is considered as indicator of plant growth and productivity. Proline is one of the most abundant amino acids in citrus trees tissues that has an adaptive role as an osmotic substance under stress conditions (Ennab and El-Sayed, 2014). The increase in proline content with non-magnetized water (Table 5) indicated that plants were more stressed than those irrigated with magnetized water. These results were also confirmed by those reported by Fanous et al. (2017) and El-Khayat and Abd El-Wahd (2019). These results also support the results of vegetative growth (Table 3) and root dry matter, (Table 4) which generally indicated the role of magnetized water and NPK fertilization in improving plant tolerance to salt stress.

Table 5: Effect of magnetized water and NPK fertilization on leaf chlorophyll, total carbohydrate and proline contents of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Chlorophyll (µ gm/cm^2)						Total carbohydrates (%)		Proline (µ gm/g FW)	
	a		b		total					
	2019	2020	2019	2020	2019	2020	2019	202	2019	2020
NMW	36.58	37.70	12.58	13.60	49.16	51.30	8.26	8.61	0.667	0.561
MW	39.72	40.56	14.93	14.39	54.64	54.96	9.05	9.39	0.436	0.475
L.S.D. ($p \leq 5\%$)	0.76	0.47	0.14	0.05	0.63	0.47	0.22	0.05	0.047	0.033
100% NPK	40.19	41.22	15.63	15.81	55.82	57.03	9.32	9.77	0.541	0.510
80% NPK	38.53	39.70	13.68	14.06	52.21	53.76	8.79	9.35	0.542	0.515
60% NPK	35.74	36.48	11.95	12.11	47.67	48.60	7.86	7.89	0.572	0.528
L.S.D. ($p \leq 5\%$)	0.93	0.57	0.18	0.06	0.78	0.58	0.27	0.06	ns	ns
NMW+100% NPK	38.75	40.15	14.72	15.55	53.47	55.70	8.89	9.43	0.628	0.521
NMW+80% NPK	37.56	38.49	12.45	13.84	50.01	52.33	8.20	8.82	0.653	0.540
NMW+60% NPK	33.44	34.47	10.57	11.41	44.01	45.88	7.70	7.60	0.721	0.622
MW+100% NPK	41.64	42.29	16.54	16.08	58.18	58.37	9.75	10.11	0.455	0.500
MW+80% NPK	39.50	40.91	14.91	14.28	54.41	55.19	9.38	9.88	0.432	0.490
MW+60% NPK	38.00	38.50	13.34	12.82	51.34	51.32	8.03	8.19	0.423	0.435
L.S.D. ($p \leq 5\%$)	1.32	0.81	0.82	0.09	1.10	0.83	0.38	0.09	0.081	0.057

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

3.2. Leaf Nutrient Contents

3.2.1. Macronutrients

Likewise, magnetized water significantly improved leaf N, P, K, Ca and Mg of contents Washington navel orange trees, in comparison to non-magnetized water during both seasons (Table 6). Similar results were reported in Valencia orange (Aly et al., 2015). Adequate contents of macronutrients were also found in pear seedlings treated with saline water (4000–5000 mg/l) using the magnetic technology (Osman et al., 2014). Similar results were also reported on pomegranate trees (Okba et al., 2022).

Application of NPK fertilization either at 80 or 100% was also effective improving leaf N, P, K, Ca and Mg contents in Washington navel orange in both seasons (Table 6). These results support the previous findings on Kinnow mandarin (Karuna et al., 2017). NPK fertilization significantly increased leaf N, P, K, Ca and Mg of Washington navel orange trees (El-Gioushy and Eissa, 2019).

The highest leaf N, P, K, Ca and Mg contents were also recorded with the combined application of magnetized water and NPK at 80% NPK, followed by those received 100% NPK without significant differences between both treatments in both seasons (Table 6). Washington navel orange trees treated with magnetized water and compost (4 kg) showed high levels of N, P, K, Ca and Mg compared to the control (Mostafa et al., 2016). The application of humic acid either directly to the soil or with magnetized-water irrigation resulted in the highest levels of N, P, K and Mg in Washington navel orange trees (El-Dengawy et al., 2019). Irrigation with magnetized saline water, in combination with NPK fertilization at 80% improved the levels of N, P, K, Ca and Mg in banana plants (El-Kholy et al., 2015).

