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Feasibility of Air Injection into Subsurface Drip Irrigation System

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ABSTRACT

There is no doubt that, a concept of improving the efficiency of irrigation system is developed day after day. It is know that, the modern irrigation is pressurized irrigation system, where the fluids movement into the close pipes under pressure, and the fluid in motion depends on the force of laminar and turbulent flow as subsurface drip irrigation (SDI) which has a strong competitive edge because of its greater WUE compared to other irrigation methods. Recently many researches refer to oxygation as away to improve (WUE), more producing yield and optimizing the use of SDI. Venturi is an essential part of the modern irrigation system components and is responsible for injecting soluble fertilizers using the pressure difference and fluid force movement which can used professionally for air injection. Therefore, this work aimed to study the effect of air injection (airgation) within root zone under subsurface drip irrigation using a modified instrument of Venturi that suction the air to be mixed with irrigation water and carefully injected into the system. In order to evaluate the effect of different lateral types (Gr 30, 50 cm, T tape and Leaky pipe) with and without air injection on emitters Cv. and emission uniformity, soil water distribution, soil nutrients availability and their effect on growth, yield and quality parameters in carrots (*Daucus carota* L.). The experiment carried out during the 2017-2018 growing season in open field at Dokki side, belongs to the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), at Giza Governorate, Egypt, in a clay soil.

The results showed that the air injection under subsurface drip irrigation enhance growth, yield and quality of carrot with improving the Cv. characteristics of emitters and rise the availability of macronutrients within root zone. In addition, the beneficial effect of aeration is clearly shown with the lateral type of Gr 30 cm and Leaky pipe in all previous characteristics and soil water pattern especially, in the second season which Gr 30 cm appear more efficiency

Keywords: Air injection, Venturi instrument, subsurface drip irrigation and Carrot crop.

Introduction

The ideal soil composition for plant growth would include close to 50:50% mix of air and water in the soil pore space, or about 25% air in the soil, by volume (assuming a total porosity of 50%). Many researchers believe that in most soils microbiological activity and plant growth become severely inhibited when air filled 20% of pore space or 10% of the total soil volume with correspondingly high water content that filled pores block. In fact also, subsoil are usually more deficient in oxygen than are topsoil, not only because of the water content that usually higher, but also the total pore space are generally much lower in the deeper horizons; in addition the pathway for diffusion of gases into and out of soil is longer for deeper horizons (Nyle and Ray, 2002). Oxygation refers to irrigation of crops with aerated water, through air injection using the venturi principle or the supply of hydrogen peroxide in the root zone, both using subsurface drip irrigation (SDI) system (Chen *et al*., 2011). Soil aeration by means of injection of atmospheric air into the soil via subsurface drip irrigation system can accelerate the depletion of water from macro pores and increase the oxygen concentration in the soil air (Vyrlas *et al.,* 2014). This action can enhance the yield and quality of crops particularly those grown on heavy soils the advantages are linked to the abundance of air in the rhizosphere with higher level of dissolved oxygen in the water, which can effect on many soil reaction

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and in turn many soil properties. The most obvious of these reactions are associated with microbial activity that play important role for the breakdown of organic matter and nutrient availability in soil while, in poor aeration condition, soil microorganisms can extract most of dissolved O_2 in the water for metabolic purpose with the time anaerobic organisms take over, and anaerobic conditions soon prevail. Also low O_2 level constrain root respiration, a process that provides the energy needed for nutrient and water absorption; plants seen in low spots as a result of excess water more susceptible to wilt and reduce their uptake, as well as soil compaction is owing to poor aeration because it can decrease the exchange of gases even soil water content below field capacity (Chen *et al*., 2011 and Abuarab *et al.* 2019). Also, there were a problems can facing the irrigation system and caused a poor aeration such as long duration irrigation events result in root development concentrated around the emitters and the relatively low hydraulic conductivity mainly in heavy soils retains the saturation in the root zone, resulting in lack of air, which is detrimental to the root functioning and directly influences crop development which can be avoided with supplying oxygen.

Air injection is applicable to the subsurface drip irrigation system; various researchers have shown that crop yield and quality can be increased using air injection into the irrigation system. Goorahoo *et al.* (2004) found that there was a 14% increase in the number of melons and 16% increase in the weight of melons harvested due to air injection. Abuarab *et al.* (2013) appeared that that corn yield increases due to air injection 12.27% than without air with highly root distribution, stem diameter, plant height, number of grains per plant and (WUE). Abuarab *et al.* (2019) reported that, potato yield was higher than under non-aerated treatments by 48.9% and water productivity values were higher by 61.7% with higher vegetative growth parameters.

Moreover, it is noted that air injection has a positive effect in the irrigation system itself, such as a reduction in the formation of algae in the tubing due to the oxygen, and the suspension of solids due to micro bubbles, which reduces the possibility of emitter clogging. Where, SDI systems have the capability of frequently supplying water to the root zone while reducing the risk of cyclic water stress that with several types of drippers which can be influenced differently with air injection effecting on the efficiency of the irrigation system which intended purpose.

Carrot crop is an important short duration root vegetable grown for fresh market human food in Egypt. Lack of soil oxygen directly affects root growth because among plant physiologists that the air relations of roots have an extremely important bearing on both the vegetative and the reproductive phases of plant growth for its direct influence on the absorption of water and on the absorption of nutrient ions from the soil solution, as well as on the more direct respiratory requirements of the roots as needed for the continual proliferation of new root tissue and root hairs. It has been shown many times that on submerged soils and soils impermeable to air, most plants develop poorly or die early Durell, (2019).

For these reasons, the objective of this investigation was to evaluate the feasibility of air injection into subsurface drip irrigation system as best management within different lateral types (Gr 30, 50 cm, T tape and Leaky pipe) on carrot crop production.

Materials and Methods

An open field experiment was carried out through installing a subsurface drip irrigation system that combined different lateral types at 20 cm soil depth and an air injection using a modified Venturi that slowly mixes air with the water delivered and then injected within the active root zone.

Location site, crop details and soil description

This study was performed in open field of Dokki side, belongs to the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research Center (ARC), at El-Giza Governorate, Egypt which situated at 30° 03` N latitude, 31° 20` E longitude and mean altitude 70 m above sea level. The experimental area has an arid climate condition with cool winters and hot dry summers and the monthly mean climatic data for both growing seasons of 2017 and 2018 which summarizes in Table (1). Daily soil water balance and crop water requirements were estimated with a computer software IRRI-CLAC program. Daily weather data was used to calculate reference evapotranspiration (ET_o) according to Penman–Monteith equation. Water flow meters were fixed in each treatment to control the amounts of irrigation water delivery (L/m^2). All the experimental plots received the same amount of water by a gate valve (16 mm) that was fixed in each head laterals line.

