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RESEARCH ARTICLE

EFFECT OF IRRIGATION SCHEDULING UNDER SURFACE AND SUB-SURFACE LOCALIZED IRRIGATION SYSTEMS ON BEAN PRODUCTIVITY

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Abstract

The sustainable agricultural development strategy relies on optimizing field irrigation water use through modern systems that align with Egypt's goal of efficient water utilization. Given limited water resources and the government's push for modern irrigation in existing farmland, this approach promises improved economic returns and better irrigation management regarding timing and quantity. To enhance water resource utilization for local bean crops in Egyptian conditions, our research aims to improve both subsurface and surface localized irrigation systems. Addressing water scarcity, especially in older farmlands, calls for transitioning from traditional surface localized irrigation to modern methods. We conducted a 2022-2023 open field experiment on clay soil at Giza Governorate. The research objectives were studying the impact of two irrigation methods; surface localized irrigation method and subsurface localized irrigation method with three different levels of irrigation water applications, on moisture distribution, water productivity and some physiological indicators of crop; plant length, number of branches, number of horns, number of seeds, plant weight and productivity. The results showed no significant difference between the treatment of surface localized irrigation with 100% water requirements and subsurface localized irrigation with 80% water requirement. Consequently, using subsurface localized irrigation with only 80% of irrigation requirements will achieve almost the same results with less irrigation water consumption. On the same regard, results showed that, the highest water productivity was obtained in the treatments A80 (4.7 kg/m³) compared to the treatments B80, C80 and A100 where the water productivity were 4.5 kg/m³, 4.4 kg/m³ and 4.3 kg/m³ respectively, meanwhile the lowest water productivity was obtained in the treatment C100 which was 3.5 kg/m³.

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Introduction:-

Fava beans hold a significant role as a valuable plant-based source of protein, offering essential micronutrients and presenting a wide array of culinary possibilities. Within the innovative realm of the food industry, fava beans find

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application in various forms, including plant-based meat substitutes, fortified gluten-free products, and serving as a natural source of color, protein, and fiber in extruded foods. Notably, key studies underscore their successful integration into diverse food products, thus enhancing their nutritional profiles. Nevertheless, it is essential to acknowledge that certain studies have pointed out challenges related to the acceptance of fava beans based on sensory factors (Rebeca et al., 2023).

Turning our attention to the realm of agriculture and irrigation, sustainable water usage stands as a paramount concern. The adoption of strategies geared towards the conservation of irrigation water while simultaneously maintaining acceptable crop yields carries significant potential for safeguarding this increasingly constrained resource (Toscano et al., 2014). Notably, the context of Egypt is particularly pertinent, where the total available water supply amounts to 55.5 billion cubic meters annually, with the agricultural sector accounting for a substantial 85% of this allocation (El-shafei and Seley, 2017).

Dry beans, scientifically known as *Phaseolus vulgaris* L., are some nutritious human food rich in protein, phosphorus, zinc, iron, vitamin B1, and dietary fiber. They hold significant global importance as a primary source of protein in human diets (Ramirez Builes et al., 2011). According to the Food and Agriculture Organization (FAO) Statistics in 2013, dry beans were cultivated across 29,290,861 hectares worldwide, yielding a total production of 23,598,102 metric tons, with an average yield of 0.806 metric tons per hectare. In the specific context of Egypt, dry bean cultivation covered a total area of 26,768.9 hectares, resulting in a production of 69,486 metric tons, with an average yield of 2.594 metric tons per hectare.

Mohendran et al. (2013) shed light on the efficacy of subsurface localized irrigation as a means of delivering water and essential nutrients directly to the root zones of crops within the subsoil layer. This approach is advantageous in that it minimizes water loss, rendering it more efficient than surface localized irrigation. Building upon this theme, Abdel-Aal and Hassan (2013) conducted a comprehensive study to assess the irrigation efficiency, water conservation, cowpea yield, yield components, water productivity, and net profit associated with traditional, trickle, and subsurface localized irrigation systems in sandy soil conditions. Their experimental results revealed noteworthy improvements in various parameters when employing subsurface localized irrigation. Notably, application efficiency, distribution uniformity, and irrigation efficiency all exhibited substantial gains when compared to traditional trickle, sprinkler, and traditional systems. Moreover, trickle systems demonstrated increased pod yield and water productivity (WUE) compared to subsurface, sprinkler, and traditional systems, further highlighting the advantages of modern irrigation techniques.