3.2.2. Micronutrients

Similarly, magnetized water significantly improved leaf Fe, Mn, Zn and Cu contents of Washington navel orange trees, in comparison to non-magnetized water during both seasons (Table 7). Magnetized water improved the levels of Fe, Mn, Zn and Cu in Washington navel orange (Ghaffar, 2016), Valencia orange trees (Aly et al., 2015) and pear seedlings (Osman et al., 2017).

Leaf Fe, Mn, Zn and Cu contents were also improved with NPK fertilization at 100%, followed by that at 80% with significant differences between both NPK levels on all micronutrients, except for Fe in both seasons (Table 7)). Fertilization with NPK at 100:50:33.3% resulted in the highest concentrations of Fe, Mn and Zn in Washington navel orange leaves (El-Gioushy and Eissa, 2019). Fertigation with NPK at 60% (240:54:54) improved the levels of Zn, Cu, Fe, Mn and B in Kinnow mandarin trees (Karuna et al., 2017).

Magnetized water along with NPK fertilization at 100 or 80% effectively improved leaf Fe, Mn, Zn and Cu contents in both seasons (Table 7). Similar results were reported on: Volkamer lemon, Sour orange, Troyer citrange and Cleopatra mandarin citrus rootstocks (Mohamed et al., 2015) and Valencia orange trees (El-Khayat and Abdel-Wahd, 2019).

3.2.3. Leaf Na^+ and Cl^-:

Irrigation with magnetized water effectively reduced leaf Na and Cl contents during both seasons (Table 8).

Table 6: Effect of magnetized water and NPK fertilization on leaf N, P, K, Ca and Mg contents of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NMW	1.89	2.05	0.181	0.190	1.78	1.72	2.25	2.33	0.542	0.547
MW	2.24	2.27	0.251	0.227	1.95	2.04	2.67	2.74	0.627	0.617
L.S.D. ($p \leq 5\%$)	0.08	0.09	0.010	0.010	0.06	0.05	0.05	0.07	0.010	0.010
100% NPK	2.14	2.23	0.228	0.217	1.93	1.93	2.47	2.56	0.626	0.623
80% NPK	2.10	2.24	0.226	0.221	1.91	1.98	2.52	2.60	0.620	0.634
60% NPK	1.95	2.01	0.193	0.188	1.74	1.75	2.39	2.45	0.506	0.488
L.S.D. ($p \leq 5\%$)	0.09	0.12	0.012	0.012	0.08	0.07	0.07	0.09	0.012	0.012
NMW+100% NPK	1.95	2.11	0.193	0.198	1.89	1.83	2.38	2.46	0.572	0.577
NMW+80% NPK	1.99	2.14	0.183	0.202	1.82	1.80	2.26	2.33	0.568	0.590
NMW+60% NPK	1.74	1.90	0.168	0.171	1.63	1.55	2.13	2.20	0.485	0.474
MW+100% NPK	2.33	2.36	0.264	0.236	1.98	2.03	2.57	2.66	0.680	0.670
MW+80% NPK	2.22	2.35	0.270	0.241	2.01	2.16	2.79	2.87	0.673	0.679
MW+60% NPK	2.17	2.12	0.218	0.204	1.86	1.95	2.65	2.70	0.528	0.503
L.S.D. ($p \leq 5\%$)	0.14	0.17	0.018	0.018	0.11	0.09	0.09	0.12	0.018	0.018

