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Effect of Single and Double Inlet Subsurface Drip Irrigation on Corn Yield under Egyptian Condition

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ABSTRACT

The best method for applying and spreading water, as well as for providing plants with nutrients, has long been thought to be drip irrigation systems. A field experiment was carried out in 2022 during the planting season to examine the impact of drip irrigation systems on the production of maize (White Triple Hybrid 324) on the Giza research station farm, Giza governorate (18 m above sea level, 30^34/N latitude, 29˚55/E longitude). Two types of laterals (T-tape and GR) and two distinct lateral designs (double and single inlets) were assessed for use with subsurface and surface drip irrigation systems. This study's primary objective was to evaluate conventional irrigation with single and double intake irrigation in terms of soil moisture, corn yield, and water consumption efficiency under two different lateral types—GR and T-tape—with a 50-meter lateral length. The results demonstrated that, in comparison to single inlet irrigation, double inlet irrigation and the type of lateral T-tape improved irrigation water use efficiency (WUE) by increasing soil moisture content at soil profile and grain yield percentage, especially when applied under varying lateral lengths. Under the length of the lateral expansion in a drip irrigation system, the yield and water use efficiency declined. At varying lateral lengths, T-tape treatment typically resulted in increases yield, water use efficiency, soil moisture emission uniformity, and yield compared to GR treatment.

Keywords: drip irrigation – lateral - use efficiency

INTRODUCTION

The minor use of water is in agriculture, making it one of the most essential inputs in production. In the next 50 years, the total evapotranspiration from agricultural land might quadruple if consumption trends and production methods stay the same. More importantly, it is projected that there would be a need to boost water productivity. by moving to an irrigation system that is more efficient, like contemporary irrigation systems. Egypt's main source of freshwater is the Nile. The majority of Egypt's fresh water supplies are used for agriculture. 85 percent of the annual water supply and 89 percent of the Nile's flow are used by irrigated cropland. Furthermore, 80 percent of Egypt's water needs for irrigation and agriculture come from the Nile. Imam *et al*. (2015) said that the flow average velocity, emitter spacing, pipe inside diameter, emitter inside diameter, and emitter length are parameters affecting the pressure drop. Mansour. (2016) said that traditional trickle irrigation systems suffer from an unequal distribution of water and nutrients along the laterals due to a large fall in pressure at the extremities of laterals. As a result, a decline in plant growth and output displays the same pattern. Hussien. (2015) said that one of the best irrigation technologies for increasing WUE is subsurface drip irrigation (SSDI), which delivers small amounts of water at brief intervals with little to no damage. Water loss via deep percolation, runoff, and soil evaporation causes plants to absorb more water and nutrients, increasing (WUE). These issues might be resolved by subsurface drip irrigation (SSDI), which supplies water below the soil's surface and has shown promise in terms of grape productivity and water Efficiency (Ma *et al*., 2019). Hussein (2007) A double intake system offers the highest water pressure uniformity along the lateral line compared to a single inlet system. A double intake system produced the best distribution of emitter discharge, fertilizer, and other chemical treatments compared to a single inlet system. The closed drip network type double inlet achieved the greatest results in terms of distribution uniformity and also the lowest pressure drop when various dripper line lengths and kinds, whether built-in dripper or on-line dripper, were evaluated Tayel *et al*., 2019. Morad *et al.* (2020) said that when study on irrigation management for maize crops in sandy soil using three types of emitters (GR, antiroot GR, and T-tape).the optimal irrigation management strategy was utilizing compost with an antiroot GR sub-surface trickling system, which generated the best yield. The best yield came from compost used in a sub-surface trickle system with antiroot GR, however compost used in a sub-surface trickle system with t-tape gave a good production. Jahad (2010) reported that When the lateral ends are joined in a subunit (double inlet system), it is possible to outperform the single inlet system in terms of hydraulic performance and emission uniformity. By joining the ends of the laterals in the subunit, the main proposed system plan seeks to enhance the distribution pressure in the system. Utilizing and managing water resources continues to be difficult in developing countries like Egypt with semi-arid to dry climates. Maize (Zea Mays L.), which is used to make dry feed at rates up to and bread to the extent of 20%, is recognized as one of Egypt's main grain crops due to its significance in human, animal, and poultry nutrition. It is also used in a number of industries, such as the 70% extraction of oil, glucose, and fructose. With an 800,000 hectare planted area, its output in Egypt for the marketing year 2021/22 (October-September) is

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6.4 million metric tons. (USAD, 2021). Ibrahim and Soliman(2022) demonstrated that Egypt's area used for growing maize varied between two maximums: around 1657.8 thousand acres in 2003 and approximately 2335.63 thousand acres in 2018. Awwad *et al* (2023) said that using T-tape irrigation systems—more particularly, using T-tape at soil depths of 10 and 20 cm—increased agricultural production for the maize crop and, as a result, water productivity using the same amount of water as GR irrigation systems. Corn is the third most valuable grain crop next to wheat and rice (Abou El-Hassan *et al*., 2014). In Egypt, corn is one of the most leading grain crop in economic importance. Corn crop is used as human food, animal feed and pharmaceutical and industrial materials (Azizian and Sepaskhah, 2014).