The carrots (*Daucus carota* L.), cv. 'Kuroda Max' from Takii Seed Company was directly sown on 20 September in both growing seasons of 2017 and 2018. Plants were declined 15 cm within and between rows, after established and appearance of the first two true leaves. All the tested air injection and different lateral types were fertilized with the recommended NPK fertilizers per faddan at the rates of 150 kg ammonium sulphate (20.5% N), 150 kg super phosphate (15.5% P_2O_5), 150 kg potassium sulphate (48% K_2O) and and 5 m^3 of compost. The amounts of N and K fertilizers for each plot were divided into three doses, which applied were every 21 days after planting while the P fertilizer was applied at planting time. All the other agriculture practices were performed according to the standard recommendations for commercial growers, by Carrots cultivation guide, (2014). The soil at the experimental site is classified as a clay soil and the physical and chemical analyses of the soil, before adding the mixed fertilizer were presented in Table (2) that estimated according to A.O.A.C., (2005).

Table 1: Monthly growing season climatic data for the experimental site.

Month		First season				Second season			
		Sep.	**Oct.**	**Nov.**	**Dec.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Temp. **C°**	Max.	38.8	36.9	27.4	23.5	37.2	35.3	28.3	22.8
	Min.	18.2	14.1	9.9	5.8	23.8	13.1	12.1	7.0
RH_AVG %		53.0	57.0	65.0	67.0	56.0	59.0	65.0	68.0
Wind speed (m/sec)		0.6	0.4	0.3	0.3	0.9	0.6	0.4	0.4
Soil temp. AVG C°		27.3	24.2	20.1	17.7	27.9	25.4	21.5	17.0
Radiation MJ/m^2		601	429	294	256	438	420	319	268
Et_o mmday^{-1}		4.1	2.6	1.6	1.2	3.9	2.8	1.7	1.2
Total water consumptive use (L/m^2)		354.69				274.77			

Table 2: Soil physical and chemical properties for experimental area.

Soil depth	Texture	Sand (%)	Silt (%)	Clay (%)	Bulk density (gm cm^{-3})	EC 1:5 (dS m^{-1})	pH (1:2.5)	Total $CaCO_3$ (%)
00-30	Clay	38.6	4.3	57.1	1.2	3.2	7.9	3.6

Experimental design and treatments:-

Subsurface laterals were placed 20 cm under the soil surface in a trench, then the trenches were carefully backfilled with the previously removed soil. A modified Venturi with an internal diameter of 1 inch was installed in the mainline to slow suction the air to be mixed with irrigation water and carefully injected into the subsurface irrigation system (Fig. 1). The venturi, injector gas inlet port was fitted with supplying units of (spring, ball sealer, seal and gas input nozzle) to prevent the laterals of press under the soil. A gate valve was installed between in and out Venturi unit to adjust the pressure between them, and allow the air injected within water flow. The uniformity of air injection was performed using Multi-parameter analyser (Eijkelkamp 18.28), with accomplished rate of 12% by volume according to Bhattarai *et al.* (2004) using a graduated gate valve that attached with the venturi orifice to careful mixing air with 94% air emission uniformity.

The experiment was set up in a split plot design where, with and without aeration was applied as the main plot and four treatments of lateral types (Gr 30, 50 cm, T tape and Leaky pipe) were applied as sub main with three replicates of 15 x 1 m plot size.

Components of subsurface drip irrigation system:-

The layout of the experimental subsurface drip irrigation system with air injection unit was illustrated in (Fig. 1) and the description of the components was explained as followed:-

1. Control head (C.H.):- C.H. is located at the water source supply. It consists of pump unit, pressure gauge, non-return valve, screen filter, control valves, pressure regulator, and air injector.
2. Mainlines (M.L.):- M.L. was made from UPVC pipe, having 50 mm diameter, used to deliver water from the source to the sub-main.

3. Sub-main line (S.M.):- S.M. was made from UPVC pipe, having 32 mm diameter, used to deliver water from the source to the Lateral.
4. Lateral lines: - They were made from LDPE, 16 mm diameter with built-in emitters 45 m length.
5. Air injector unit: - was made from UPVC pipe, having 1 inch internal diameter, used to deliver air to the emitters within active root zoon.

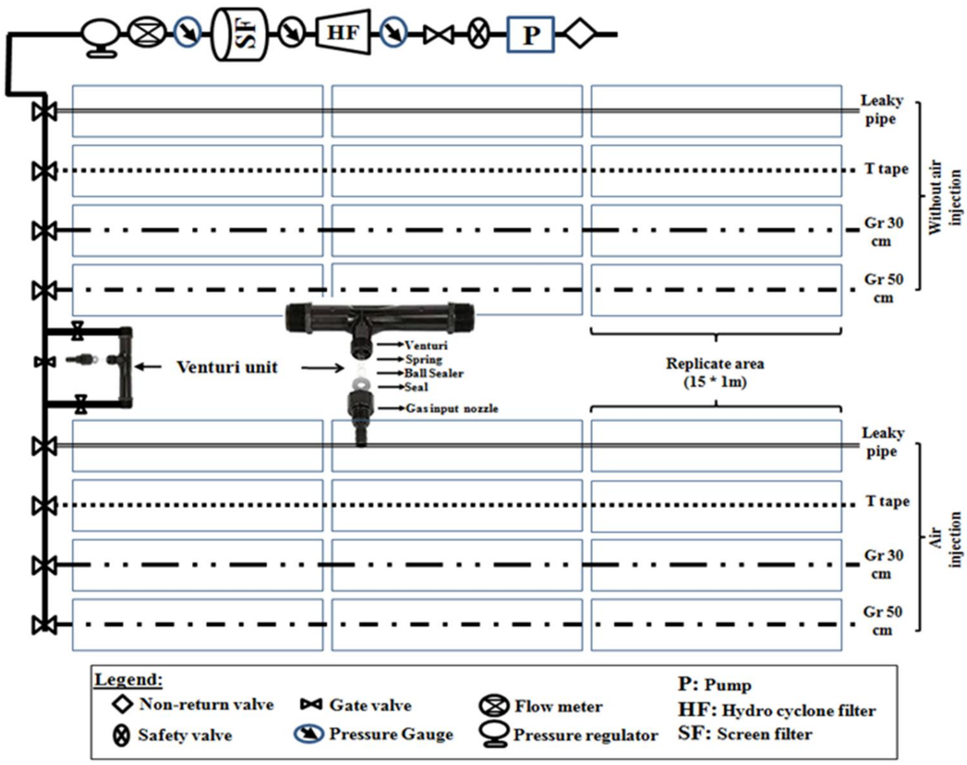
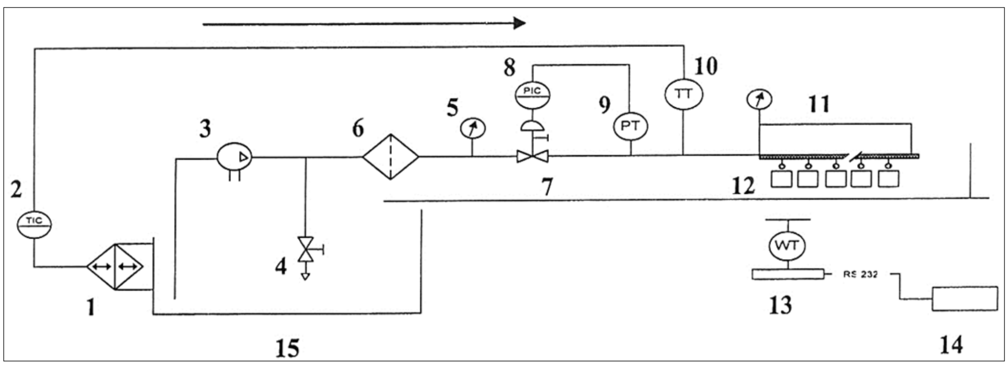