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

Table 7: Effect of magnetized water and NPK fertilization on leaf Fe, Mn, Zn and Cu contents of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Fe (mg/L)		Mn (mg/L)		Zn (mg/L)		Cu (mg/L)	
	2019	2020	2019	2020	2019	2020	2019	2020
NMW	42.8	47.3	29.8	31.0	16.1	15.2	08.2	08.6
MW	59.6	62.6	32.8	34.5	19.7	20.1	10.0	10.8
L.S.D. ($p \leq 5\%$)	2.5	2.3	0.22	0.30	0.19	0.21	0.30	0.09
100% NPK	56.2	56.8	33.5	36.1	20.2	20.3	10.7	10.9
80% NPK	54.8	58.0	32.4	32.7	19.2	17.9	09.4	10.7
60% NPK	42.6	50.2	28.0	29.5	14.4	14.8	07.2	07.6
L.S.D. ($p \leq 5\%$)	3.1	2.8	0.27	0.37	0.24	0.26	0.37	0.12
NMW+100% NPK	48.2	51.5	31.4	33.8	18.1	17.2	9.5	09.8
NMW+80% NPK	46.8	49.7	31.2	30.7	16.8	15.6	8.5	09.5
NMW+60% NPK	33.4	40.9	26.8	28.5	13.5	12.9	6.6	06.7
MW+100% NPK	64.3	62.2	35.7	38.4	22.3	23.5	11.9	12.1
MW+80% NPK	62.9	66.3	33.6	34.7	21.6	20.3	10.4	11.9
MW+60% NPK	51.8	59.5	29.2	30.5	15.4	16.7	07.9	08.5
L.S.D. ($p \leq 5\%$)	4.4	4.0	0.38	0.52	0.34	0.37	0.52	0.17

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

Table 8: Effect of magnetized water and NPK fertilization on leaf Na and Cl contents of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Na (%)		Cl (%)	
	2019	2020	2019	2020
NMW	0.237	0.234	0.357	0.317
MW	0.157	0.153	0.290	0.270
L.S.D. ($p \leq 5\%$)	0.010	0.010	0.010	0.10
100% NPK	0.194	0.189	0.306	0.281
80% NPK	0.190	0.186	0.305	0.277
60% NPK	0.207	0.206	0.359	0.322
L.S.D. ($p \leq 5\%$)	0.012	0.012	0.012	0.012
NMW+100% NPK	0.235	0.228	0.339	0.305
NMW+80% NPK	0.232	0.220	0.330	0.291
NMW+60% NPK	0.245	0.255	0.401	0.356
MW+100% NPK	0.153	0.150	0.273	0.257
MW+80% NPK	0.148	0.152	0.280	0.264
MW+60% NPK	0.169	0.158	0.317	0.288
L.S.D. ($p \leq 5\%$)	0.018	0.018	0.018	0.018

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

Application of NPK was also effective reducing Na and Cl levels with the lowest values recorded at either 80 or 100%. Same effect was noticed with the interaction treatments of irrigation and fertilization, with no significant differences between both treatments, in both seasons. These results are consistent with the previous reports (Mostafa et al., 2016; El-Dengawy et al., 2019; Mahmoud et al., 2019). The role of magnetized water in reducing Na and Cl ions could be attributed to its role in solubilizing Na and Cl salts and leaching them down in the soil (Hilal et al., 2013).

3. Fruit Set, Drop, and Total Yield:

Irrigation with magnetized water resulted in increased and decreased the percentages of fruit set and fruit drop, respectively, and hence improved total fruit yield (kg/tree) in both seasons, as indicated in Table 9. Similar results were reported in Valencia orange (Aly et al., (2015), Balady and Fremont mandarin (Hamdy et al., 2015), Washington navel orange (El-Dengawy et al., 2019), and Murcott mandarin (Abou-Baker et al., 2019). This effect could be referred to mitigating the deleterious effects of salinity, which in turn improved overall plant nutritional state and growth (Ezz et.al., 2017; Fanous et. al., 2017). In this respect, Fanous et al., (2017) confirmed the positive role of magnetized water on crop production of apricot, peach, and flame seedless grape.