The main objectives of the study are to choose the best methods to deliver water to plant (single or double inlet), the effect of the different lengths of lateral on both application methods, the consequence of the two types of lateral on both application methods and in addition to increasing water use efficiency (WUE) for corn crop under the Egyptian conditions in the case of using subsurface drip irrigation (SSDI).

MATERIALS AND METHODS

Description site

During the 2022 planting season, a field experiment was carried out at Giza research station farm, located 18 meters above sea level at 30˚34/N latitude and 29˚55/E longitude in the Giza governorate. Maize seeds (White Triple Hybrid 324) were sown on July 16, 2022. The spacing between plants' inter-row was 0.5 meter, and seeds were placed on border with a display of 0.7 meters. The flow rate discharge of the emitter is 4.0 l/h, and the distance between each dripper is 0.5 m. The subsurface irrigation system'lateral tube is located at a depth of 15 cm under three repetitions in a randomized design for the experiment.. A drip irrigation system was used to carry out the irrigation. Prior to irrigation, the amount of water applied was determined by calculating the Evapo-transpation for each treatment.In the Laboratory of the Agricultural Engineering Research Institute (AEnRI) in Dokki, Giza, soil and irrigation water were examined. According to Black (1965), random samples were taken from the experimental site's four soil layers (0–15, 15–30, 30-45, and 45–60 cm) in order to assess the mechanical and physical qualities of the soil, as indicated in table (1). The average values of the soil bulk density, permanent wilting point (PWP), field capacity (FC), saturation hydraulic conductivity (Ks), and particle size distribution were displayed in the table 1 double-ring infiltrometer was used to measure the amount of soil infiltration. Final infiltration rate was defined as saturation hydraulic conductivity. The irrigation water's chemical analysis is displayed in Table (2). Examined were soil and irrigation water in the Laboratory of the Agricultural Engineering Research Institute (AEnRI) in Dokki, Giza. As stated in table (1), Black (1965) states that random samples were taken from each of the four soil layers at the experimental site (0–15, 15–30, 30-45, and 45–60 cm) in order to evaluate the mechanical and physical characteristics of the soil. The soil bulk density, field capacity (FC), saturation hydraulic conductivity (Ks), permanent wilting point (PWP), and particle size distribution average values are shown in Table 1. The amount of soil that was infiltrated was measured using a double ring infiltrometer. Hydraulic conductivity at saturation was considered the maximum infiltration rate. The results of the irrigation water's chemical analysis are shown in Table (2).

Table 1. Mechanical soil analysis and some physical properties of experimental site.

Soil depth, cm	Particle size distribution			Soil texture	Field capacity %	permanent wilting point %	soil bulk density g/m^3	saturation hydraulic conductivity cm/h
	Sand %	Silt%	Clay%					
0-15	10.42	31.25	58.33	Clay	44.80	21.36	1.10	2.59
15-30	13.00	32.00	55.00	Clay	41.45	21.40	1.22	
30-45	12.00	29.00	59.00	Clay	39.00	21.00	1.28	
45-60	12.00	28.00	60.00	Clay	37.40	20.85	1.31	

Table 2. Chemical analysis of the irrigation water

PH	EC (ds/m)	Cations,(meq/L)				Anions,(meq/L)				SAR (%)
		Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Co_3^{-2}	Hco_3^{-2}	Cl^{-1}	So_4^{-2}	
7.80		1.14	1.21	1.15	0.20	0.00	1.81	0.94	0.95	1.06

Under subsurface drip irrigation, two irrigation designs under two type of lateral for lateral line are tested under constant length of lateral as shown in Figure 1.

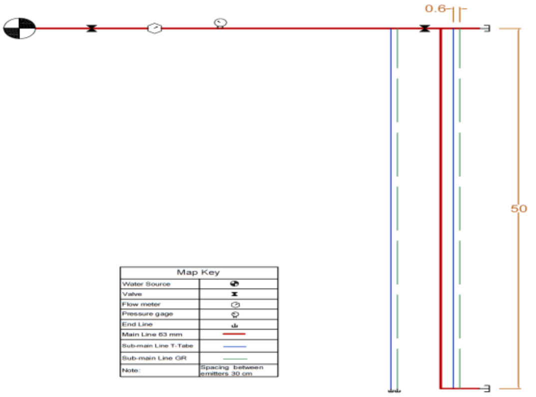

Fig. 1. Experimental layout of the sub surface drip irrigation system (Single inlet- Double inlet)

The abbreviations of the four treatments are:

1- Type of irrigation design (Single inlet–Double inlet)

2-Type of laterals: contains two types (GR and T-tape).