Fig. 1: Hydraulic diagram of the micro-irrigation system, Venturi air injection unit and treatments.

Evaluation parameters:-

A hydraulic test bench was used to compare and evaluate the different drip irrigation systems before and after end of the experimental as shown in Fig. (2):-



1- Temperature conditioning
2- Temperature regulator;
3- Multi stage pumping unit;
4- Manual discharge valve
5- Direct reading pressure gauge
6- Strainer filter
7- Pressurized air regulating valve
8- Compressor
9- Pressure transmitter
10- Temperature transmitter
11- Lines of pipes including tested emitters (3 m)
12- Water collectors for each emitter in test
13- Weighing scale
14- Personal computer; and
15- Water tank.

Fig. 2: Trickle irrigation test facility.

Methods of calculation:-

Pressure-flow relationships:

The emitter discharge is usually characterized by the relationship between discharge, pressure and an emitter discharge exponent. The equation for emitter flow that has been used by many researchers (Keller and Karmeli, 1974) can be expressed as:

$$q = kp^x$$

Where:

q = emitter flow rate, l/h,
k = constant of proportionality that characterizes each emitter.
p = operating pressure, bar, and
x = emitter discharge exponent that characterizes the flow regime.

The pressure influence on emitter discharge variation can be presented in two ways, either directly as the average of emitter discharge or as a percentage of discharge change that occurs at the actual operating pressure and pressure of 1 bar with the same water temperature, divided by the discharge at pressure of 1 bar according to AENRI and MSAE, (2002) as follows:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} * 100$$

Where:

q_{var} = the emitter flow variation, (%);
q_{max} = maximum emitter flow, (l/h), and
q_{min} = minimum emitter flow, (l/h).

In general criteria for $q_{var.}$ values are; 10-20 % acceptable; greater than 20%, not acceptable according to ASAE (1996).

Emitter manufacture's coefficient of variations:

The manufacture's coefficient of variation "CV" indicates the unit to unit variation in flow rate for a given emitter. The emitter manufacture's coefficient was calculated by measuring the discharge from a sample of the new emitters according to AENRI and MSAE, (2002) as follows:

$$CV = s/q_a$$

Where:

CV= manufacturer's coefficient of emitter variation;
q_a= average flow rate (l/h), and
s= standard deviation of emitter discharges rates at a reference pressure head.

Statistical uniformity Coefficient (CU):

Statistical uniformity was recommended for drip irrigation lateral line (Bralts *et al.,* 1981), and calculated as follows:

$$CU = 100(1-CV)$$

Where:

CU = statistical uniformity coefficient, %, and
CV = manufacturer's coefficient of emitter variation.

Emission uniformity (Eu):

Emission uniformity is used to indicate performance for emitters. Values were calculated according to the following equation (Keller and Karmeli, 1974).

$$Eu = (q_n/q_a)100$$

$$Eua = 1/2\left(\frac{q_n}{q_a} + \frac{q_a}{q_x}\right)100$$

Where:

Eu = emission uniformity, %,
Eu_a = absolute emission uniformity, %,
q_x = average of the highest 1/8 of the emitter flow rate, l/h,
q_n = average of the lowest 1/4 of the emitter flow rate, l/h, and
q_a = average of all emitter flow rate, l/h.

All of the subsurface dripper, Gr 30 cm 50 cm, T tape and Leaky pipe were evaluation before used as show in the (Table 3):-

Table 3: Performance of subsurface dripper according to ASAE, (1996).

Pressure (bar)		**0.50**	**0.75**	**1.00**	**1.25**
Flow rate (l/h)	Gr 30 cm	2.5996	3.3300	3.9676	4.2196
	Gr 50 cm	3.1188	3.8776	4.0488	4.0808
	T tape	1.2903	1.5647	1.8180	2.0493
	Leaky pipe	6.3566	10.5066	13.8826	21.540

Measurements:-

Soil water pattern:-

Water pattern and distribution within the soil around the emitters of different laterals were determined, by taken some of soil samples by hand auger from different distances and depths around the emitter Bohm's method (1979). Each individual sample was weighed with mass of empty clean can and lid (g), thin drying at 105 C° at 24 h, thin reweigh to determine the different between them (weighing method). The water pattern was described using computer software Surfer program version 8.

Soil nutrient availability:-

After harvest available nutrient within 30 cm soil profile were extracted except N by $NH_4HCO_3^-$ DTPA as described by Soltanpour and Schwab (1977). While, Available nitrogen was extracted by 2N KCl and it was determined by Kjeldahl method according to Black (1965), Potassium was determined by a flame photometer, according to Page *et al.* (1982). Fe, Mn, Cu and Zn were determined by using Atomic Absorption (model GBC 932).

Crop parameters:-

A sample of three plants were taken from each treatment replicate to measure the physical properties of plant height (cm), Number of leaves per plant, Vegetative fresh weight (g), Root fresh weight (g), Length (cm), Diameter (cm) and Firmness was measured using Magness and Ballouf pressure tester. The chemical properties of Chlorophyll (Spad) was determined using (Minolta chlorophyll meter Spad-501), Vegetative dry weight (g), Root dry weight (g), Total soluble solid (TSS) was recorded using hand refractometer, Total carotenoid content (mg 100 g^{-1}), Total sugar content (mg 100 g^{-1}) and Root fiber (%) were determined. Yield quantity and quality of Shelf life and total yield m^{-2} g were measured. Water indicators included Water use efficiency kg m^{-3} and Water economy kg m^{-3} was calculated.

Statistical analyses:-

The collected data were subjected to combined analysis of variance (ANOVA) of split plot design (Gomez and Gomez, 1984). Levene test (1960) was run prior to the combined analysis to test the homogeneity of individual error terms. Least significant difference (LSD) test was used to detect the significant differences among means at 0.05 probability levels and Duncan's multiple range test was conducted at a significance level of $p<0.05$.