Numerous studies have undertaken the task of examining the distribution of soil water content in the context of both surface and subsurface trickle irrigation. The majority of these studies have relied on deterministic approaches. A more in-depth exploration of the relevant theories and methodologies for predicting soil water dynamics during trickle irrigation can be found in Subaiah (2013), which serves as an invaluable resource for comprehending these intricacies. Additionally, specific examples pertaining to both surface and subsurface systems are elucidated in detail within the literature, shedding light on the nuances of water behavior along both vertical and horizontal axes within the soil profile. Understanding these dynamics assumes paramount importance in terms of meeting the precise water requirements of plants and optimizing water usage efficiently.

However, it is essential to consider the impact of certain limitations inherent to surface trickle irrigation systems. Due to the constriction of lateral water movement attributable to negative pressure in subsurface layers of the soil, situations may arise wherein deep percolation or surface soil wetting occurs. These circumstances can compromise the overall efficiency of surface trickle irrigation systems, necessitating a deeper exploration of potential solutions (Rodríguez Sinobas et al., 2021; Appels and Karimi, 2021).

The management of Water to produce green bean is priority at all stages of plant growing due to its impacts on stand installments, pod set and quality. The crop must be provided with effective irrigation to ensure vigorous growth. Irrigation is a vital for its plant and pod growth (Smesrud et al., 1997). Common irrigation methods practiced for green bean production in this region are wild flooding, furrow and basin. In general, the farmers over irrigate, resulting in high water losses and low irrigation efficiencies (Yazar et al., 2002). With drip irrigation systems, water and nutrients can be delivered directly to the crop at the root level, having positive effects on yield and water saving (Phene and Howell, 1984; Bozkurt et al., 2006). For these reasons, drip irrigation systems have seen widespread use in the world in recent years.

In this research, the primary objective of our study is to investigate the effects of utilizing trickle irrigation systems, T-tape system, within a clay soil field. We seek to comprehensively evaluate key parameters such as crop productivity, moisture distribution, and some physiological indicators of crop as plant length, number of branches, number of horns, number of seeds, plant weight, and addition to water productivity. Our research is positioned to provide valuable guidance to farmers who are transitioning from traditional surface localized irrigation to modern techniques. Our aim is to assist them in selecting the most suitable irrigation system and equip them with the knowledge necessary to effectively manage these systems.

Material and Methods:-

An open-field experiment was conducted at Giza Governorate it is located between latitudes of 30° 1' 18.4" N - 31° 11' 47.8" E during the 2022-2023 season. The objective was to assess the suitability of the T-tape trickle irrigation system for bean cultivation. The experiment involved nine different treatments, each with varying levels of water application at 60%, 80%, and 100% (Table 1).

Table 1. Treatments of irrigation systems.

60% ET			80% ET			100% ET		
A ₆₀	B ₆₀	C ₆₀	A ₈₀	B ₈₀	C ₈₀	A ₁₀₀	B ₁₀₀	C ₁₀₀
Surface localized irrigation	subsurface localized irrigation (25cm)	subsurface localized irrigation (50cm)	Surface localized irrigation	subsurface localized irrigation (25cm)	subsurface localized irrigation (50cm)	Surface localized irrigation	subsurface localized irrigation (25cm)	subsurface localized irrigation (50cm)

To evaluate the performance of the T-tape trickle irrigation system in clay soil, nine treatments were implemented, utilizing T-tape with a flow rate of 8 liters per hour per meter under an operating pressure of 1.0 bar and lateral line length 50 m with nominal diameter 16 mm while the spacing between lateral was 80 cm.

The pump unit which used in the experimental was electrical with diameter of suction pipe 8 inch and diameter of delivery pipe 6 inch and the maximum power 56 hp with maximum discharge 150 m³/h (1470 rpm) where the manufactory country of pump is Germany (Model NT-125) and filtration unit which used in the experiment achieved through both a sand filter and a screen filter. The total amount of water applied under the tape irrigation system for the bean crop during the season was 3120 cubic meters per feddan for 100%, for 80% was 2496 cubic meters per feddan and for 60% was 1872 cubic meters per feddan.

Some physical and mechanical properties:

Soil bulk density was assessed using the core method, following the guidelines outlined by Black (1965). Table (2) presents the experimentally obtained soil bulk density data from the study area.

The determination of field capacity was based on the method introduced by Peters (1965). Likewise, the permanent wilting point was established through pressure membrane testing, in accordance with the procedures outlined by Stakman and Vander Hast (1962).

