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Effect of long-term drip fertigation on some parameters of soil fertility

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THE EFFECT of long-term cultivation practices including fertilization through drip irrigation (fertigation) on some parameters of soil fertility using logical function was taken under consideration in this study. Representative soil samples were collected in 2021 from an area planted with avocado trees in 1997. Results showed that the change in soil fertility of the tested area at parallel and perpendicular to drip irrigation lines were 109% and 110% respectively relative to control treatment (non-fertigated soil) equal 100%. Based on the logical function, the total indices of the tested soil parameters related to soil fertility were 34.0, 36.5, 37.8 with soil fertility classes of L (Low), L and M (Medium) for control, at 1 and 2 m from tree in parallel to drip irrigation line respectively. Soil fertility classes at parallel and perpendicular to drip irrigation line were L and L respectively. It could be concluded that the soil fertility class of the investigated soil changed as affected by the long-term of drip fertigation by about 7, 11 and 12, 10 % relative to the non-fertigated soil at 1 and 2 m from tree in parallel and perpendicular to drip irrigation lines respectively.

Keywords: Soil fertility assessment, Relative change in soil fertility, logical function, long-term effects.

1. Introduction

Detailed information on the level of soil fertility/degradation is still very limited although the demand for land for agricultural production has increased due to the high population (Ghanem et al., 2021). Although the appropriate management of the soil that depends on the information leads to improving food quality and soil fertility levels and avoiding its deterioration, there is a severe lack of studies dealing with the change in the physical and chemical properties of soil, especially in the new areas after a relatively long period (long-term) of irrigation and continuous fertilization through a system drip (drip-fertigation). Also, the impact of these changes on the level of soil fertility has not yet been evaluated (Brevik and Sauer 2015).

Fertigation is the most common method for supplying water and nutrients to the soil (Pérez-Castro et al., 2017 and optimizing fertilizer use efficiency for plant development (Senthilkumar et al., 2017). Fertigation provides better nutrient distribution in soil to improve root growth and yield (Sandal and Kapoor, 2015). Hence, the irrigation and fertilization system can have a direct effect on root growth and development (Chilundo et al., 2017). This effect can be more pronounced by the irrigation system and fertilization strategy, which acts on the spatial distribution of moisture and nutrients in the soil profile as well as on the development and distribution of the root system (Santos et al., 2016).

Long-term monitoring of changes in soil physical and chemical properties contributes for sustainable

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land use. Xue, et al. (2020) reported that the Long-term mismanagement may led to soil nutrients imbalances. Consequently, monitoring is necessary to avoid negative consequences of fertigation on soil quality in the form of reduced fertility, and crop productivity (Sun et al., 2018). They added that the influence of drip fertigation on physical and chemical soil properties in arid and semi-arid conditions is well documented. For example, the long-term use of specific type of fertilizers like acidic or basic or neutral may affect soil properties. Therefore, it is imperative to study the effect of drip fertigation on the changes of soil physico chemical properties (Singh et al., 2018). Previous study showed that human activities have changed the spatial pattern of soil nutrients resulting in irregular spatial distribution of soil fertility (Dong, et al. 2021). Therefore, it is important to realize the spatial variation of soil properties and identify areas with low or high soil fertility, which could further guide site-specific soil management policies (Shi, et al. 2020). Alteration of soil characteristics by anthropogenic impact changes functional capacities of the soil. Agricultural technologies and current practices like mono-cropping, residue management, mineral fertilization, overuse of pesticides, heavy agricultural machinery, inadequate management practices of soil and irrigation, can significantly affect soil quality and soil fertility by changing soil physical and chemical properties (Elbasiouny, 2018). By the identification of the changes in some soil properties of the tested soil and evaluating the fertility of the soil, appropriate programs and recommendations can be put in place to improve the land and crop service operations (AbdelRahman et al., 2016 and Page et al., 2020).

Logical functions are used in spreadsheets to test whether a situation is true or false. Depending on the result of that test, it can be then elect to do one thing or another. It can be then use the IF logical function to determine which calculation to perform or action to take depending on the outcome of the test. The IF function can be used to display different information depending on the outcome of the condition test (Kassoff and Valente 2006).

This research aims mainly to study the effect of long-term drip fertigation practices including drip fertigation on the changes in some soil parameters related to soil fertility using a simple approach for the assessment in a newly fertigated area.

2. Materials and Methods

2.1 Field experiment

Soil samples were collected from Um Saber farm of the modern agriculture company in Beheira Governorate, from an area cultivated with avocado trees from 1997. The specific study area is located at 30° 32' 22.386" N latitude and 30° 47' 51.082" E longitudes and at an altitude of 74 m above sea level. The soil type of the study area is sandy. Irrigation water delivered by water pump from El-Nasr canal and irrigated by drip system.

2.2. Field Data:

The experimental area is covered by the previously accumulated fallen avocado leaves as organic straw for soil mulch. The drip irrigation system consists of three lateral lines made of black polyethylene (PE) 16 mm diameter with built-in drippers of 4 L/h discharge and 50 cm in between. An additional sprinkler system was in the middle every two trees to maintain the humidity around avocado trees to an appropriate degree. The experimental area is often fertigated 2-3 times weekly with the liquid fertilizers of the recommended formulae using Vensure of 250 L/h, with a plastic barrel as a reservoir for concentrated fertilizers. The liquid fertilizer contains ammonium nitrate (33% N), nitric acid (10% N), phosphoric acid (60% P_2O_5), potassium sulfate (50% K_2O), calcium nitrate (15% N, 29% Ca), magnesium sulfate (16% MgO), Fe-EDDHA (6% Fe), Zn-EDTA (13% Zn), Mn-EDTA (13% Mn) with pH ranged between 6-6.5 in the final fertigation solution.

2.3. Soil sampling and analyses:

Soil samples were taken to represent the depths of 0-25, 25-50, 50-75, and 75-100 cm from four different soil profiles around the tested trees. Two soil profiles at parallel and two at perpendicular direction to the drip irrigation lines in two different distances from the tested tree at 1 or 2 m (i.e., 32 separate soil samples for each tested trees) as shown in the following sketch (**Figure 1**). In addition, soil samples of similar depths were taken from a non-cultivated area (control) which was selected on the border of the studied area. Where, the non-cultivated soils have not received any irrigation or fertilization for the last 30 years **Figure 1**.

Soil samples were prepared for physical and chemical analyses using the recommended procedures. The particle size distribution was determined using the pipette method (Gee and Bauder, 1986). Soil bulk density (BD) were determined using a graduated cylinder according to method described by Klute (1965). Soil particle (PD) density by pycnometer according to Blake and Hartge (1986). The following equation was used to calculate soil total porosity according to Klute (1965):

Soil total porosity=100 × (1 - (BD/PD)).