Results and Discussion

Evaluation of subsurface drip irrigation system:-

Both of Figure 3 and Table 4 show the experimental results of different dripper's performance and give the emitter flow-pressure relation as well as the regression equation at the end of the experimental. The data showed that there is a close relationship between emitter flow rates and pressure for the four samples (built-in emitters Gr 30, 50 cm, Leaky pipe and T tape). In addition, data indicated that according to ASAE standard, all of the built-in emitters under study subsurface drip irrigation type were acceptable according to its specification. The results also indicated that, air injection can effect on the performance of the subsurface drip irrigation system. According our results, we can exactable that air injection can observably enhance the performance of Gr 30 cm and leaky pipe types, and the results are compatible with both (Bhattarai *et al.,* 2010 and Abuarab *et al.,* 2019). The result values of all tested parameters like CV, Eu, and q_{var} with air injection clearly improve performance of built-in emitters Gr 30 cm and leaky pipe with more used, in contrary those of two other laterals of Gr 50 cm and T tape.

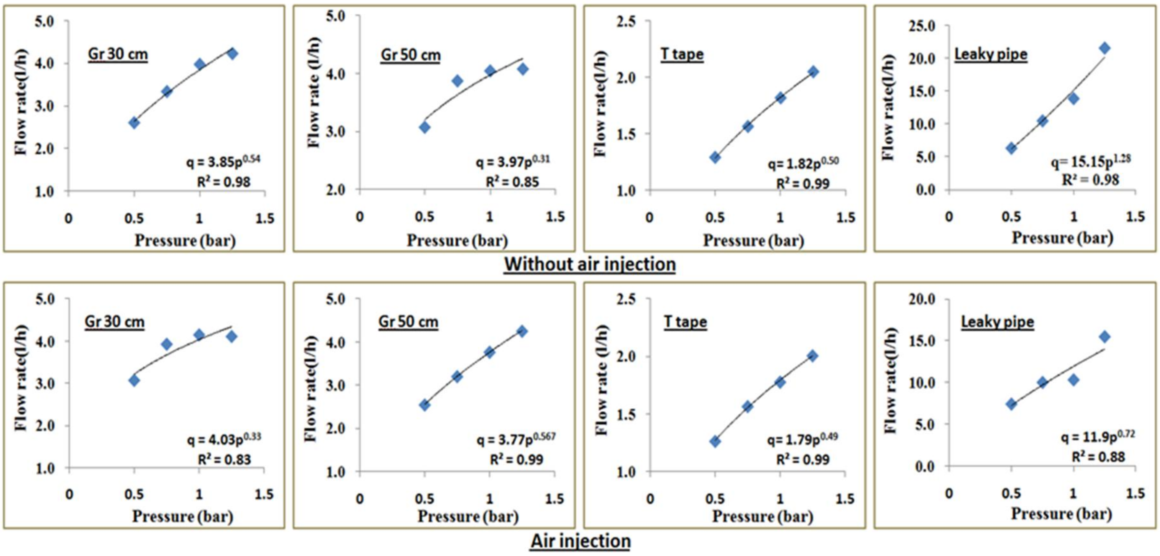


Fig. 3: Polynomial regression equations for performance of each subsurface dripper with the coefficients (R^2) in the end of the experimental.

Table 4: Hydraulic characteristics of different subsurface drippers in the end of the experimental according to ASAE, (1996).

Hydraulic characteristics		Without air injection				Air injection			
		Gr 30 cm	Gr 50 cm	T tape	Leaky pipe	Gr 30 cm	Gr 50 cm	T tape	Leaky pipe
(CV %) at (1 bar)	value	4.75	3.33	2.18	5.6	3.11	3.09	5.6	4.39
	ASAE standard	Excellent	Excellent	Excellent	Very good	Excellent	Excellent	Very good	Excellent
Parameters	Emitter discharge exponent (x)	0.54	0.31	0.50	0.77	0.33	0.56	0.53	0.72
	Flow coefficient(k)	3.85	3.97	1.82	10.00	4.03	3.77	1,79	11.90
Emission uniformity (Eu %)	value	94.81	97.06	95.7	92.57	96.1	95.61	93.77	95.23
	ASAE standard	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Emitter flow variation (q_{var} %)	Value	12.95	8.68	6.85	12.76	7.89	8.15	16.93	10.01
	classification	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Soil water pattern:-

Figure 4 shows the effect of air injection and various types of subsurface drippers on contour lines of soil water pattern and distribution within three soil sectors of carrots root zone by using Surfer 8 computer software for simulating wetting pattern. The contour lines of water distribution under drippers of different types of subsurface laterals were more closer at Gr 30 cm and Leaky pipe than the other type of treatments, which led to the emergence of a large wetted area within root zone around the field capacity without moisture stress or salt impacts. In addition, the boundary layers of salt were isolated as affected by frequency of emitter discharge in Gr 30 cm and Leaky pipe (small distance between emitters) compared to other long-distance laterals. The extent of soil wetted volume in an irrigation system determines the sufficient amount of water needed to wet the root zone. Excessive emitter spacing will cause inadequate distribution of water in the root zone (Neetha, 2017).

The results in the same table also show that there was an effect on the soil water pattern and distribution by injecting air into the root zone using subsurface irrigation system. Also, the soil volume affected by air is probably limited to a chimney column directly above the emitter outlet so, soil water movement and distribution depends on the type and number of emitters and their discharge, which carry a different volume of air injection. These results are agreement with Goorahoo *et al.,* (2002); Huber, (2000); Bhattarai *et al.,* (2004), Bhattarai *et al.,* (2005); Abuarab *et al.,* (2013) and Vyrlas *et al.,* (2014).