Mechanical analysis of the soil under investigation was carried out using established standard protocols as described by Black (1965). Table (2) provides an overview of some key physical and mechanical properties of the soil profile representing the selected area.

Table 2. Soil physical and mechanical properties.

Soil Depth (Cm)	Particle size distribution			Soil Texture	Bulk Density Mg/m ³	Field capacity, %	Wilting point, %	Available water, %
	Sand, %	Silt, %	Clay, %					
0-15	16.4	35.2	48.4	Clay	1.31	47.7	23.2	24.5
15-30	17.4	36.2	46.7		1.22	46.2	27.2	19
30-45	17.4	35.5	47.1		1.23	43.3	23.4	19.9
45-60	15.3	30.7	54		1.25	44.6	25.4	19.2

Moisture Content and water Distribution in the soil:

The moisture content and water distribution in the soil were assessed immediately after irrigation, within two hours, at the root zone. This was accomplished using a soil moisture unit equipped with three watermark sensors designed to measure soil water tension in the field (fig. 1). Soil samples were collected at three locations, each situated 15 cm from the lateral line, both horizontally and vertically, and directly beneath the outer point across the entire root zone. These samples were taken at depths of 0-15 cm, 15-45 cm, and 45-60 cm after irrigation for all the different treatments. Moisture content within each layer and at varying distances from the water source (outer point) was determined according to the method described by Liven and Van Rooyen (1979). This analysis was conducted within specific areas for each treatment, corresponding to the T-tape treatments, and was carried out at distances of 0 cm, 15 cm, and 30 cm from the emission point across the entire root zone. Depths included the soil surface, 25 cm, and 50 cm, following irrigation for the various irrigation treatments.



Fig. (1) The device for measuring soil water tension with three watermark sensors.

Water use efficiency (Water productivity)

Water productivity was estimated based on the following equation (Amer et. Al 2017 and Howell, 2003):

$$\text{Water productivity (Water use efficiency)} = \frac{\text{Crop yield kg/fed}}{\text{Water applied m}^3/\text{fed}} \dots\dots\dots (4)$$

Bean crop

The fava bean crop was cultivated in growing seasons 2022 - 2023. The planting process commenced on 20 November 2022 and harvested on 20 April 2023, with a spacing of 50 cm between hills. After a period of twenty-one days, thinning was performed, leaving one plant per hill. Harvesting was carried out after a duration of 150

days. To support the growth of the crop, nitrogen fertilizers were introduced into the irrigation water throughout the growing season. The application followed the recommended doses provided by the Ministry of Agriculture in Egypt.

Results and Discussion:-

The primary objectives of this research were studying the impact of two irrigation methods, surface and subsurface localized irrigation methods with three different levels of irrigation water applications on the productivity of bean crops (measured in kilograms per feddan). This investigation encompassed an analysis of moisture distribution, some physiological indicators of crop; plant length, number of branches, number of horns, number of seeds, plant weight and water productivity in kilograms per cubic meter. The overarching aim was to provide valuable guidance to farmers in selecting the appropriate irrigation system and equipment while also aiding them in effectively managing their irrigation systems.

Moisture Content and Water Distribution:

Variations in the wetted area, representing moisture content values, were influenced by irrigation treatments in fig. (2). Moisture content values of soil profile with treatments under level of water application ET100% was the highest for surface localized irrigation (A100) and the lowest moisture was subsurface localized irrigation with 50 cm depth (C100). For A100, the highest moisture content value was 26% and the lowest was 23.5%. However, for C100 the highest moisture content value was 18.5% and the lowest one was 16%. In fig (3), moisture content of compensation of irrigation water under water application ET100 was in general from 20% to 15% over the season of irrigation, the highest moisture content value was 27% and the lowest one was 10%.