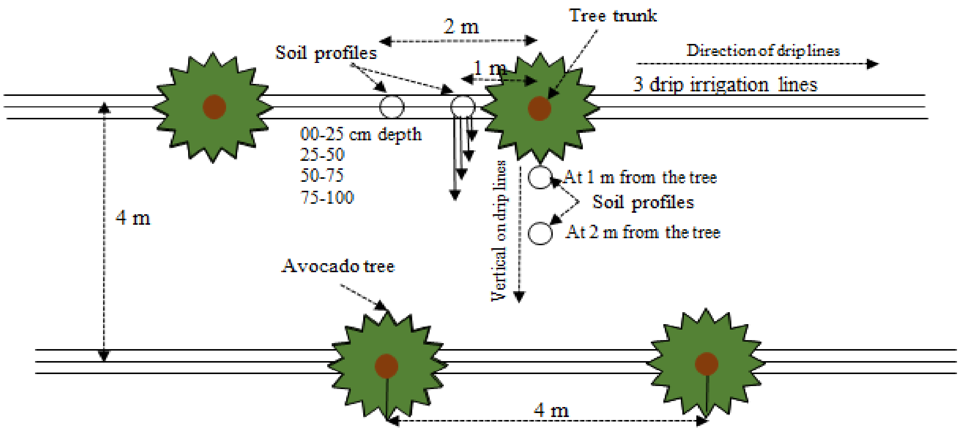

Fig. 1. A sketch showing the method of collecting soil samples in three different directions around the tree trunk.

Soil permeability as saturated hydraulic conductivity K_{sat} in mm/h was determined according to Elhakim (2016). Soil saturated percentage (SP) and $CaCO_3$ were determined using the methods described by Pansu and Gautheyrou (2006). Soil organic matter (OM) was determined using Walkley and black method as described by Nelson and Sommer (1982). Electrical conductivity ($EC_{1:5}$) was determined using an EC meter (Model YSI 32). Soil $pH_{1.2.5}$ was measured using a glass electrode pH meter in soil suspension with water (ratio 1:2.5) according to Mclean (1982). Cation exchange capacity (CEC) in the tested soil samples was determined using the sodium acetate-ammonium acetate method as described by Richards, (1954). Available soil phosphorus was determined using Olsen method as described by Jackson, (1973). Soil available potassium, calcium, magnesium, iron, zinc, manganese and copper contents were determined using standard methods as described by Jackson (1973).

2.4. Mathematical methodology

The change in the tested soil parameters related to soil fertility were assessment using the logic function (IF) as available and described in Microsoft Excel "2016".

In this work, the following limitation levels of the tested soil parameters related to soil fertility were used: very low (VL), low (L), medium (M), good (G) and very good (VG) with the limitation indices of 1, 2, 3, 4 and 5 respectively. Soil fertility index developed based on the limitation values and the indices of the related soil parameters as recommended by McRae and Burnham (1981).

The number of the tested parameters equal 15, and the soil parameter index for each equal to 1, 2, 3, 4 or 5 for VL l, M, G, VG respectively. Soil fertility index mainly estimated depending on the limitation levels of the tested soil parameters, especially those associated with soil fertility. The total soil fertility parameters indices (TSFPI) can be estimated as equal to the number of the tested soil parameters times the soil parameters indices.

The soil fertility class (SFC) could be assessment using the following suggestion total soil fertility parameters indices (TSFPI):

SFC is very good (VG) if TSFPI<=75, SFC is good (G) if TSFPI<=67.5 as 60+(75-60)/2, SFC is medium (M)) if TSFPI<=52.5 as 45+(60-45)/2, SFC is low (L) if TSFPI<=37.5 as 30+(45-30)/2, and SFC is very low (VL) if TSFPI<=22.5 as 15+(30-15)/2. The following suggested equation can be used to evaluate the Relative change in soil fertility (RSFC) after a long-term of drip fertigation and subjected to the different soil management:

$$RSFC = 100 \times \frac{TSFPI_{Treatment}}{TSFPI_{Control}}$$

Where: RSFC is the relative change in soil fertility, $TSFPI_{Treatment}$ is the total soil fertility parameters indices of treatments affected by the long-term of drip fertigation, and $TSFPI_{Control}$ is the total soil fertility parameters indices of control (non-fertigated soil).

2.5. Statistical Analyses

Analysis of variance (ANOVA) for the data was performed using SAS, V.9. (SAS, 1976). Mean separation was performed only when the F-test indicated significant differences among the treatments, (at $P \leq 0.05$) according to Duncan's multiple range test.

3. RESULTS

3.1. Effects of long-term drip fertigation on soil physical characteristics

Results in **Table 1** and **Figure 2** show the response of the different surface and subsurface soil layers parallel or perpendicular to irrigation drip lines to about 30 years of drip fertigation. It could be observed that there are no changes in the clay contents in the surface soil layer (0-25 cm depth) of the tested soil profiles taken around the tree trunk in either parallel or perpendicular on drip irrigation lines compared with the control soil.

Results revealed that the average clay contents decreased from 8.12% in the control treatment (the non-fertigated soil) to 6.24 and 5.67 at 1 and 2 m from the tree and decreased to 6.18 and 5.74% at parallel and perpendicular on drip irrigation lines respectively (**Table 1 and Figure 2**). The highest clay contents were found in the deeper layers of soil profiles taken parallel to drip irrigation lines. However, results in (**Table 1**) indicated that the decreases clay content were observed in the whole soil profile (0-100 cm). Also, there is a slight increase of clay fraction in the soil layers of 0-25 and 25-50 cm.

A slight increase in silt content was observed in the surface soil layer (0-25 cm depth) at 1 and 2 m from tree particularly at parallel to drip irrigation lines. Silt content increased from 10.1% in the control treatment to 15.8 and 21.8 % at 1 and 2 m from tree at the tested parallel direction (**Table 1)**. The changes in clay and silt contents were more pronounced for 0-50 cm depth than the soil layer of 50-100 cm. In general, Data revealed that silt and sand content increased with decreasing clay contents.

No substantial changes were observed in particle density (PD), bulk density (BD) and porosity as affected by about 30 years of drip fertigation in new reclaimed soil or desert area (**Table 1**). Particle (real) density (PD) and bulk density (BD) of the non-fertigated soil profile (control) ranged between 2.57-2.62 and 1.54-161 g/cm^3 respectively.

Table 1. Some physical characteristics of four sequence layers of soil profiles taken at 1 and 2 m from tree in parallel and perpendicular to the drip irrigation lines of avocado trees.