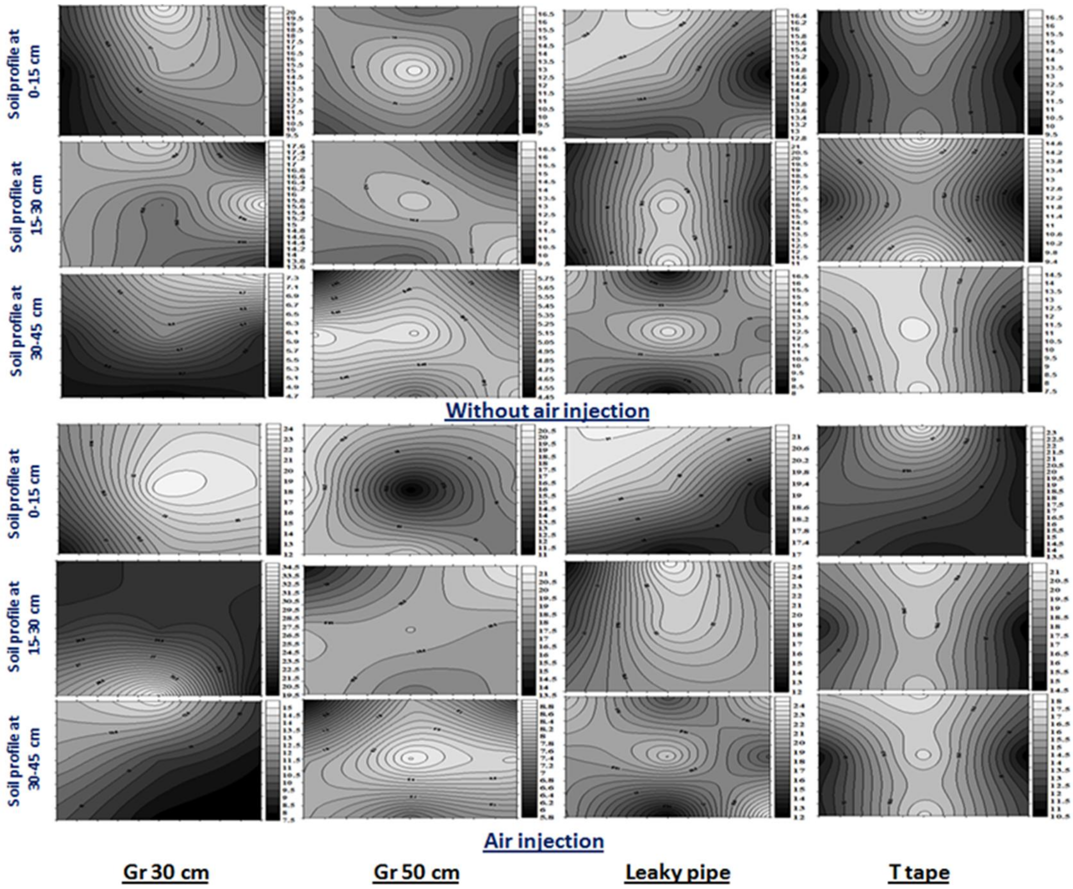


Fig. 4: The contour lines of soil water pattern and distribution at different soil depths as affected by various types of subsurface drippers and air injection.

Soil nutrient availability:-

The results in table (5) show that application of air injection exhibits a clearly exceeded of available macronutrients nutrients N, P and K at the different types of subsurface drippers against without air injection practices, while there was a decrease in micronutrients availability (Fe, Mn, Cu and Zn) with air injection but this decrease didn't exceed the critical level of soil micronutrients especially with lateral of GR 30 cm and leaky pipe laterals as Soltanpour and Schwab (1977) reported. This mainly due to that, aeration directly affects the availability of N, Mn, and Fe and indirectly affects the availability of many other nutrients, in a well-aerated soil, the supply of oxygen is sufficient to maintain normal aerobic respiration by soil microbes while, oxygen is an important example of a strong oxidizing agent, since it rapidly accepts electrons from many elements thus it can oxidize both organic and inorganic substances all aerobic respiration requires O_2 to serve as the electron acceptor as living organisms oxidize organic carbon to release energy for life. However, if soil is poorly aerated due to excess water or compaction, some of the soil microbes will switch to anaerobic respiration and use alternatives to oxygen (O_2) to breathe. Some of these alternatives to O_2 include plant available nitrate (NO_3^-) that is converted to gases and lost to the atmosphere as called denitrification. In addition, during anaerobic respiration, some microbes will convert unavailable forms of Fe, Mn and Cu oxides into soluble, plant available forms as called reduction (Manitoba, 2013). Oxygen also has a dramatic impact on microbial activity and rate of decomposition applying compost a reservoir of many nutrients furthermore, the hydrogen ions release from compost exchanged with K on exchange sites of the clay micelle and also P from its unavailable compounds (Abd El- Rahman, 2012). Microbial decomposition is greatest at moisture contents near field capacity because at field capacity, soils tend to provide a balance of both air and water. Nevertheless, it tends to be slower in case of insufficient soil aeration. Also, the dynamics and fate of agrochemicals in the soil with aerated water irrigation differs from those of non-aerated water irrigation, e.g. oxygen provided greater salt exclusion by roots compared to non-aerated treatments (Bhattarai *et al.,* 2010). For these direct or indirect reasons, many nutrients can be in soluble form and easy to plant uptake by roots of crops in case of air condition. These findings are in confirmed with Nyle and Ray, (2002) who reported that soil aeration helps determine the specific chemical species present and, in turn, the availability, mobility, and possible toxicity of various elements in soils.

The results observed also that, there was a beneficial effect of aeration appeared with subsurface lateral of GR 30 cm in regard to nutrients availability followed by Leaky pipe, this increase may be due to the uniformity of soil moisture distribution and content within root zone that enhanced the large wetted area expand of soil sector width around the field capacity without moisture stress or salt impacts thus, aeration allows water to move through soil, carried the nutrients to the plants furthermore, a good aeration in soil allows roots to develop or penetrate soil that can facilitate nutrients and water uptake. These results agree with Manitoba (2013) who indicated that moist soils increase the rate of diffusion because soil water is the pathway for ion movement and the thickness of water films determines the ease of nutrient movement to the root.

Table 5: Effect of air injection and different types of irrigation lateral on macro and micronutrient availability within 30 cm soil sector.

Elements	Air injection				Without air injection			
Lateral types	GR 50 cm	T tape	Leaky pipe	GR 30 cm	GR 50 cm	T tape	Leaky pipe	GR 30 cm
N ppm	116.7	114.3	149.3	168.0	98.0	93.3	100.3	128.3
P ppm	6.01	3.55	6.98	7.24	3.64	3.40	3.67	4.37
K ppm	8.67	7.05	9.70	9.85	7.87	7.57	8.59	9.00
Fe Mm/l	0.173	0.147	0.187	0.203	0.193	0.183	0.197	0.233
Mn Mm/l	0.177	0.173	0.207	0.217	0.207	0.193	0.210	0.213
Cu Mm/l	0.340	0.330	0.341	0.345	0.350	0.333	0.370	0.393
Zn Mm/l	0.383	0.353	0.400	0.417	0.397	0.357	0.403	0.447

Crop parameters:-

Several interesting differences were found in carrot crops as affected by different types of subsurface drippers understudy with and without air injection which can clearly pronounced in the taken picture Fig. (5). General observation that, the growing carrot plants were markedly affected by air injection into subsurface irrigation under the different types of drippers under study in the two seasons of the experiment. This result can refer to more direct respiratory requirements of the roots as needed for the continual proliferation of new root tissue and root hairs led to a direct influence on the absorption of water and nutrient ions from the soil solution which effect on plant growth consequently Durell, (2019). These results agree with (Bhattarai *et al.,* 2004) who found that increased oxygen enhances K and P uptake. Also adequate aeration on the root zone soil create a favorable conditions that encouraged the availability of macronutrient in the soil.