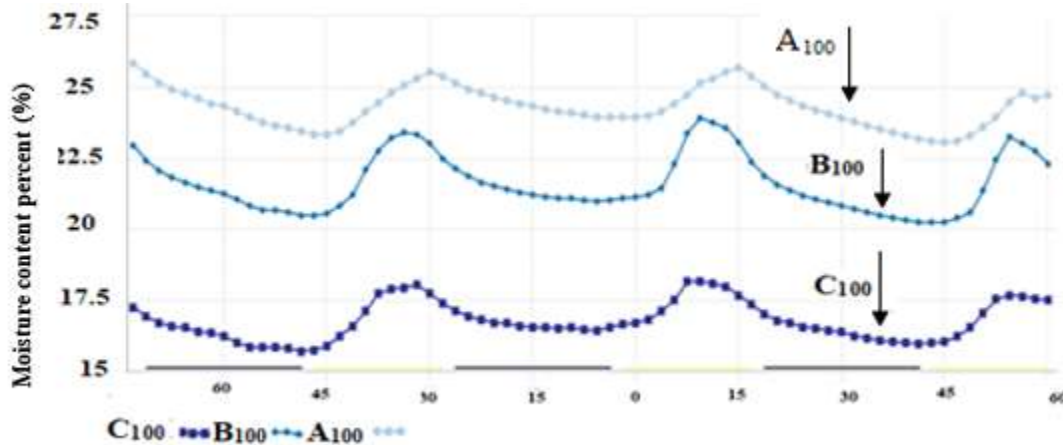


Fig. (2) Moisture content percent of soil profile with all treatments under level of water application 100%.

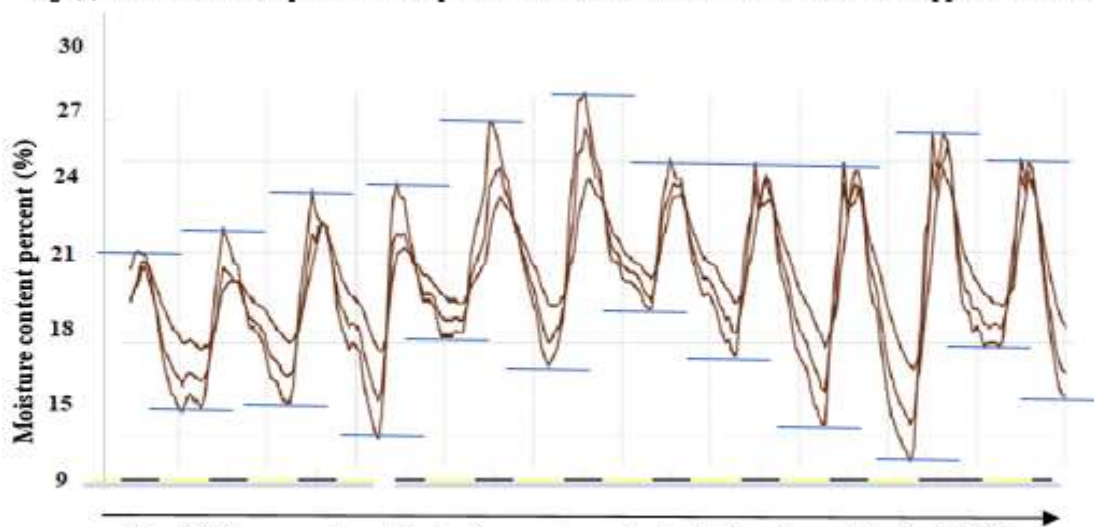


Fig. (3) Compensation of irrigation water under level of water application 100%.

In fig.4.moisture content values of soil profile with treatments under level of water application ET80%, the highest values were for surface localized irrigation with ET80 (A80) and the lowest moisture was subsurface localized irrigation with 50 cm depth (C80). For A80, the highest moisture content value was 21% and the lowest was 18%. However, for C80 the highest moisture content value was 14.5% and the lowest one was 12.5%. Moisture content of compensation of irrigation water under water application ET80 was in general from 17% to 10.5% over the season of irrigation, the highest moisture content value was 22% and the lowest one was 10% (Fig. 5).

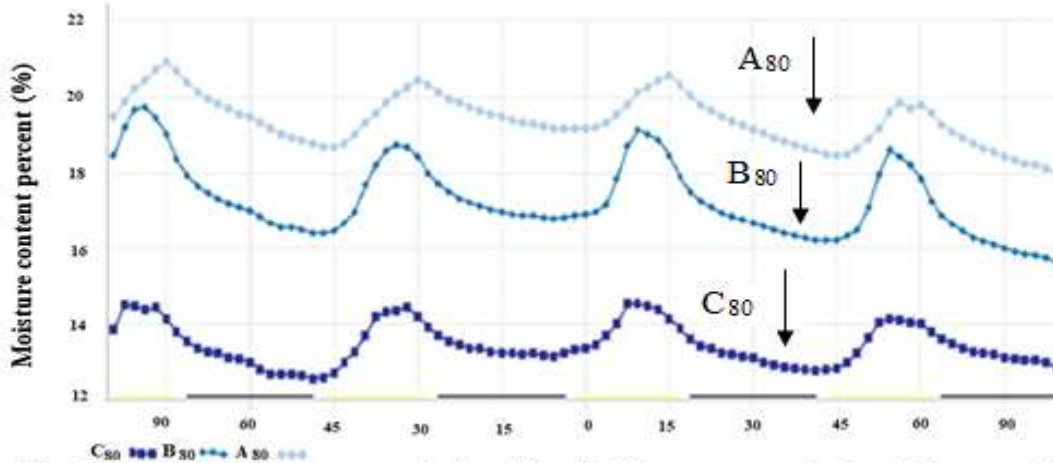


Fig. (4) Moisture content percent of soil profile with all treatments under level of water application 80%.