Hydraulic evaluation of emitters

The National Irrigation Laboratory investigated the hydraulic properties of different emitter types at the Agricultural Engineering Research Institute (AEnRI) Dokki, Giza.

Flow characteristics of emitter

A long path emitter with a 4 L/h discharge rate was employed in the current study. The power curve equation provided by Keller and Karmli (1974) and the emitter flow rate vs. pressure curve were computed. Like this:

$$q = KH^{X} \qquad (1)$$

where:

q= Emitter discharge, (L/h).

K= Constant of proportionality that characterizes each emitterstter.

H= Operating pressure,(bar)

X= Emitter discharge exponent that is characterizes by the flow regime.

Manufacturing coefficient of variation(C_V)

To determine the manufacturing coefficient of variation (CV), an independent experiment was conducted prior to the field trial. Thirty new emitters were monitored for flow rate as samples at reference uniform pressure (nominal operating pressure). The formula provided by Solomon (1987) was used to compute the CV value.

$$CV = \frac{S}{\bar{q}} \qquad (3.2)$$

Where:

S= the standard deviation of flow rate values, (l/h), at reference pressure.
$\bar{q}$ = average flow rate of the emission points sampled, (l/h)

Emission uniformity and application efficiency (EU)

Using the EU test, which measures the pressure at each lateral's far end and inlet under normal circumstances, the emission uniformity (EU) of the lateral line was ascertained in the field. Equation was calculated using the following equation by Keller and Karmli (1975) was used to compute emission uniformity (EU):

$$EU = 100\left(1 - \frac{1.27\,Cv}{\sqrt{e}}\right)\frac{qm}{qav} \qquad (3)$$

Where

C_V = the manufacture coefficient of variation (%).
e = the number of emitter per plant.
qm = the minimum emitters discharges.
qav = the average emitter discharge, (L/h).

Planting process

In the corn crop, the seeds (White Triple Hybrid 324) were sowed on July 16 ,2022 using a planter. The distances between the ridge and the grains in the row were 30 cm and 50 cm, respectively.

Soil moisture Monitoring

Before and immediately after irrigation, the soil moisture content was measured between drippers every 10 cm and to a depth of 45 cm. The soil moisture distribution patterns under drip tape and soil conditioner treatments were then depicted using the SURFER program to examine the impact of soil conditioners on soil-water holding capacity and, consequently, soil moisture content. To depict the movement of soil water throughout the entire soil profile and the distribution of soil moisture as contour lines. In order to produce contour maps, 3D surface maps, 3D wireframe maps, shaded relief maps, rainbow colour "Image" maps, post maps, classed post maps, vector maps, and base maps, XYZ data is transformed using the Surfer software package. The model received the data in an XYZ coordinated format, with X as shown in Figure 2 .

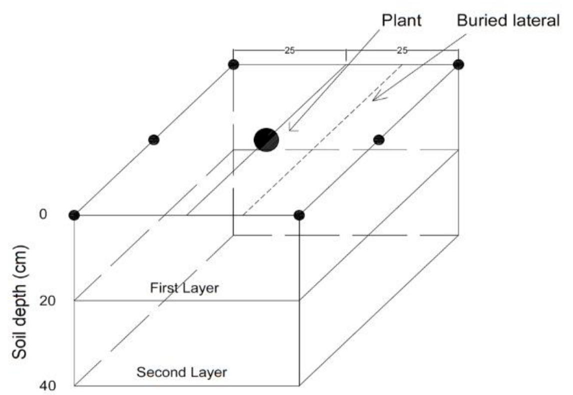

Fig. 2. Location of soil samples with 8 spots at each soil layer in determining soil moisture distribution with depth for each treatment

Growth parameters

1- Height of plant (The measurement using the meter)
2 – Leaf Area (The measurement using the planmeter)

corn yield

Plant samples (nine plants) from each treatment were collected at harvest in order to calculate the seed yield (ton/fed).

Water use efficiency

The following formula (Kirda *et al*. 2004) was used to determine water usage efficiency (WUE):

$$\text{"}WUE = Y/I\text{"} \quad (3.5)$$

where:

WUE: water use efficiency in Kg L^{-1}
Y: Yield per plant in Kg
I: Irrigation water applied per plant in liter

RESULT AND DISCUSSION

Hydraulic characteristics of emitter:

Pressure discharge curve

For each type of emitter, the impact of pressure on the emitter discharge was different. Equation 3 provides two ways to present the influence of pressure: directly as the average emitter discharge or as a variable percentage of discharge at the same real operating pressures at 100 kPa as shown in Figure 3 and Figure 4.