Other possibility caused this observation of progressive root growth as a result of increasing the efficiency of subsurface irrigation system with air injection application within the two seasons. While, it is clear to detect from the picture that the application of air injection within lateral of GR 30 cm and leaky pipe system led to a high yield and best quality of carrot crop with air injection than without. This result mainly due to the uniformity of soil moisture distribution and content within root zone with air injection.

On the other hand, there is other evidence to root growth sensitivity to O_2 deficiency noticeable from this picture in case without air injection under different types of subsurface drippers, which reduces root elongation and leads to a root system incapable of sustaining water and nutrient requirements. This mainly rendered to that plant roots require adequate oxygen for root respiration as well as for sound metabolic function of the root and plant meanwhile, deficiency in oxygen cause dramatically reduces the efficiency of cellular adenosine tri phosphate (ATP) production, which has diverse ramifications for cellular metabolism and developmental process (Chen *et al.*, 2011). This result matched with those obtained researchers involved vegetable crops by (Bhattarai *et al.,* 2006 Goorahoo *et al.,* 2008, Abdel-Aziz, 2017) they observed increases in tomato, strawberry and carrot yields, improvements in growth characteristics and in soil quality with root zone aeration.

We can say; air injection increase the soil ability to hold the oxygen content with irrigation water within root zone hence, carrot plants will grow healthier with most suitable nutrient-water conditions compared without air injection. This response will increase root growth as well as the growth parameter hence, increasing the water indicators (Heuberger *et al.,* 2001, Chen*, et al,* 2011, Bhattarai *et al.,* 2010 and Abuarab *et al.,* 2013).

{The characters of A, B, C and D appear the laterals of Gr 50 cm, T tape, Leaky pipe and Gr 30 cm without air injection respectively where the characters of E, F, G and H appear the laterals of T tape cm, Gr 30, Leaky pipe and then Gr 50 cm with air injection respectively two growing seasons}

Fig. 5: Carrot growing variation according to the air injection and different types of subsurface drippers during two growing seasons of 2017-2018.

a. Growth parameters:-

Data reported in Table (6) show plant growth factors as (Plant height - Number of leaves - Vegetative fresh weight - root fresh weight (g) - Root length and Diameter (cm) - Root firmness).

Results indicated that irrigation system with GR 30 cm has the best significantly effect on all plant growth factors except root firmness, followed by leaky pipe, GR 50 cm and T tape, respectively as shown in Table (6). The results of the statistical analysis also showed that the treatment of the subsurface irrigation system of GR 50 cm gave the highest value of root firmness followed by GR 30 cm and then T tape and leaky pipe with no difference between them.

Irrigation system in the second season as the same results as in the first season in all plant growth factors, the highest values are obtained at GR 30 cm followed leaky pipe then GR 50 cm then T tape, except root firmness GR 50 cm gave the highest value then GR 30 cm followed by leaky pipe and T tape with no significant between them.

One can extrapolate from the Table (6) air injection was significantly the best in all plant measurements values except root firmness that without air was the highest.

In regard to the interaction effect, the highest values of most plant growth factors (plant height - root fresh weight (g) - root length) were obtained by air injection with subsurface lateral of GR 30 cm, while number of leaves, vegetative fresh weight and root diameter were obtained by air injection with leaky pipe system, on the other hand the highest value of root firmness was obtained by subsurface lateral of GR 50 without air injection that observed in the first season. While in the second season, data observed that, subsurface lateral of GR 30 cm with air injection achieved the significant highest values of all studied growth factors except root firmness, this results mainly due to the increasing of subsurface lateral GR 30 cm efficiency and the enhancement of the soil condition with air injection application which more observed in the second season.

This could be explained by the fact that plant roots require adequate oxygen for root respiration as well as for sound metabolic function of the root and the whole plant (Payero *et al.,* 2008 and Abdel-Aziz, 2017).

Table 6: Effect of different types of irrigation lateral, air injection and their interaction on growth parameters of carrot plants.

Treatment		Plant height cm		Number of leaves plant^{-1}		Vegetative fresh weight (g)		Root fresh weight (g)		Root length cm		Root diameter mm		Root Firmness	
						First season									
Lateral type	GR 50 cm	32.5	C	14.8	B	23.3	C	42.7	B	17.7	B	28.2	B	4.6	A
	T tape	31.3	D	12.3	C	20.2	C	27.2	C	16.2	C	27.8	B	4.1	C
	Leaky pipe	36.8	B	17.7	A	32.7	B	43.2	B	17.3	B	32.3	A	4.3	C
	GR 30 cm	37.7	A	18.2	A	38.0	A	51.5	A	20.3	A	31.5	A	4.4	B
Air Injection	With	35.8	A	17.0	A	33.5	A	50.4	A	19.0	A	31.8	A	4.2	B
	Without	33.4	B	14.5	B	23.6	B	31.8	B	16.8	B	28.2	B	4.5	A
Interaction	GR 50 cm*With	34.0	bc	13.0	c	34.0	c	43.3	c	19.7	ab	30.7	c	4.4	bc
	T tape*With	32.3	c	13.3	c	18.3	e	32.7	e	17.3	a	28.0	c	4.2	c
	Leaky pipe*With	37.0	ab	24.0	a	44.0	a	49.3	b	18.3	a	36.0	a	4.1	d
	GR 30 cm*With	39.7	a	17.7	b	37.7	b	76.3	a	20.7	a	32.3	bc	4.2	c
	GR 50 cm*Without	31.0	c	16.7	bc	12.7	f	42.0	c	15.7	b	25.7	e	4.8	a
	T tape*Without	30.3	c	11.3	c	22.0	d	21.7	g	15.0	b	27.7	de	4.1	d
	Leaky pipe*Without	36.7	ab	11.3	c	21.3	de	37.0	d	16.3	b	28.7	c	4.5	b
	GR 30 cm*Without	35.7	b	18.7	b	38.3	b	26.7	f	20.0	a	30.7	c	4.6	b
						Second season									
Lateral type	GR 50 cm	34.3	B	12.33	B	45.6	C	55.00	B	18.4	B	33.8	C	4.6	A
	T tape	31.5	C	11.67	B	44.6	C	56.33	B	19.1	B	32.0	C	3.9	C
	Leaky pipe	36.2	A	16.67	A	49.5	B	95.33	A	20.6	A	34.2	B	4.0	C
	GR 30 cm	36.8	A	16.67	A	52.0	A	89.00	A	21.0	A	37.0	A	4.2	B
Air Injection	With	35.9	A	15.3	A	54.8	A	87.8	A	21.9	A	36.7	A	3.9	B
	Without	33.5	B	13.3	B	41.1	B	60.1	B	17.7	B	31.8	B	4.4	A
Interaction	GR 50 cm*With	36.0	ab	13.0	bc	51.8	bc	65.0	c	19.5	b	35.0	b	4.4	b
	T tape*With	31.3	c	11.3	c	48.9	c	55.3	cd	21.2	b	32.3	c	3.8	d
	Leaky pipe*With	38.0	a	17.0	b	63.0	a	99.3	b	22.5	ab	36.0	b	3.5	d
	GR 30 cm*With	38.3	a	20.0	a	55.3	b	131.3	a	24.3	a	43.3	a	4.0	c
	GR 50 cm*Without	32.7	bc	11.7	c	39.5	de	45.0	d	17.3	c	32.7	c	4.7	a
	T tape*Without	31.7	c	12.0	c	40.3	de	57.3	c	16.9	c	31.7	c	4.0	c
	Leaky pipe*Without	34.3	a	16.3	b	36.0	e	91.3	b	18.6	bc	32.3	c	4.4	b
	GR 30 cm*Without	35.3	a	13.3	b	48.7	c	46.7	d	17.8	c	30.7	c	4.4	b