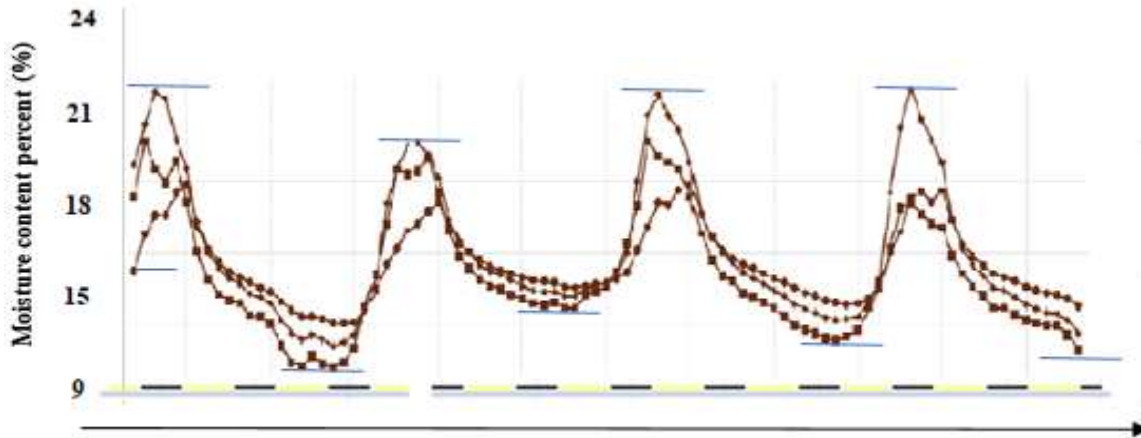


Fig. (5) Compensation of irrigation water under level of water application 80%.

In fig.6. Moisture content values of soil profile with treatments under level of water application ET 60% was the highest for surface localized irrigation (A60) and the lowest moisture was subsurface localized irrigation with 50 cm depth (C60). For A60, the highest moisture content value was 18.5% and the lowest was 13%. However, for C60 the highest moisture content value was 4 % and the lowest one was 2 %. Moisture content of compensation of irrigation water under water application ET60 was in general between irrigation period from 6 % to 15% over the season of irrigation, the highest moisture content value was 13 % and the lowest one was 0.8% (Fig. 7).

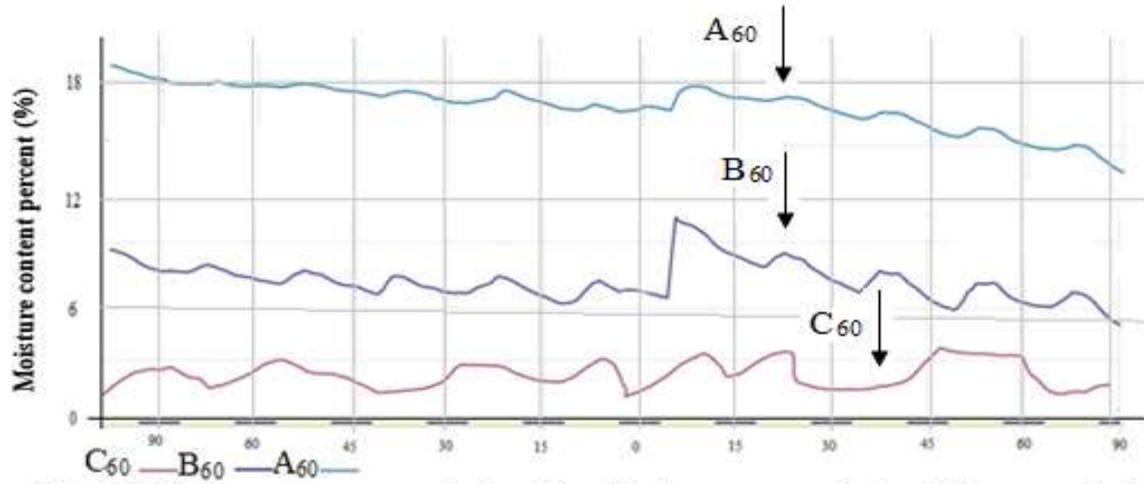


Fig. (6) Moisture content percent of soil profile with all treatments under level of water application 60%.