Soil characteristics	Soil depth in cm											
	0-25	25-50	50-75	75-100	0-25	25-50	50-75	75-100	0-25	25-50	50-75	75-100
	Non-fertigated soil				At 1 m from tree				At 2 m from tree			
	Control				Parallel to drip irrigation lines							
Clay-%	5.00^{g}	5.00^{g}	12.6^{a}	9.80^{b}	6.42^{cf}	5.34^{fg}	6.00^{eg}	8.03^{c}	6.13^{dg}	5.10^{fg}	5.01^{g}	7.34^{dc}
Silt-%	10.0^{f}	10.0^{f}	15.0^{c}	12.3^{de}	15.8^{c}	11.5^{df}	10.0^{f}	10.8^{ef}	21.7^{a}	19.9^{ab}	10.0^{f}	15.0^{c}
Sand-%	84.9^{b}	84.9^{b}	72.4^{i}	78.4^{f}	78.2^{f}	83.9^{bd}	84.2^{bc}	81.5^{de}	72.2^{i}	75.1^{gh}	84.9^{b}	77.5^{f}
SP-%	18.5^{cf}	16.7^{f}	17.8^{df}	17.5^{ef}	21.6^{b}	18.6^{cf}	18.4^{cf}	17.9^{df}	20.3^{d}	25.9^{a}	22.1^{bd}	22.1^{bd}
Permeability-mm/h	20.3^{d}	20.3^{d}	25.9^{a}	24.0^{ac}	23.1^{ad}	23.1^{ad}	22.1^{bd}	22.8^{ad}	20.3^{d}	25.9^{a}	22.1^{bd}	22.1^{bd}
Porosity-%	41.5^{ae}	40.6^{be}	39.4^{cf}	38.9^{df}	43.9^{ab}	41.7^{ad}	36.7^{f}	40.3^{bf}	44.2^{a}	41.9^{ad}	40.4^{be}	39.5^{cf}
PD-g/cm_3	2.56^{cd}	2.63^{ab}	2.61^{ac}	2.61^{ac}	2.55^{d}	2.60^{ad}	2.65^{a}	2.62^{ab}	2.51^{e}	2.60^{ad}	2.60^{ac}	2.61^{ac}
BD-g/cm_3	1.55^{ac}	1.54^{bd}	1.55^{ac}	1.60^{ab}	1.40^{f}	1.51^{cd}	1.56^{ac}	1.56^{ac}	1.43^{ef}	1.51^{cd}	1.55^{ac}	1.58^{ac}
$CaCO_3$-%	0.64^{a}	0.38^{cd}	0.50^{b}	0.38^{cd}	0.44^{bc}	0.36^{cd}	0.17^{fg}	0.19^{eg}	0.38^{cd}	0.29^{de}	0.24^{ef}	0.13^{fg}
OM-%	0.19^{g}	0.18^{g}	0.11^{g}	0.11^{g}	1.06^{a}	0.70^{c}	0.12^{g}	0.09^{g}	0.98^{ab}	0.53^{cf}	0.24^{fg}	0.29^{eg}
	Control				Perpendicular on drip irrigation lines							
Clay-%	5.00^{g}	5.00^{g}	12.6^{a}	9.80^{b}	5.03^{g}	7.00^{ce}	7.04^{c-e}	5.03^{g}	6.04^{d-g}	5.00^{g}	5.06^{g}	5.60^{fg}
Silt-%	10.0^{f}	10.0^{f}	15.0^{c}	12.3^{de}	10.1^{f}	19.1^{b}	16.7^{c}	7.58^{g}	12.4^{de}	16.8^{c}	12.5^{de}	13.0^{d}
Sand-%	84.9^{b}	84.9^{b}	72.4^{i}	78.4^{f}	85.0^{b}	73.8^{hi}	76.3^{fg}	87.4^{a}	81.4^{e}	78.2^{f}	82.4^{ce}	81.7^{ed}
SP-%	18.5^{cf}	16.7^{f}	17.8^{df}	17.5^{ef}	20.5^{bc}	18.9^{ce}	19.6^{be}	18.6^{cf}	19.5^{cd}	20.2^{bc}	19.9^{bd}	20.2^{bc}
Permeability-mm/h	20.3^{d}	20.3^{d}	25.9^{a}	24.0^{ac}	22.6^{ad}	25.1^{ab}	23.7^{ad}	22.4^{ad}	20.7^{dc}	22.3^{ad}	20.6^{cd}	22.3^{ad}
Porosity-%	41.5^{ae}	40.6^{be}	39.4^{cf}	38.9^{df}	43.0^{ac}	41.6^{ae}	40.8^{ae}	39.7^{cf}	40.8^{ae}	41.0^{ae}	39.9^{cf}	38.0^{ef}
PD-g/cm^3	2.56^{cd}	2.63^{ab}	2.61^{ac}	2.61^{ac}	2.59^{bd}	2.61^{ac}	2.62^{ab}	2.61^{ad}	2.59^{bc}	2.61^{ac}	2.62^{ac}	2.61^{ac}
BD-g/cm^3	1.55^{ac}	1.54^{bd}	1.55^{ac}	1.60^{ab}	1.47^{de}	1.52^{cd}	1.55^{ac}	1.57^{ac}	1.53^{bd}	1.54^{bd}	1.57^{ac}	1.62^{a}
$CaCO_3$-%	0.64^{a}	0.38^{cd}	0.50^{b}	0.38^{cd}	0.29^{de}	0.29^{de}	0.37^{cd}	0.17^{fg}	0.30^{de}	0.35^{cd}	0.09^{g}	0.36^{cd}
OM-%	0.19^{g}	0.18^{g}	0.11^{g}	0.11^{g}	0.66^{cd}	0.73^{cb}	0.38^{dg}	0.27^{fg}	0.50^{cf}	0.57^{ce}	0.15^{g}	0.33^{eg}