* Similar letters indicate nonsignificant at 0.05 levels.

b. Chemical characteristic:-

Measurements of chemical characteristics for carrot crop as (Chlorophyll (Spad) - Vegetative dry weight (g) - Root dry weight - Total soluble solid (TSS) - Total carotenoid and Sugar content (mg/

100 g) - Root fiber (%)) under different subsurface drippers and air-conditioning and without air at the end of the two studied seasons are presented in Table (7). From the tabulated data, it is obvious that, air injection has a strong significant effect on all studied chemical characteristics while there were significant enhancement for all the parameters compared with without air injection. The results also showed that, the best transactions in chemical characteristics measurements of chlorophyll content, vegetative dry weight, total sugar content and root fiber were achieved under the subsurface drip irrigation leaky pipe and GR 30 system practice, in both seasons.

Table 7: Effect of different types of irrigation lateral, air injection and their interaction on chemical characteristic of carrot plants.

Treatment		Chlorophyll Spad		Vegetative dry weight (g)		Root dry weight (g)		Total soluble solids (TSS)		Total carotenoid mg 100 g^{-1}		Total Sugar Content mg 100 g^{-1}		Root fiber %	
First season															
Lateral type	GR 50 cm	33.17	B	4.63	B	5.76	B	9.00	C	15.02	D	4.75	B	21.63	A
	T tape	31.33	C	4.27	B	3.72	C	8.60	D	15.57	C	4.57	B	15.58	C
	Leaky pipe	33.83	B	6.48	A	6.70	A	10.67	A	17.07	A	5.13	A	18.23	B
	GR 30 cm	35.50	A	7.44	A	5.87	B	9.82	B	15.92	B	4.95	A	21.68	A
Air Injection	With	35.6	A	6.9	A	6.5	A	10.1	A	16.6	A	5.0	A	21.1	A
	Without	31.3	B	4.6	B	4.5	B	8.9	B	15.2	B	4.7	B	17.5	B
Interaction	GR 50 cm*With	34.3	b	6.4	b	5.8	c	2.2	b	15.4	c	4.9	b	24.1	a
	T tape*With	33.7	b	4.2	c	4.2	d	9.2	c	16.4	b	4.7	c	13.9	e
	Leaky pipe*With	35.0	b	8.8	a	9.4	a	8.7	a	18.0	a	5.4	a	24.2	a
	GR 30 cm*With	39.3	a	7.9	ab	6.7	bc	12.2	ab	16.6	b	5.2	ab	22.1	b
	GR 50 cm*Without	32.0	b	2.8	e	5.8	c	10.4	c	14.7	d	4.6	c	19.2	c
	T tape*Without	29.0	c	4.3	c	3.3	e	8.8	c	14.7	d	4.5	c	17.3	d
	Leaky pipe*Without	32.7	b	4.1	c	4.0	d	8.5	b	16.1	bc	4.9	b	12.3	d
	GR 30 cm*Without	31.7	bc	6.9	b	5.0	cd	9.2	bc	15.2	cd	4.7	bc	21.3	b
Second season															
Lateral type	GR 50 cm	31.33	B	7.44	B	8.53	B	8.82	B	15.37	C	4.85	B	22.33	A
	T tape	27.83	C	6.68	C	5.13	C	8.30	B	14.87	C	4.75	B	15.12	C
	Leaky pipe	34.67	A	8.79	A	9.97	A	10.73	A	15.97	A	5.12	A	18.30	B
	GR 30 cm	34.50	A	9.18	A	7.00	B	10.00	A	16.07	B	5.02	A	21.68	A
Air Injection	With	33.5	A	9.4	A	9.6	A	10.0	A	16.3	A	5.1	A	22.2	A
	Without	30.7	B	6.7	B	5.7	B	8.9	B	14.8	B	4.8	B	16.5	B
Interaction	GR 50 cm*With	33.0	cd	8.7	bc	9.8	b	9.4	b	15.7	c	4.9	b	24.6	a
	T tape*With	28.0	e	7.3	c	5.6	d	9.0	bc	16.1	bc	4.8	bc	17.3	c
	Leaky pipe*With	35.3	ab	10.2	a	13.9	a	11.2	a	16.4	b	5.2	a	24.9	a
	GR 30 cm*With	37.7	a	11.4	a	9.1	b	10.6	a	17.1	a	5.3	a	22.1	b
	GR 50 cm*Without	29.7	e	6.2	d	7.2	c	8.3	c	15.1	d	4.8	c	20.1	b
	T tape*Without	27.7	e	6.1	d	4.7	d	7.6	c	13.6	e	4.7	c	13.0	d
	Leaky pipe*Without	34.0	bc	7.4	c	6.1	cd	10.2	ab	15.5	cd	5.0	ab	11.7	d
	GR 30 cm*Without	31.3	de	7.0	cd	4.9	d	9.4	b	15.1	d	4.7	c	21.3	b

* Similar letters indicate nonsignificant at 0.05 levels.

Corresponding to the interaction of different types of subsurface drippers and air injection application leaky pipe and GR 30 subsurface drip irrigation types as long with air injection gave the highest values of studied chemical characteristics with no significant differences except total carotenoid and root fiber, leaky pipe system with air injection recorded the highest values of them in the first season. Meanwhile, in the second season GR 30 subsurface drip irrigation injected with air has the significantly high values of all studied chemical characteristics except root fiber that compared with no air injection which gave the lowest values of all parameters under all types of subsurface drippers understudy. The reasons for low values of carrot chemical properties with some treatments without air injection are probably linked to a sustained wetting front around emitters. These emitters impose a condition of low oxygen content in the root-dense rhizosphere surrounding emitters that impede root respiration, and negatively impact on plant uptake of water and nutrients, leading to constrained yield performance (Bhattarai *et al.,* 2010 and Durell, 2019).

c. Water indicators, yield quantity and quality:-

Water indicators as (Water use efficiency - Water economy) beside yield quantity and quality of carrot crops such (Shelf life - Total crop yield - Total marketed yield) under different types of irrigation lateral and air injection are presented in Table (8).