Table 9: Effect of magnetized water and NPK fertilization on fruit set, drop and yield of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Fruit set (%)		Fruit drop (%)		Yield			
					Kg/tree		ton/feddan	
	2019	2020	2019	2020	2019	2020	2019	2020
NMW	1.97	2.71	12.59	11.25	54.87	52.09	09.21	08.74
MW	2.53	3.26	09.49	09.00	65.35	67.49	11.63	11.33
L.S.D. ($p \leq 5\%$)	0.09	0.08	0.39	0.12	1.98	0.86	0.22	0.14
100% NPK	2.53	3.33	09.21	08.56	70.83	69.24	11.89	11.62
80% NPK	2.34	3.28	11.64	10.67	63.34	63.06	11.22	10.58
60% NPK	1.89	2.35	12.28	11.14	46.16	47.07	08.16	07.90
L.S.D. ($p \leq 5\%$)	0.11	0.10	0.48	0.15	2.42	1.05	0.28	0.17
NMW+100% NPK	2.18	3.02	09.97	08.89	64.76	60.70	10.87	10.19
NMW+80% NPK	1.98	2.98	13.45	12.33	59.97	55.35	10.07	09.29
NMW+60% NPK	1.77	2.13	14.37	12.55	39.88	40.23	06.69	06.75
MW+100% NPK	2.88	3.64	08.45	08.58	76.90	77.79	12.91	13.06
MW+80% NPK	2.70	3.58	09.83	09.02	66.72	70.77	12.38	11.88
MW+60% NPK	2.01	2.57	10.19	09.74	52.44	53.92	09.62	09.05
L.S.D. ($p \leq 5\%$)	0.16	0.15	0.68	0.22	3.43	1.49	0.39	0.24

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

The higher the NPK fertilization level, the higher the fruit set and the lower the fruit drop percentages were recorded in both seasons. As a result, total fruit yield was the highest at 100% NPK (Table 9). It was reported that NPK and Mg fertilization improved fruit set and reduced preharvest fruit drop, and hence improved the number of navel orange fruit per tree (Zaghloul and Knany, 2012). Similar results were reported on mandarin (Nasreen et al., 2013) and lime trees (Ismaiel and Habasy, 2021). NPK fertilization was found necessary to induced early flowering, enhance fruit set and reduce fruit drop of Mosambi orange trees (Nirgude et al., 2016). Initial and final fruit sets were increased with increased levels of NPK fertilization (El-Gioushy and Eissa, 2019).

The interaction effect of magnetized water and fertilization was best at 80% NPK during both seasons. Similar results were reported on Williams banana (El-Kholy et al., 2015). Helaly (2018) and Selim (2019) indicated that magnetized water and NPK at either 100 or 75% NPK recorded the highest fruit number per plant and total yield.

5. Fruit Quality

5.1. Physical characteristics

Irrigation with saline magnetized water improved fruit weight (g) and volume (ml), peel thickness (mm), fruit firmness (kg/cm^2) and produced juice (ml) during both seasons (Table 10). Similar results were reported on Balady and Fremont mandarins (Hamdy et al., 2015). Magnetized water improved fruit weight, shape and volume, and juice volume of Washington Navel orange (El-Dengawy et al., 2019), as well as fruit quality and total yield of Valencia orange (El-Khayat and Abdel-Wahd, 2019).

Fertilization with NPK at 100%, followed by 80% and then 60% recorded the highest values of fruit weight (g), volume (ml) and firmness (kg/cm^2), and juice volume (ml) in both seasons. Similar results were reported on sweet orange (Quaggio et al., 2006) and mandarin trees (Nasreen et al., 2013).

The combined application of magnetized water and 100% NPK has the most pronounced effect on fruit physical characteristics during both seasons. Similar findings were reported on banana plants (El Kholy et al., 2015). The combined application of magnetized water and compost improved the fruit quality of Washington navel (Mostafa et al., 2016; El-Dengawy et al., 2019) and Valencia orange trees (El-Khayat and Abd El-Wahd, 2019).

5.2. Chemical characteristics

Irrigation with magnetized saline water significantly increased fruit TSS, TSS/acid ratio, and vitamin C, but decreased acidity compared to the control during both seasons (Table 11). Similar results were reported on Valencia orange (Aly et al., 2015) and mandarin trees (Hamdy et al., 2015; Abou-Baker et al., 2019).

The higher the NPK fertilizer level, the higher the fruit TSS, TSS/acid ratio, and vitamin C; however, fruit acidity has decreased with increased levels of NPK (Table 11). Similar results were reported by Quaggio et al. (2006), Karuna et al. (2017), and Ismaiel and Habasy (2021).