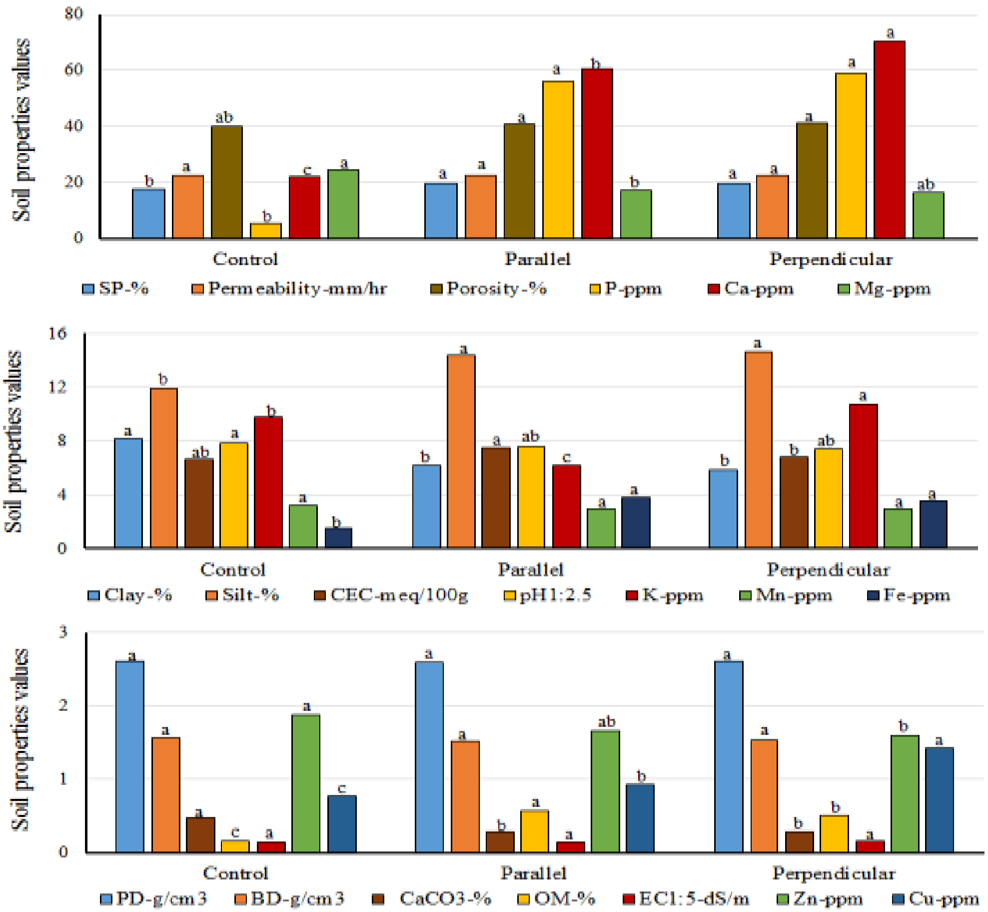

Fig. 2. Changes in some soil physical and chemical properties at parallel and perpendicular on drip irrigation lines relative to control treatment after 30 years of drip fertigation.

Soil porosity as a ratio of nonsolid volume to the total volume of soil (Indoria *et al*., 2020) ranged between 39.0 to 41.6 g/cm^3 for the non-fertigated soil. It could be also observed that porosity of the surface soil layer is slightly higher than that of subsurface soil layers.

The results obtained for the non-fertigated soil samples showed that the values of the soil water saturation (SP) were 18.5, 16.7, 17.8 and 17.5 at 0-25, 25-50, 50-75 and 75-100 cm depth (**Table 1**). It could be also observed a slight increase in the soil saturation percentage (SP) from 17.7 in the control soil to 19.2 and 20.4 in the soil samples taken from the soil profiles parallel to drip irrigation lines and to 19.4 and 20.0 % in perpendicular on drip lines for the long-term fertigated soil at 1 and 2 m from tree respectively.

Despite, the presence of calcium carbonate is very low in all soil profiles either in fertigated or non-fertigated soil, it has been observed a slight decrease in its contents from 0.45 in the non-fertigated soil to about 0.25% in average for the long-term fertigated soil. Soil calcium carbonate ($CaCO_3$) in the non-fertigated soil (control) ranged between 0.38 to 0.6 % (**Table 1 and Figure 2**).

As expected in such arid region, soil organic matter in the non-fertigated soil were 0.19, 0.18, 0.11 and 0.11 % at 0-25, 25-50, 50-75 and 75-100 cm with average value of 0.15 % (**Table 1**). The organic matter contents in the fertigated soil markedly increased from 0.15 in the control treatment to 0.6 and 0.51% in parallel soil profiles with drip irrigation lines and to 0.51 and 0.39% in perpendicular soil profiles on drip irrigation linesat 1 and 2 m from tree respectively.

3.2. The effects of long-term drip fertigation on some soil chemical characteristics

Soil exchangeable cations (CEC) for soil samples taken from the non-fertigated soil were 6.02, 6.71, 6.80 and 7.02 meq/100g soil at 0-25, 25-50, 50-75 and 75-100 cm with average value of 0.22 % (**Table 2**). Cation exchange capacity increased from 6.64 in the control treatment to 8.14 and 7.35

meq/100 g soil in parallel soil profiles (**Table 2**) to drip irrigation lines and to 7.37 and 6.25 meq/100 g soil in perpendicular soil profiles on drip irrigation linesat 1 and 2 m from tree respectively (**Table 2**).

pH of the non-fertigated soil were slightly alkaline as shown in (**Table 2**), where its values ranged between 7.74-7.94 with average of 7.81 average as shown in **Figure 2**. It could be observed that the long-term of drip fertigation had a slight effect on soil pH of all the tested soil profiles either at parallel or perpendicular on drip irrigation lines at 100 or 200 cm away from tree trunk (**Table 2**). The average values of pH decreased from 7.81 in control to 7.58 and 7.52at 1 and 2 m from tree parallel to drip irrigation lines and decreased to 7.34 and 7.36at 1 and 2 m from tree parallel to drip irrigation lines respectively.

Concerning nutrients availability in the soil samples taken from the non-fertigated soil, data in **Table 1** and **Figure 2** showed that the soil available P ranged between 4.98-6.34 ppm with average of 5.43 ppm.

Electrical conductivity ($EC_{1:5}$) values ranged from 0.13 to 0.18 dS/m in soil samples taken from the non-fertigated soil (0.15 dS/m average). In general, the values of electrical conductivity ($EC_{1:5}$) were very low either in fertigated or non-fertigated soil. Its values ranged between 0.11-0.26 dS/m (**Table 2**).

Results indicated a slight increase in salt accumulation after long-term (about 30 years) drip fertigation particularly at depth of 50-100 cm in perpendicular direction on drip irrigation lines. It could be also observed a slight decrease in salt accumulation after long-term drip fertigation at depth of 50-100 cm in parallel direction to drip irrigation lines (**Figure 3**).

Data revealed that the available phosphorus contents increased from 5.43 in the control treatment (non-fertigated soil) to 57.9 and 54.6 ppm in the soil profiles parallel to drip irrigation lines, and 58.7 and 60.2 ppm in soil profiles perpendicular on drip lines at 1 and 2 m from tree respectively.