Table 8:- Effect of different types of irrigation lateral, air injection and their interaction on water indicators beside yield quantity and quality of carrot plants.

Treatment		Shelf life		Total yield m^{-2} g		Total Marketable yield m^{-2} g		Water use efficiency Kg m^{-3}		Water economy Kg m^{-3}	
First season											
Lateral type	GR 50 cm	40.2	B	1289.7	B	966.57	B	3.37	B	2.41	B
	T tape	24.0	C	1268.2	B	831.4	C	3.32	B	2.21	B
	Leaky pipe	48.0	A	1559.9	A	1251.4	A	4.13	A	2.95	A
	GR 30 cm	40.5	B	1518.0	A	1196.9	A	3.94	A	2.74	A
Air Injection	With	48.1	A	1534.0	A	1276.8	A	3.98	A	2.79	A
	Without	28.3	B	1283.9	B	846.3	B	3.40	B	2.37	B
Interaction	GR 50 cm*With	43.3	b	1458.9	bc	1192.1	b	3.81	c	2.51	bc
	T tape*With	29.7	cd	1349.3	c	1012.5	c	3.52	d	2.33	c
	Leaky pipe*With	72.7	a	1714.7	a	1454.8	a	4.48	a	3.20	a
	GR 30 cm*With	46.7	b	1613.2	ab	1447.9	a	4.12	b	3.12	a
	GR 50 cm*Without	37.0	bc	1120.6	d	741.0	de	2.92	e	2.32	c
	T tape*Without	18.3	d	1187.1	d	650.4	e	3.12	de	2.09	d
	Leaky pipe*Without	23.3	d	1405.1	d	1047.9	bc	3.79	c	2.71	b
	GR 30 cm*Without	34.3	c	1422.7	cd	946.0	cd	3.77	c	2.36	c
Second season											
Lateral type	GR 50 cm	55.0	B	1318.2	B	842.0	B	3.23	B	2.47	B
	T tape	41.0	B	1146.7	C	810.6	B	3.24	B	2.27	B
	Leaky pipe	80.2	A	1470.9	A	1153.0	A	3.82	A	2.90	A
	GR 30 cm	73.0	A	1427.1	A	1184.1	A	3.77	A	2.76	A
Air Injection	With	74.1	A	1438.9	A	1174.6	A	3.86	A	2.83	A
	Without	50.5	B	1242.6	B	820.2	B	3.17	B	2.37	B
Interaction	GR 50 cm*With	56.0	c	1354.7	bc	1119.7	bc	3.75	bc	2.71	b
	T tape*With	49.0	cd	1252.9	d	927.4	cd	3.58	c	2.51	c
	Leaky pipe*With	81.0	b	1592.2	a	1254.3	ab	4.16	a	3.09	a
	GR 30 cm*With	110.3	a	1555.9	ab	1396.9	a	3.96	ab	3.00	a
	GR 50 cm*Without	54.0	c	1281.8	d	564.2	d	2.71	d	2.22	d
	T tape*Without	33.0	d	1040.5	d	693.7	d	2.90	d	2.03	d
	Leaky pipe*Without	79.3	b	1349.7	cd	1051.7	c	3.48	c	2.71	b
	GR 30 cm*Without	35.7	d	1298.3	d	971.2	c	3.58	c	2.51	c

* Similar letters indicate nonsignificant at 0.05 levels.

The results showed that in all the following calculations, air injection was better than without air injection while it refer to the significant increase in all parameters with air injection. This trend may be led to that soil aeration helps to improve the growth and spread of roots, thus increasing the ability of the plant to benefit from the added irrigation water and thus improving the water productivity and reducing total irrigation requirements. On the other hand, a lack of oxygen in the soil limits the growth of the roots, which is reflected in the cycle of the root's total weakness and the inability to absorb water, which leads to an increase in the amount of water lost by deep percolation and thus to a significant inefficiency in the use of irrigation water (Abuarab *et al.,* 2019).

Referring to the differences between irrigation types of leaky pipe and GR 30 statically effected on shelf life, total crop yield, total marketed yield, water use efficiency and water economy, especially in the second season than GR 30 and T tape types. This favorable of two lateral types may be mainly due to slow and frequent application of water to the soil is suitable through emitters along surface drip irrigation or partially buried water delivery pipes that led to increase both water use efficiency and water economy.

Concerning the interaction effect of both different types of irrigation lateral and air injection, air injection, leaky pipe subsurface drip irrigation systems as long with air injection gave the highest significant values of all studied parameters in the first season, in the second GR 30 drip irrigation system with air injection treatment led to an increment with significant values of shelf life, total crop yield, total marketed yield, water use efficiency, water economy than other types under study at all.

This perhaps, due to the soil moisture distribution that was around field capacity and soil nutrients availability that can achieved by GR 30 lateral type with air injection, these results coinciding with Vyrlas *et al.,* (2014). Thus, we can say that, GR 30 lateral type get more efficient than without air injection. This finding is consistent with Qassim (2003) who demonstrated that to avoid surface wetting and to minimize evaporation loss associated with drip irrigation and more water use efficient and economy beside crop quality and quantity, practices such as air injection within subsurface drip irrigation should be taken in concern.

Conclusion

Air injection within irrigation systems can increase root zone aeration and add value to grower investments in subsurface drip irrigation technique. The increase in yields and potential improvement in soil quality associated with the root zone aeration implies that the adoption of the subsurface drip irrigation-air injection technology primarily as a tool for increasing carrot productivity. This study also concluded that, either Gr 30 cm lateral or leaky pipe types with air injection were suitable for carrot crop production while commercially, subsurface dripper of Gr 30 cm which most practical and inexpensive than other type and it can be used efficiently to achieve air injection inside the effective root zone, and realizing crop yield productivity and quality beside water use efficiency and water economy especially with more of using.

Future studies should focus on the available technique with low-price and preserve the pressure force within control unit of irrigation system with using different available indigenous materials for subsurface drip irrigation-air injection technology which can lead to a suitable system for different soil types and conditions in order to increase the returns of different crops production.

Depend on our results, it can be said that, air injection is a method for enhancing the performance of subsurface drip irrigation systems by adding air directly within the root zone of crop to adjust the balance of aerobic aquatic soil, especially heavy clay soils to overcome the negative effects of poor soil aeration. While, irrigation strategy should not be limited to maintain the water only, but also include a feasibility of air for enhancing the performance of the system the root zone of the plant must be well supplied with both water and oxygen.

Generally, as known drip irrigation system came a major part for developing agriculture in Egypt. So, this work plan came to add a new dimension for using subsurface drip irrigation system. Using air through drip systems added a new advantage for drip application specification in clay soil and carrot crop.

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