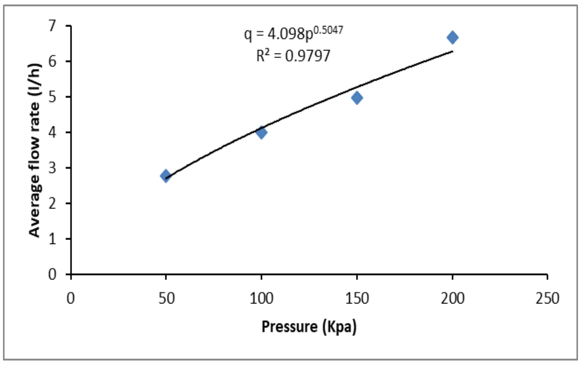

Fig. 3. Linear regression for 4 L/h pressure GR emitter characteristic curve

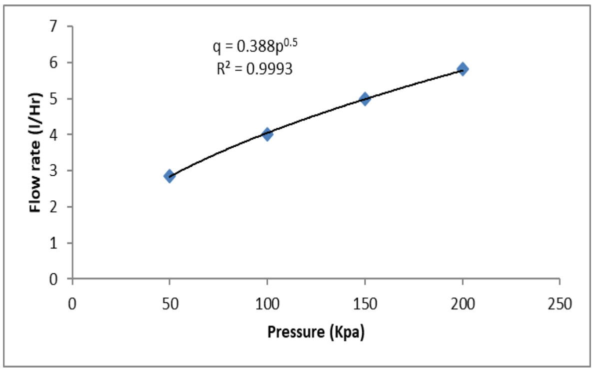

Fig. 4. Linear regression for 4 L/h pressure GR emitter characteristic curve.

Table (3) showed the variation in emission uniformity (EU) and coefficient of manufacturing variation (CV) for the various dripper types.

Emission uniformity (EU) and coefficient of manufacturing variation (CV)

Variation in the emitter's hydraulic properties, including the emission discharge exponent, coefficient of manufacturing variation, and Emission Uniformity (EU) (CV).

Table 3. Hydraulic characteristics of tested emitter at Bar

Dripper	X Ponent	EU %	C_V %	Classification according to ASABE		
				X Ponent	EU %	C_V %
GR	0.500	94.5	1.49	Turbulent	excellent	excellent
T-tape	0.500	95.5	2.96	Turbulent	excellent	excellent

C_V = coefficient of manufacturing variation
EU = emission uniformity

Water application and Crop coefficient (KC) for maize during the season

Water application required per maize plant was computed for each irrigation event based on the recorded parameters of the climate condition in the experimental site. Crop evapotranspiration (ET_P) and the value of crop coefficient (Kc) of maize along the growing season. Which has been taken from the literature (FAO56)?

Fig .(5) and Table (4) showed the amount of water added during the season and crop coefficient under sub surface drip irrigation system. The amount of water increased gradually during the season. Crop coefficient increased gradually the season then it goes down again. The mid-season stage (60-75) consumed the highest value compared to other stages.

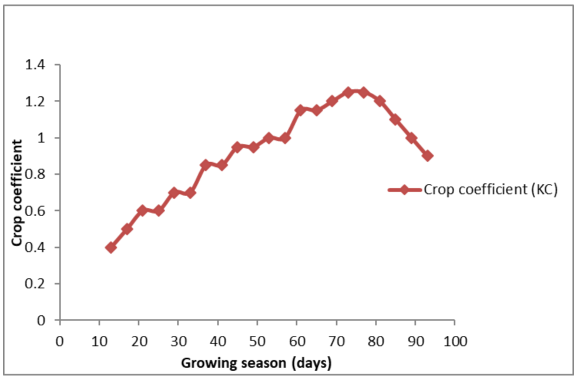

Fig. 5. Maize crop coefficient variation during the season.

Table 4. amount of water added to maize during the season

Time after crop cultivation (days)	Crop coefficient (KC)	Water application (m^3/fed)
13	0.4	53.08
17	0.5	55.22
21	0.6	72.31
25	0.6	75.33
29	0.7	110.25
33	0.7	122.30
37	0.85	153.86
41	0.85	161.0
45	0.95	166.375
49	0.95	145.22
53	1.0	176.81
57	1.0	175.15
61	1.15	195.61
65	1.15	198.025
69	1.2	199.57
73	1.25	211.57
77	1.25	203.7
81	1.2	183.95
85	1.1	186.17
89	1.0	162.11
93	0.9	145.90
Total		3153.5

Soil moisture distribution

The distribution of soil moisture content with soil depth along the soil profile for each treatment reflexes the status water in the soil profile around the root zone. The contour maps were conducted for the two of water application (Single and double inlet).