Concerning micronutrient availability in the soil samples represent the non-fertigated soil taken as a control treatment, data revealed that the available Fe, Zn, Mn and Cu ranged between 0.87-1.91, 1.83-1.91, 2.4-5.61 and 0.31-1.76 respectively. It could be observed that the highest values of these micronutrient elements were found in the surface soil layer (0-25 cm depth). The available Fe contents in the tested soil profiles increased from 1.49 in the control (non-fertigated soil) to 2.8 and 4.17 ppm in the soil profiles parallel to drip irrigation lines and 3.3 and 3.35 ppm in soil profiles perpendicular on drip lines at 1 and 2 m from tree respectively (**Table 2**).

Table 2. Some chemical characteristics of four sequence layers of soil profiles taken at 1 and 2 m from tree in parallel and perpendicular on the drip irrigation lines of avocado trees.

Soil characteristics	Soil depth in cm											
	0-25	25-50	50-75	75-100	0-25	25-50	50-75	75-100	0-25	25-50	50-75	75-100
	Non-fertigated soil				At 100 cm far from tree				At 200 cm far from tree			
	Control				Parallel to drip irrigation lines							
$EC_{1:5}$-dS/m	0.13^{cf}	0.18^{bc}	0.13^{cf}	0.14^{cf}	0.14^{cf}	0.26^{a}	0.11^{ef}	0.12^{ef}	0.14^{cf}	0.12^{ef}	0.11^{f}	$0.13^{d f}$
$pH_{1:2.5}$	7.78^{ab}	7.74^{ab}	7.94^{a}	7.77^{ab}	7.76^{ab}	7.83^{ab}	7.23^{b}	7.46^{ab}	7.50^{ab}	7.53^{ab}	7.53^{ab}	7.50^{ab}
CEC-meq/100g	6.03^{ef}	6.70^{cf}	6.76^{cf}	7.00^{bc}	8.03^{ab}	8.30^{a}	8.10^{ab}	8.10^{ab}	6.84^{cf}	7.06^{be}	6.35^{df}	7.21^{ae}
P-ppm	6.34^{b}	4.98^{b}	5.23^{b}	5.16^{b}	58.3^{a}	57.1^{a}	55.5^{a}	60.6^{a}	55.9^{a}	59.7^{a}	49.7^{a}	52.9^{a}
K-ppm	9.30^{be}	12.2^{b}	7.25^{dh}	10.2^{bd}	9.13^{bf}	5.89^{eh}	5.89^{eh}	5.17^{fh}	9.50^{be}	4.81^{gh}	4.09^{h}	4.81^{gh}
Ca-ppm	36.1^{df}	16.5^{f}	18.7^{ef}	17.3^{f}	100.9^{a}	50.6^{cd}	47.7^{cd}	42.4^{ce}	100.0^{a}	60.0^{cd}	42.1^{ce}	39.4^{cf}
Mg-ppm	28.7^{a}	27.0^{a}	18.3^{ce}	24.0^{ac}	25.3^{ab}	13.1^{ef}	6.02^{g}	23.2^{ac}	26.3^{a}	10.0^{fg}	14.7^{df}	20.1^{bd}
Fe-ppm	0.87^{i}	1.91^{fi}	1.47^{hi}	1.71^{gi}	4.90^{b}	2.95^{dg}	2.83^{dg}	2.79^{dg}	6.31^{a}	4.13^{bd}	3.21^{cf}	3.02^{cg}
Zn-ppm	1.83^{ad}	1.89^{ab}	1.85^{ac}	1.91^{a}	1.62^{df}	1.63^{df}	1.69^{bf}	1.67^{cf}	1.69^{be}	1.68^{cf}	1.65^{cf}	1.66^{cf}
Mn-ppm	5.61^{a}	2.82^{df}	1.97^{g}	2.40^{eg}	4.27^{b}	2.34^{eg}	2.09^{fg}	2.78^{df}	2.35^{eg}	3.66^{bc}	2.91^{de}	3.17^{cd}
Cu-ppm	1.76^{b}	0.54^{ef}	0.31^{f}	0.44^{ef}	0.48^{ef}	0.85^{cf}	0.45^{ef}	0.46^{ef}	1.45^{bc}	1.48^{bc}	1.52^{bc}	0.72^{df}
	Control				Perpendicular on drip irrigation lines							
$EC_{1:5}$-dS/m	0.13^{cf}	0.18^{bc}	0.13^{cf}	0.14^{cf}	0.21^{b}	0.14^{cf}	0.14^{cf}	0.17^{cd}	0.14^{c-f}	0.13^{cf}	0.16^{ce}	0.17^{cd}
$pH_{1:2.5}$	7.78^{ab}	7.74^{ab}	7.94^{a}	7.77^{ab}	7.36^{ab}	7.30^{ab}	7.30^{ab}	7.40^{ab}	7.46^{ab}	7.36^{ab}	7.36^{ab}	7.26^{ab}
CEC-meq/100g	6.03^{ef}	6.70^{cf}	6.76^{cf}	7.00^{bc}	7.41^{ad}	7.06^{be}	7.80^{ac}	7.18^{ae}	6.57^{df}	6.30^{df}	5.74^{f}	6.37^{d-f}
P-ppm	6.34^{b}	4.98^{b}	5.23^{b}	5.16^{b}	66.6^{a}	49.4^{a}	62.9^{a}	55.5^{a}	58.0^{a}	61.3^{a}	56.2^{a}	65.2^{a}
K-ppm	9.30^{be}	12.2^{b}	7.25^{dh}	10.2^{bd}	10.9^{bd}	8.05^{ch}	8.77^{bg}	5.89^{eh}	17.0^{a}	11.6^{bc}	8.06^{ch}	10.2^{bd}
Ca-ppm	36.1^{df}	16.5^{f}	18.7^{ef}	17.3^{f}	108.4^{a}	61.9^{cd}	54.6^{cd}	53.5^{cd}	63.4^{cd}	86.0^{ab}	49.3^{cd}	63.7^{bc}
Mg-ppm	28.7^{a}	27.0^{a}	18.3^{ce}	24.0^{ac}	19.2^{ce}	15.1^{df}	15.4^{df}	16.1^{df}	24.2^{ac}	19.1^{ce}	5.03^{g}	10.0^{fg}
Fe-ppm	0.87^{i}	1.91^{fi}	1.47^{hi}	1.71^{gi}	4.30^{bc}	3.39^{ce}	2.94^{dg}	2.58^{eh}	2.86^{dg}	4.31^{bc}	3.27^{ce}	2.94^{dg}
Zn-ppm	1.83^{ad}	1.89^{ab}	1.85^{ac}	1.91^{a}	1.49^{ef}	1.65^{cf}	1.62^{df}	1.60^{ef}	1.47^{f}	1.70^{be}	1.64^{cf}	1.62^{df}
Mn-ppm	5.61^{a}	2.82^{df}	1.97^{g}	2.40^{eg}	4.12^{b}	2.74^{df}	2.25^{eg}	3.17^{cd}	2.97^{ce}	2.97^{cf}	2.55^{dg}	3.21^{cd}
Cu-ppm	1.76^{b}	0.54^{ef}	0.31^{f}	0.44^{ef}	0.99^{ce}	1.31^{bd}	2.56^{a}	0.72^{df}	1.23^{bd}	1.34^{bd}	1.10^{be}	1.28^{bd}