The combined application of magnetized water and 100% NPK fertilizers increased TSS, TSS/acid ratio, and vitamin C, but decreased acidity. Similar results were reported by El Kholy et al. (2015), El-Dengawy et al. (2019), and El-Khayat and Abd El-Wahd (2019).

Table 10: Effect of magnetized water and NPK fertilization on fruit weight g), fruit volume (ml), peel thickness (mm), fruit firmness (Newton) and fruit juice (ml) of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	Fruit weight (g)		Fruit volume (ml)		Peel thickness (mm)		Firmness (Newton)		Fruit juice (ml)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
NMW	263.0	265.8	262.8	268.9	52.3b	52.3b	09.9	09.5	087.16	076.0
MW	280.3	295.6	285.7	299.2	57.6a	59.6a	10.7	10.5	099.20	090.5
L.S.D. ($p \leq 5\%$)	2.02	1.87	1.83	1.80	0.48	1.10	0.49	0.23	0.94	1.14
100% NPK	279.20	291.7	281.7	293.9	54.5b	58.5a	10.5	10.2	096.30	090.0
80% NPK	271.80	282.3	275.1	284.6	56.0a	56.0b	10.3	10.1	093.80	081.9
60% NPK	264.15	268.2	266.0	273.6	54.5b	53.5c	10.0	09.7	089.45	077.9
L.S.D. ($p \leq 5\%$)	2.12	2.29	2.25	2.20	0.59	1.34	ns	0.23	1.15	1.39
NMW+100% NPK	271.2	273.4	267.1	274.2	51.0e	55.0d	10.0	09.7	090.0	080.0
NMW+80% NPK	264.1	269.5	265.9	268.8	54.0c	52.0e	09.9	09.7	087.8	075.2
NMW+60% NPK	253.9	254.7	255.5	263.8	52.0d	50.0f	09.8	09.1	083.7	073.0
MW+100% NPK	287.2	310.0	296.4	313.7	58.0a	62.0a	11.1	10.8	102.6	100.0
MW+80% NPK	279.5	295.2	284.4	300.5	58.0a	60.0b	10.7	10.6	099.8	088.6
MW+60% NPK	274.4	281.7	276.5	283.4	57.0b	57.0c	10.3	10.3	095.2	082.9
L.S.D. ($p \leq 5\%$)	2.99	3.25	3.18	3.12	0.83	1.90	ns	0.41	1.63	1.97

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

Table 11: Effect of magnetized water and NPK fertilization on TSS%, acidity%, TSS/acid ratio and vitamin C (mg/100ml juice) of Washington navel orange trees during the 2019 and 2020 seasons

Treatments	TSS (%)		Acidity (%)		TSS/acid ratio		Vitamin C (mg/100 ml)	
	2019	2020	2019	2020	2019	2020	2019	2020
NMW	11.06	12.04	0.92	1.03	11.99	11.65	43.75	51.77
MW	11.55	12.67	0.81	0.87	14.33	14.49	48.03	59.05
L.S.D. ($p \leq 5\%$)	0.09	0.06	0.05	0.04	0.96	0.73	0.67	0.65
100% NPK	11.53	12.50	0.84	0.92	13.80	13.60	47.20	56.82
80% NPK	11.25	12.43	0.87	0.94	13.02	13.28	45.98	56.11
60% NPK	11.13	12.14	0.90	1.00	12.65	12.33	44.49	53.31
L.S.D. ($p \leq 5\%$)	0.11	0.08	ns	0.05	ns	0.89	0.82	0.78
NMW+100% NPK	11.21	12.17	0.89	0.98	12.59	12.42	44.62	52.42
NMW+80% NPK	11.05	12.09	0.93	1.02	11.9c	11.85	43.56	52.34
NMW+60% NPK	10.92	11.87	0.95	1.11	11.48	10.69	43.07	50.55
MW+100% NPK	11.85	12.84	0.79	0.87	15.01	14.79	49.78	61.22
MW+80% NPK	11.46	12.77	0.81	0.87	14.14	14.71	48.40	59.88
MW+60% NPK	11.35	12.42	0.85	0.89	13.83	13.97	45.91	56.07
L.S.D. ($p \leq 5\%$)	0.16	0.11	ns	0.08	ns	1.26	1.17	1.12

NMW= nonmagnetic water, MW= magnetic water, NPK = nitrogen, phosphorus and potassium fertilization.