1-Contor maps of soil moisture content using double inlet with T-tape lateral under length of lateral 50 cm.

From Fig 6 using double inlet irrigation with emitters flow rates equal to 4 L/h the following results paper that soil layers the vertical axis starting from zero level at soil surface to depth 10 cm the soil mean moisture content was 20.5 % before irrigation and increased to 28% after irrigation in the soil top layers(0-10cm) increasing to 21.5%before irrigation at second layers(10-20cm) and increased to 29% after irrigation in the same layer then the soil mean moisture content was decreasing at the third layer(20- 30cm) to 20% before irrigation and increased to 26% then the soil mean moisture content was decreasing at the last layer (30-40cm)to 18.5% before irrigation and increased to 24.8% after irrigation.

2-Contor maps of soil moisture content using double inlet with GR lateral under length of lateral 50 cm.

From Fig. 7 using double inlet irrigation with builtin GR emitters flow rates equal to 4 L/h the following results paper that soil layers in the vertical axis starting from zero level at the soil surface to depth 10 cm the soil mean moisture content was 20 % before irrigation and increased to 27.5% after irrigation in the soil top layers(0-10cm) increasing to 21%before irrigation at second layers(10-20cm) and increased to 28% after irrigation in the same layer then the soil mean moisture content was decreasing at the third layer(20- 30cm) to 19% before irrigation and increased to 25.5% then the soil mean moisture content was decreasing at the last layer (30-40cm)to 18% before irrigation and increased to 24.5% after irrigation.

3-Contor maps of soil moisture content using single inlet with T-tape lateral under 50 cm lateral of length.

From Fig.8 using double inlet irrigation with T-tape emitters flow rates equal to 4 L/h the following results paper that soil layers in vertical axis was starting from zero level at soil surface to depth 10 cm the soil mean moisture content was 15.6% before irrigation and increased to22.1% after irrigation in the soil top layers(0-10cm) increasing to 17.6%before irrigation at second layers(10-20cm) and increased to24.8%after irrigation in the same layer then the soil mean moisture content was decreasing at the third layer(20- 30cm) to 16% before irrigation and increased to23.7 % then the soil mean moisture content was decreasing at the last layer (30-40cm)to15.2% before irrigation and increased to 22.1%after irrigation.

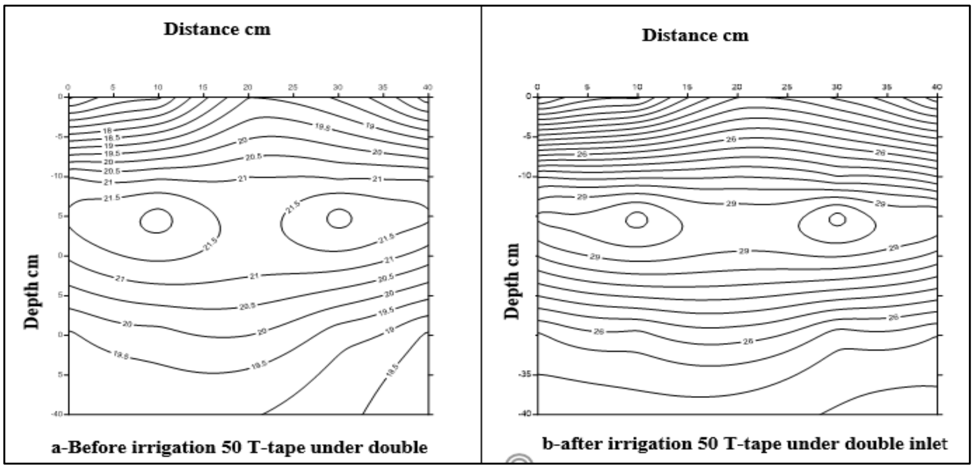

Fig. 6. Soil moisture distribution (a) before and (b) after irrigation under using double inlet with T-tape lateral under length of lateral 50 cm.