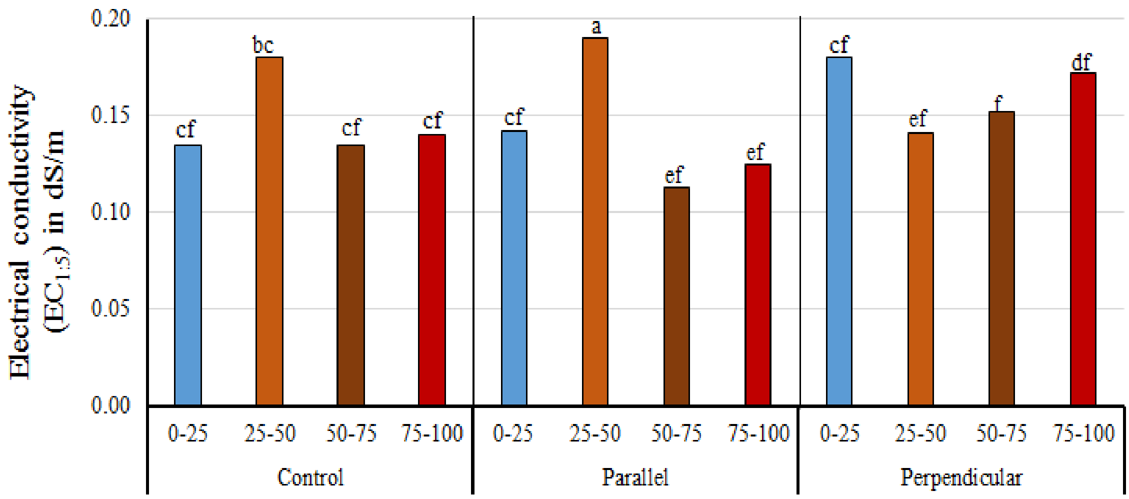

Fig. 3. Soil salinity distribution pattern after about 30 years of drip ferigation in the tested light soil.

The long-term drip fertigation in the studied area had no substantial effects on the available potassium (K), magnesium (Mg), zinc (Zn), manganese (Mn) and copper (Cu) contents in the tested soil profiles either in parallel or in perpendicular on drip irrigation lines (**Table 2**).

3.3. Soil fertility assessment after long term of drip fertigation in newly area

Some of the tested soil characteristics well known as soil fertility parameters which are expected to be among the most important soil parameters which clearly affect the availability of air, water and nutrients for growing crops (Havlin *et al*., 2005). These soil parameters can be listed in the follows:

Cation exchange capacity (CEC), Soil saturation percentage (SP), Soil permeability (permeability-mm/h), Soil calcium carbonate ($CaCO_3$), Soil organic matter (OM), $pH_{1:2.5}$, Soil salinity ($EC_{1:5}$), Available P, K, Ca, Mg, Fe, Zn, Mn and Cu.

Data in **Table 3** show the elected limitation values of the tested soil parameters related to soil fertility, these limitations only cover the range from deficient up to the luxury level passing on hidden hunger, critical and sufficiency range related to soil productivity as described by Singh and Singh (2015).

The logical function tool as explained in Excel 16 could be used easier for assessment the expected effects of any of the soil properties under investigation on soil fertility, and then can be evaluate the class of soil fertility and the relative changes in soil fertility after about thirty years of soil drip fertigation (Bagherzadeh *et al*., (2018).

Table 3. The elected limitation levels of some soil parameters related to soil fertility.

Soil parameter	limitation levels and indices of some soil properties				References
	1	2	3	4	
	VL	L	M	G	
CEC-meq/100g	4.00	8.00	16.0	24.0	Ibrahim, et al. (2011)
SP-%	15.0	25.0	35.0	45.0	McRae and Burnham (1981)
Permeability-mm/h	2.50	5.00	10.0	15.0	Sys, et al., (1991) and McRae and Burnham (1981)
$CaCO_3$-%	25.0	10.0	5.00	2.00	Chalwade et al. (2006)
OM-%	0.50	2.00	5.00	10.0	Chalwade et al. (2006) and Thombe et al. (2020)
$pH_{1:2.5}$	8.50	7.0	6.10	5.10	Horneck et al. (2011)
$EC_{1:5}$-dS/m	1.50	1.50	1.00	0.50	Horneck et al. (2011)
P-ppm	20.0	40.0	60.0	80	Horneck et al. (2011)
K-ppm	150	250	400	600	Horneck et al. (2011) and Gerloff (1976)
Ca-ppm	100	200	400	600	Horneck et al. (2011)
Mg-ppm	25.0	100	250	400	Gaspar A (2019)
Fe-ppm	5.00	10.0	15.0	25.0	Thombe et al. (2020) and Ibrahim, et al. (2011)
Zn-ppm	1.00	3.00	5.00	8.00	Thombe et al. (2020) and Ibrahim, et al. (2011)
Mn-ppm	4.00	8.00	12.0	16.0	Thombe et al. (2020) and Ibrahim, et al. (2011)
Cu-ppm	0.30	0.80	1.20	2.50	Thombe et al. (2020) and Ibrahim, et al. (2011)

The logical (IF) functions used for assessment of some soil fertility parameters in different categories as previously described by Sys et al., (1991):

CEC Category =IF(CEC<=4,"VL",IF(CEC<8,"L", IF(CEC<16,"M",IF(CEC<24,"G", IF(CEC>=24, "VG","X"))))).

SP Category =IF(SP<=15,"VL",IF(SP<25,"L",IF(SP<35,"M",IF(SP<45,"G", IF(SP>=45,"VG","X"))))).

Permeability category =IF(Perm<=2.5,"VL",IF (Perm<5,"L",IF(Perm<10,"M",IF(Perm<15,"G",IF(Perm >= 15, "VG",X))))).

$CaCO_3$ category =IF(CC<=2,"VG",IF(CC<5,"G", IF(CC<10,"M",IF(CC<25,"L",IF(CC>=25,"VL", X))))).

OM category =IF(OM<=0.5,"VL",IF(OM<2,"L", IF(OM<5,"M",IF(OM<10,"G",IF(OM>=10,"VG", "X"))))).

pH category =IF(pH<=5.1,"VG", IF(pH<6.1,"G", IF(pH<7,"M", IF(pH<8.5,"L",IF(pH>=8.5,"VL", "X"))))).