CONCLUSIONS

To mitigate the deleterious effects of saline irrigation water on Washington navel orange in grown in sandy soils, a combined application of magnetized saline water and NPK fertilization at 80% was found beneficial improving overall tree growth, root growth, nutritional status and biochemical behavior, which in turn improved total yield and fruit quality. This treatment has also led to save about 20% of irrigation water. Future prospective may incorporate other cellular and molecular characteristics to improve plant tolerance to salinity.

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إستجابة أشجار البرتقال أبو سرة للرى بالماء الممغنط والتسميد بمستويات مختلفة من النيتروجين والفوسفور والبوتاسيوم

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أجريت تجربة حقلية لدراسة تأثير نوعين من مياه الري وهما: المياه المالحة ($EC = 3.58dSm^{-1}$) والمياه الممغنطة والتسميد بثلاث مستويات من النيتروجين والفوسفور والبوتاسيوم وهم ١٠٠ و٨٠ و٦٠٪ والتفاعل بينهما على صفات النمو الخضرى والجذرى والحالة الغذائية والمتمثلة فى تقدير الكلوروفيل والكربوهيدرات الكلية والحمض الامينى البرولين والعناصر الكبرى والصغرى فى الاوراق وتاثير ذلك على المحصول وجودة ثمار أشجار البرتقال ابوسرة خلال موسمي ٢٠١٩ و٢٠٢٠ في مزرعة خاصة بمنطقة النوبارية بمحافظة البحيرة، مصر. تم توزيع ستة معاملات في تصميم قطاعات كاملة العشوائية كتجربة عامليه، كل معاملة كررت ثلاث مرات بثلاث أشجار لكل مكرار.

أظهرت النتائج أن الري بالمياه الممغنطة يحسن النمو من حيث عدد الافرع على الغصن، طول الفرع، مساحة الورقة، حجم الشجرة والوزن الجاف للجذور الماصة، تحسين الحالة الغذائية للاشجار وزيادة المحصول وصفات جودة الثمار الطبيعية والكيميائية.

كما اظهرت النتائج تحسنا معنويا فى النمو ومحتوى الاوراق من الكلوروفيل والكربوهيدرات الكلية والنيتروجين والفوسفور والبوتاسيوم والكالسيوم والمغنيسيوم والحديد والزنك والمنجنير والنحاس وعقد الثمار والمحصول وجودة الثمار مع زيادة التسميد بـــ NPK من ٦٠– ١٠٠%، بينما انخفض تساقط الثمار ومحتوى الاوراق من الصوديوم والكلور فى حين ان الحمض الامينى البرولين لم يتاثر بمعاملات التسميد المختلفة.

أدت تأثيرات التفاعل بين المياه المغناطيسية ومستويات التسميد إلى زيادة معنوية في جميع المتغيرات المدروسة والتي عكست تأثيراً إيجابياً وبخاصةً التفاعل بين الماء الممغنط ومستوى التسميد بمعدل ٨٠٪ من النيتروجين والفسفور والبوتاسيوم حيث أدت هذه المعاملة إلى تحسين النمو الخضرى والجذرى للأشجار والمحتوى المعدنى والمواد الكيموحيوية وأعطت محصولًا أعلى بجودة عالية.

لذلك، وللتخفيف من الآثار السلبية لإجهاد المياه المالحة وتحسين النمو والمحصول وجودة الثمار لأشجار البرتقال ابو سرة واشنطن المزروعة في تربة رملية تحت نظام الري بالتنقيط، يمكن التوصية بالري بالمياه الممغنطة والتسميد بـــ ٨٠% NPK والتي تعتبر المعاملة الأفضل وتوفر حوالي ٢٠٪ من الأسمدة دون أي تأثير ضار على نمو وإنتاجية الأشجار.