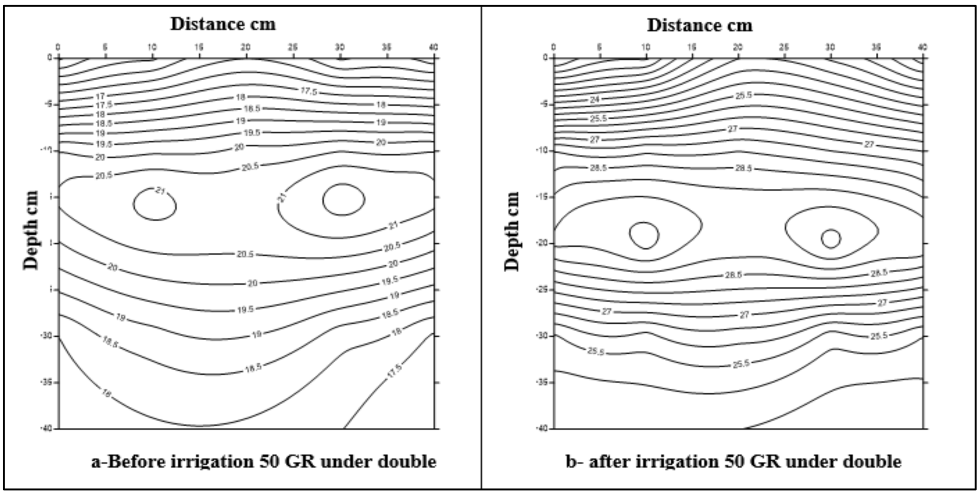

Fig. 7. Soil moisture distribution (a) before and (b) after irrigation under using double inlet with GR lateral under length of lateral 50 cm.

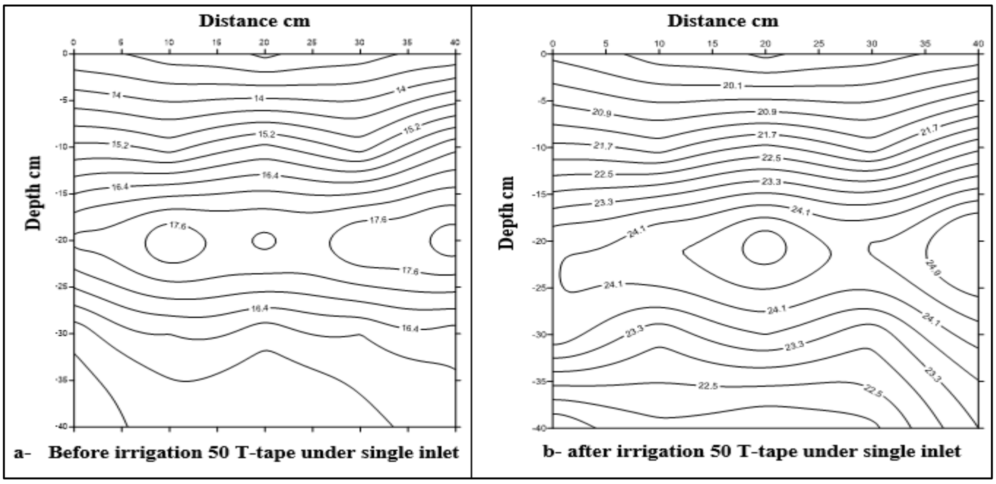

Fig. 8. Soil moisture distribution (a) before and (b) after irrigation under using single inlet with T-tape lateral under lateral length 50 cm.

4-Contor maps of soil moisture content using single inlet with GR lateral under 50 cm lateral of length.

From Fig.9 :using double inlet irrigation with T-tape emitters flow rates equal to 4 L/h the following results paper that soil layers in vertical axis was starting from zero level at soil surface to depth 10 cm the soil mean moisture content was 14.7%before irrigation and increased to20.8%after irrigation in the soil top layers(0-10cm) increasing to 16.8%before irrigation at second layers(10-20cm) and increased to23.6%after irrigation in the same layer then the soil mean moisture content was decreasing at the third layer(20- 30cm) to 15% before irrigation and increased to22.2% then the soil mean moisture content was decreasing at the last layer (30-40cm)to14.4% before irrigation and increased to 20.4%after irrigation.

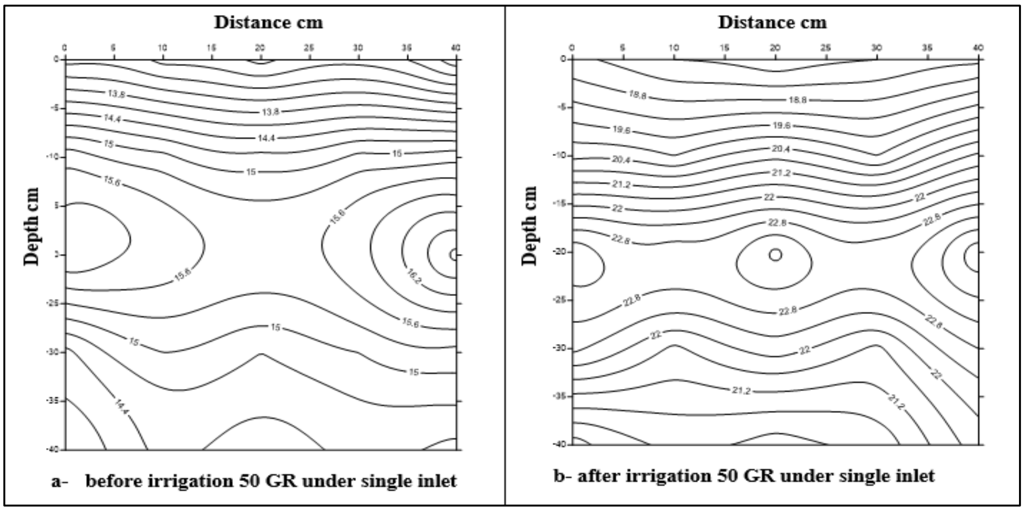

Fig. 9. Soil moisture distribution (a) before and (b) after irrigation under using single inlet with GR lateral under lateral length 50cm.