EC category =IF(EC<=0.25,"VG",IF(EC<0.5,"G", IF(EC<1.0,"M",IF(EC<1.5,"L",IF(EC>=1.5,"VL" ,"X")))))

P category =IF(P<=20,"VL",IF(P<40,"L",IF(P<60 ,"M",IF(P<80,"G",IF(P>=80, "VG","X"))))).

K category=IF(K<=150,"VL",IF(K<250,"L",IF(K <400,"M",IF(K<600,"G",IF(K>=600,"VG","X"))))).

Ca category =IF(Ca<=100,"VL",IF(Ca<200,"L", IF(Ca<400,"M",IF(Ca<600,"G",IF(Ca>=600,"VG" ,"X"))))).

Mg category =IF(Mg<=25,"VL",IF(Mg<100,"L", IF(Mg<250,"M",IF(Mg<400,"G",IF(Mg>=400, "VG","X"))))).

Fe category =IF(Fe<=5,"VL",IF(Fe<10,"L",IF(Fe <15,"M",IF(Fe<25,"G",IF(Fe>=25,"VG",X))))).

Zn category =IF(Zn<=1,"VL",IF(Zn<3,"L",IF(Zn <5,"M",IF(Zn<8,"G",IF(Zn>=8,"VG","X"))))).

Mn category =IF(Mn<=4,"VL",IF(Mn<8,"L",IF(Mn<12,"M", IF(Mn<16,"G",IF(Mn>=16,"VG","X"))))).

Cu category =IF(Cu<=0.3,"VL",IF(Cu<0.8,"L", IF(Cu<1.2,"M",IF(Cu<2.5,"G",IF(Cu>=2.5,"VG", "X"))))).

Data in **Table 4** show soil parameters assessments in different categories using logical function method as described in Microsoft office 2016, for the non-fertigated soil, at 1 and 2 m from tree either in parallel or in perpendicular on drip irrigation lines after thirty years of fertigated. The total indices of the tested soil parameters related to soil fertility were 33.3 (100), 36.5 (109) and 37.5 (111.3) with soil fertility class of L (Low), L and L for the control (non-fertigated soil) and at 1 and 2 m from tree in parallel to drip irrigation line respectively. In addition, the total indices of the tested soil parameters at 1 and 2 m from tree at perpendicular on drip irrigation line were 37.0 (111.3) and 36.5 (109.8) with soil fertility class of L and L respectively. The soil fertility class at parallel and perpendicular to drip irrigation line were 36.8 (110.5) and 36.7 (110.1) with soil fertility class L and L respectively.

The relative change in soil fertility class as influenced by the long-term cultivation with fertigation was evaluated using the TSFPI and pre-suggested total soil fertility parameters indices (STSFPI) as reference. The following is the logical function used for the estimation of the soil fertility class according to the suggested total soil fertility parameters indices:

(TSFPI)=IF(TSFPI<22.5,"VL",IF(TSFPI<=37.5,"L ",IF(TSFPI<=52.5,"M",IF(TSFPI<=67.5,"G", IF(TSFPI<=75,"VG"))))).

Results in **Table 4** showed that the relative change in soil fertility (RCSF) were about 100 and 109% for the control (non-fertigated soil), at 1 and 2 m from tree in parallel to drip irrigation line respectively. The relative changes in soil fertility of the tested soil at 1 and 2 m from tree at perpendicular on drip irrigation line were about 111 and 110% respectively.

Table 4. Some soil parameters assessments in different categories in relation to soil fertility.

Soil parameter Related to Soil fertility	Soil fertility parameters indices (SFPI)						
	Control	Paralell to drip irrigstion lines			Perpendicular on drip irrigation lines		
		100 cm	200 cm	Mean	100 cm	200 cm	Mean
SP	L 2.00	L 2.00	L 2.00	L 2.00	L 2	L 2	L 2
Soil permeability	VG 5.00	VG 5.00	VG 5.00	VG 5.00	VG 5	VG 5	VG 5
$CaCO_3$	VG 5.00	VG 5.00	VG 5.00	VG 5.00	VG 5	VG 5	VG 5
OM-%	VL 1.00	VL 1.00	L 1.50	L 1.50	L 1.5	VL 1.25	VL 1.38
CEC-meq/100g	L 2.00	L 2.00	L 2.25	L 2.63	L 2	L 2	L 2
$pH_{1:2.5}$	L 2.00	L 2.00	L 2.00	L 2.00	L 2	L 2.00	L 2.00
$EC_{1:5}$-dS/m	VG 5.00	VG 5.00	VG 5.00	VG 4.88	VG 5	VG 5.00	VG 5.00
P-ppm	VL VL	VL VL	M M	M M	M M	G M	M M
K-ppm	1.00 VL	1.00 VL	3.00 VL	3.13 VL	3.5 VL	3.5 VL	3.5 VL
Ca-ppm	1.00 VL	1.00 VL	1.00 VL	1.00 VL	1 VL	1.00 VL	1.00 VL
Mg-ppm	1.00 VL	1.00 VL	1.25 VL	1.25 VL	1.25 VL	1.00 VL	1.1 VL
Fe-ppm	1.00 VL	1.00 VL	1.25 VL	1.25 VL	1 VL	1.00 VL	1.00 VL
Zn-ppm	1.00 L	1.00 L	1.25 L	1.13 L	1 L	1.00 L	1.00 L
Mn-ppm	L 2.00	L 2.00	L 2.00	L 2.00	L 2	L 2.00	L 2.00
Cu-ppm	VL 1.00	VL 1.00	VL 1.00	VL 1.13	VL 1.25	VL 1.00	VL 1.00
	Relative change in soil fertility after about 30 years of drip fertigation - %						
	Control	100 cm	200 cm	Parallel	100 cm	200 cm	Perpendicular
Total indecies	33.3	36.5	37.0	36.8	37.0	36.5	36.7
Soil fertility class	L	L	L	L	L	L	L
Relative soil fertility change	100	109	111.3	110.5	111.3	109.8	110.1

Relative change in soil fertility (RCSF) = 100 × Total SFPI/Total indices of the control
Total indices = Number of parameters × Index of each soil parameter
The number of soil parameters related to soil fertility = 15

Discussion

Decreasing clay contents in the deeper layers of soil profiles taken parallel to drip irrigation lines may be ascribed to the effects of higher leaching occurs parallel to drip irrigation lines compared with that perpendicular drip lines (Quenard *et al.*, 2011). On the other hand, the movement of clay particles from one layer to another may be due to mechanical soil management, occurring during soil preparation for planting a new crop. These results are in agreement with that observed by Quenard *et al.*, (2011) who reported that the Movement of clay particles and other colloids through soil profiles has been investigated extensively during the past few decades. The pathway of movement is generally accepted as being predominantly downward.

Although the bulk density of soil is an indicator of soil compaction, which can reduce the volume of soil particles and the volume of pores among soil particles, in this case, the increase in the bulk density is mainly due to the high density of sand particles Morbeg and Esu (1991) and Kparmwang (1993).

Increasing soil porosity in the deeper soil layers compared with that of the surface layer may be due to the compaction by gravity as reported by Khanday and Ali (2012).

The slight change in the values of SP and soil permeability matched with the corresponding slight changes in the values of clay $CaCO_3$ and OM content (Kramarenko, *et al*., 2016). However, soil permeability refers to the movement of air and water through the soil, which is important because it affects the supply of root-zone air, moisture, and nutrients available for plant uptake.

In fact, these levels of $CaCO_3$ in the tested soil were very low. Soils of arid and semi-arid regions are closely related to their bedrocks in most chemical and mineralogical properties. Limestone rock is the predominant bedrock in such areas and even with excess leaching, a little amount of $CaCO_3$ will remain within soil horizons. In arid and semi-arid region, $CaCO_3$ mineral dominated as result of the little leaching (Chalwade, *et al.* 2006).

Organic matter is generally very low in the tested soils according to Landon (1991) ratings (>20 % very high, 10-20 % high, 4-10 % medium, 2-4 % low and < 2 % very low). Low organic matter content in such soils could be due to the rapid decomposition and mineralization of organic materials contributed by sparse vegetation in the hot semiarid climate as promoted by radiation.

The increase in soil organic matter may be attributed to the accumulation particularly at 100 cm away from the tree trunk parallel to drip irrigation lines of the annual may be due to the annual fallen leaves from avocado trees.

The total negative charges within the soil that adsorb plant nutrient cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+). As such, the soil exchangeable cations (CEC) is a property of soil that describes its capacity to supply nutrient cations to the soil solution for plant uptake.

Soil exchangeable cations (CEC) values well matched with the corresponding types of soil texture in such areas. The low CEC of the soils could be attributed to the nature of clay minerals which is kaolinite in Egypt (Hassan, *et al.*, 2011). Yakubu, *et al.*, (2011) opined that the organic matter content of soils that normally influences the CEC is generally low, particularly in light-texture soils and therefore the CEC values may not be attributed to the lower content of organic matter.

The observed slight decrease in soil pH may be attributed to the long-term use of acetic fertilizers such as ammonium sulfate, nitric acid, and phosphoric acid in fertigation system. However, these results are in agreement with that observed by Singh, *et al*., (2018) who reported that the long-term use of specific types of fertilizers like acidic or basic or neutral may affect the physicochemical properties of soil. It is worth to mentioning that the soil pH is important to plant growth because it affects the availability of nutrients (Oshunsanya, 2019).

The mean values of $EC_{1:5}$ were generally low and may be indicating a non-saline status of the tested soils according to the limits set by Schoeneberger, *et al.*, (2002). In fact, the observed slight increases in salt accumulation after long-term (about 30 years) drip fertigation at the soil layer of 50-100 cm in perpendicular direction on drip irrigation lines may attributed to the shortage of water irrigation can be reached to the soil in such direction by drip irrigation comparing with the parallel direction to water irrigation lines. On the other hand, the observed slight decreases in salt accumulation after long-term drip fertigation at depth of 50-100 cm in parallel direction to drip irrigation lines were highly expected under such conditions of using low saline irrigation water delivered from Elnasr canal (0.33 dS/m) in mulched light soil where soil permeability is very high (Guan et al., 2019 and Isabelle (2001). They mentioned that soil salinity accumulation even under long-term drip fertigation can be mitigated using low saline irrigation water, and sufficient drainage under mulched soil.

The obtained values of P in the tested soil were very low relative to that recommended by Horneck, *et al.* (2011) where the lowest P level was <20 ppm P or about 46 ppm P_2O_5. These results may be ascribed to the accumulation ability of phosphorus in soils (Husein, *et al*., 2021).

The higher values of the tested micronutrient elements found in the surface soil layer (0-25 cm depth) may reflect the effects of water shortage in such arid areas, which keep these elements in soil surface without significant leaching (Husein, *et al*., 2021).

In fact, there are many attempts to find out the absolute and accurate values for these limitation levels (Amara, *et al*., 2017, Patil, *et al*., 2016, Enang, *et al*., 2016 Abah and Petja 2015 and Masto, *et al.* 2008), but each of them is appropriate for special and specific conditions such as that concerning, soils, crop and weather conditions. However, this work relied on electing the limitations values for the tested soil parameters to match as much as possible the common environmental conditions of the area under study.

No significant differences between the relative changes in soil fertility of the tested soil at parallel and perpendicular to drip irrigation lines as influenced by long-term cultivation under drip fertigation system. However, the relative change in soil fertility class for each tested direction was almost equal (L) with relative change to control soil of about 110%.

The change in soil fertility, which reached about 10% compared to the control soil after 30 years of cultivation using drip fertigation, shows how slow the process of change is in such an arid region with high temperature and little rain or water resources. Therefore, it is expected that the process of transforming such soil into a good degree of fertility and thus improving its productivity to hundreds of years.

The increases in Soil organic carbon due long-term leaves fallen, using acetic fertilizers and using aectic liquid fertilizers and fresh water could be considered the main factors affecting soil fertility in the tested soil (Diacono, and Montemurro 2010).

Conclusion

From the aforementioned results, it could be concluded that the soil fertility class (SFC) of the investigated soil changed as affected by the long term of drip fertigation for about 30 years by about 7 and 11 % and 12 and 10 % relative to the non-fertigated soil at 1 and 2 m from tree in parallel and perpendicular to drip irrigation lines respectively. The highest change in soil fertility after the long term of drip fertigation was about 12 % relative to non-fertigated soil at 100 cm away from tree trunk in perpendicular on drip irrigation line. This followed by about 11% at 200 cm away from tree trunk in parallel to drip irrigation line. However, the relative best soil fertility class was associated with the highest soil fertility change particularly in such sandy soil.

Consent for publication: All authors declare their consent for publication.

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Conflict of interest

Salma Mohamed Abdelaziz; Manal Mubarak M.; and A.A. Ibrahim, A.A. Saad-Aldin and Mona I. Nossier declare that they have no competing interests contribution of Authors: All authors shared in writing, editing to get MSc and agree to its publication.

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An Introduction to Logical Spreadsheets

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Abstract

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