Length of plant

For all treatments, corn plant length was measured every 30 days. The measurement was started after 30 days from transplanting. Plant length as affected by tested variables is shown in Figure (10)

Results showed that there were differences between all treatments on the length of the plant through all growth stages. In general at the season, It was found that double inlet was higher than single inlet under different of types of laterals. The type of lateral called T.tape was the beast compared to GR lateral under different irrigation designs. The double inlet irrigation recorded high values under two types of lateral.

The double-inlet treatments recorded high values compared to the single-inlet treatments. Under double inlet, the type of lateral T-tape was higher than GR lateral (by 2.85%). While under a single inlet, the type of lateral T-tape was recorded as high value compared to GR lateral under the same length of lateral

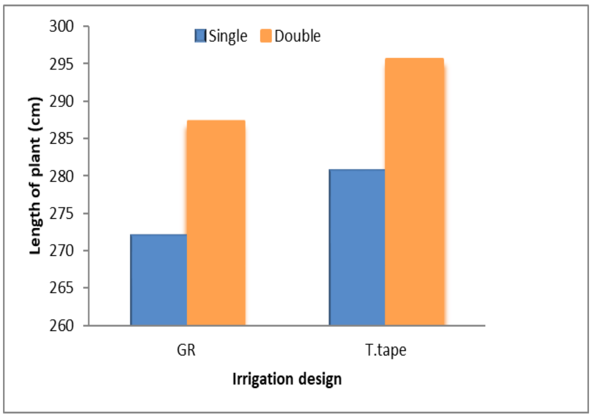

Fig. 10. Effect of two irrigation design (single and double) and two type of laterals, on length of plant

Leaf area index

The leaf area for the corn plant was measured every 30 days. The leaf area is affected by tested variables as shown in (Fig11). The results presented that the double inlet regime under (GR and T-tape) achieved the highest values of leaf area compared to the single inlet design.

From Fig it was noticed that the double inlet treatments recorded high values compared to the single inlet treatments. Under double inlet the highest plant height of 3408.9 cm^2 was recorded with treatment T.tape type. While under single inlet the minimum values of leaf area of plant 2277.2 cm^2 was recorded with treatment GR type, respectively.

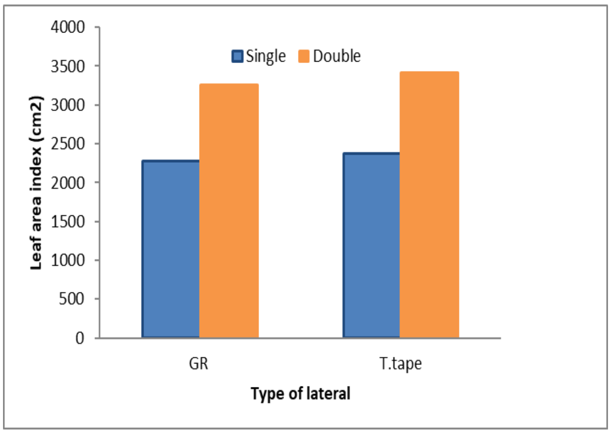

Fig. 11. Effect of two irrigation design (single and double) and two type of laterals , on leaf area index

Yield

Higher yield productivity was produced for the sub-surface than the surface treatments as can be seen in Figure. (12) Due to the highest water use by decreasing the water evaporation from the soil surface. Also, the double irrigation systems improved the yield productivity compared with single inlet treatments. The results showed that the type of lateral T-tape was higher than GR laterals. The double-inlet treatment produced a higher yield compared to the single in treatment.

Fig 12 shows the effect of the lateral length and two types of laterals under two irrigation design systems on plant yield. At lateral GR, the double inlet treatment produces a higher production than the single inlet by 36.60%. Under The T-tape treatment, the double produced a 4.8468 ton/fed. Meanwhile, the single recorded about 3.59 tons/fed.

The main advantage described for the sub-surface drip irrigation treatments is the less irrigation water is applied as agreed with Wichelns (2007). The applied irrigation water in the sub-surface drip irrigation systems would not lost evaporation from the soil surface improved maize yield productivity.

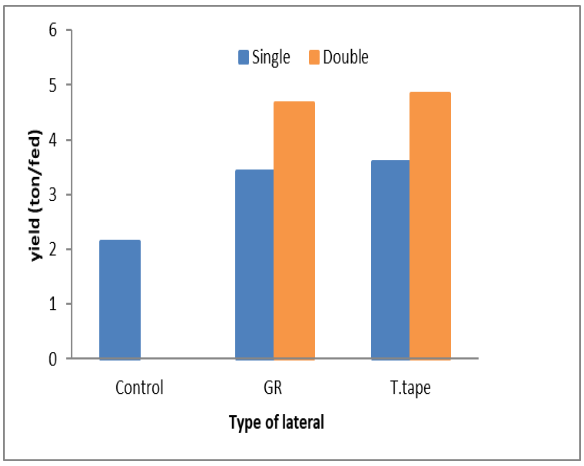

Fig. 12. Effect of two irrigation design (single and double) and two type of laterals , on yield of plant

Water use efficiency (WUE)

A crop's water use efficiency (WUE) is the amount of biomass or grain yield it uses per unit of water used. Results in Table (5) indicated that the highest WUE was 1.52 kg m^{-3} for Double inlet design while the highest WUE for Single inlet was 1.13 kg m^{-3}. At the single inlet, T-tape was higher than GR (by 5.30%).For the double inlet, T-tape was higher than GR (by 2.38%).

	Type of lateral	WUE
Control		.80
Single inlet	50 GR	1.07
	50 T-tape	1.13
Double inlet	50 GR	1.47
	50T-tape	1.52

CONCLUSION

In 2022, field studies were conducted to examine the impact of single and double-inlet subsurface drip irrigation on maize yield. The relationship between the discharge and the pressure is used to estimate the flow equation for both long path (GR) and T-tape types.

1- GR $q = 4.098p^{0.5047}$

2- T-tape $q= 3.88p^{0.5}$

The optimal operating pressure, with a discharge of 1 bar, was 1.49 and 2.96 for GR and T-tape, respectively, at which the CV was lowest. At one bar of working pressure and four L/h of average emitter discharge, the values of emission uniformity for GR and T-tape were recorded as 94.5% and 95.5%, respectively. The double inlet treatment produced the most consistent distribution of soil moisture content in the corn root zone. Corn yield rose when soil moisture content increased. The highest value for Double inlet treatment was 4.846 tons/fed at the lateral T-tape type. The maximum value, 3.593 tons/fed at, was found during single inlet treatment. The maximum water use efficiency figure during double inlet treatment was 1.52 kg/m^3 at the T-tape lateral. The highest water use efficiency during Single inlet treatment was 1.07 kg/m^3 for the lateral T-tape type.

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تأثير التغذية الفردية والمزدوجة تحت نظام الرى بالتنقيط تحت سطحى تحت الظروف المصرية.

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الملخص

يعتبر نظام الرى بالتنقيط من أفضل الانظمة لتوزيع الماء وتوصيل العناصر الغذائية للنباتات . اجريت التجربة الحقلية فى محطة بحوث الجيزة بمحافظة الجيزة بمحافظة الجيزة (١٨ متر فوق مستوى سطح البحر ، دائرة عرض ٣٠ ٣٤شمالا ، خط طول ٢٩ ٥٥ شرقا) خلال موسم الزراعة لعام ٢٠٢٢ لدراسة تأثير تصميم الرى بالتنقيط على انتاج الذرة (هجين أبيض ثلاثى ٣٢٤). تم تطبيق نظامين مختلفين (تغذية فردية – تغذية مزدوجة) تحت نوعين مختلفين من الخراطيم (GR – T.tape) تحت نظام الرى بالتنقيط تحت سطجى . الهدف الرئيسى من البحث هو دراسة تأثير التغذية الفردية والمزدوة على رطوبة التربة والانتاجية لنبات الذرة وكفاءة استخدام المياه ومقارنته بالرى التقليدى تحت نوعين من الخراطيم (GR- T.tape). أظهرت النتائج أن التغذية المزدوجة مع خراطيم T.tape ارتفاع نسبة الرطوبة حول النبات مما أدى الى ارتفاع الانتاجية وأيضا ارتفاع كفاءة الاستفادة مقارنه بنظام التغذية المزدوجة . ومقارنه بالرى التقليدى بالرى تحت سطحى كان الرى التقليدى اقل انتاج وكفاءة استفادة .وكلما زادت طول خط التنقيط تقل الانتاجية وكذلك كفاءة الاستفادة . وأيضا خراطيم T.tapeافضل من GR توزيع الرطوبة الذى يؤثر على الانتاجية وكفاءة الاستفادة.