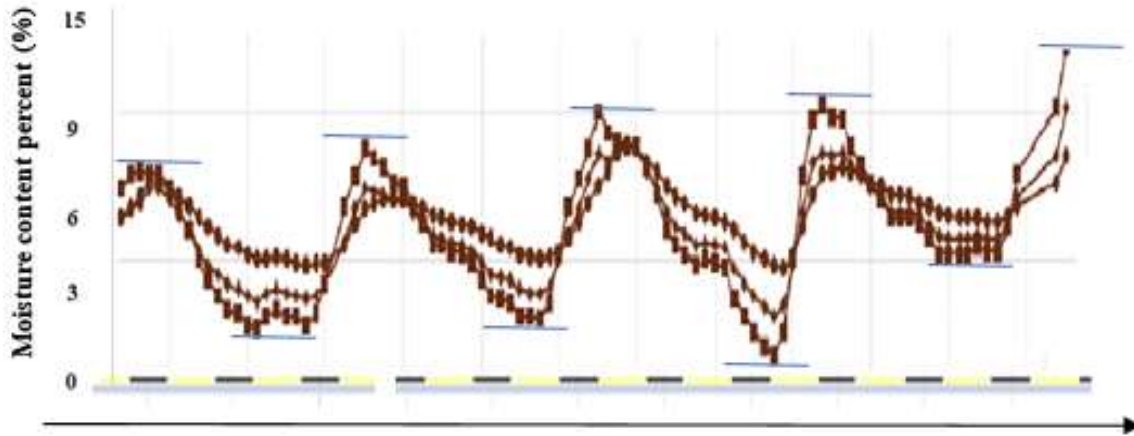


Fig. (7) Compensation of irrigation water under level of water application 60%.

For surface localized irrigation in fig. (8), there were different levels of water application for surface localized irrigation (A60, A80 and A100) 60, 80 and 100 of water requirements. It was observed that 60% of water needs was the lowest values during the season, however 80% and 100% were almost similar in their values through the season. The highest value of moisture content is 36% by A80 and the lowest moisture content value was 8% by A60.

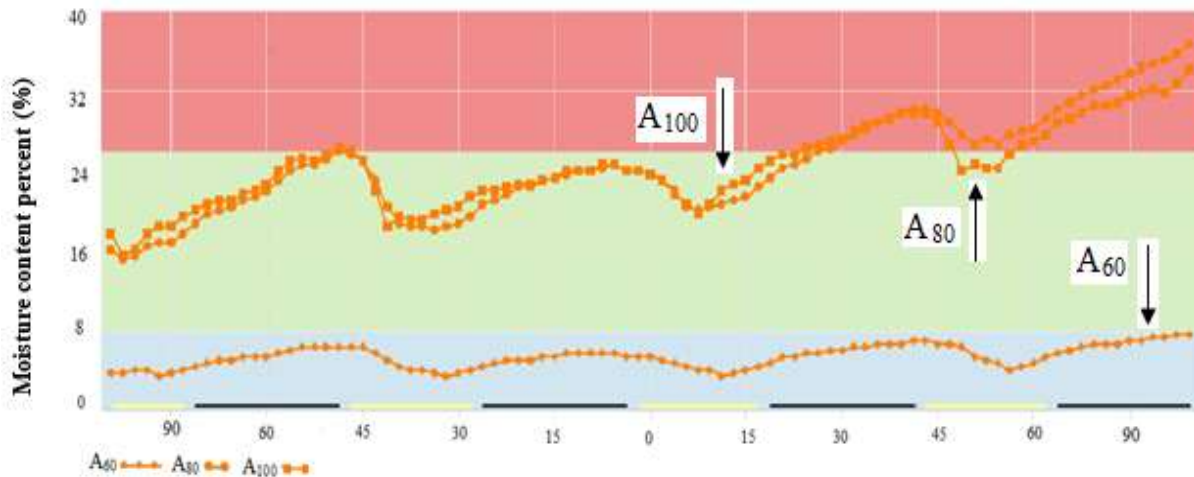


Fig. (8) Moisture content percent of soil profile with surface localized irrigation under varying levels of water application.

In the other side in fig. (9), there were different levels of water application for sub-surface localized irrigation (25), (B60, B80 and B100) 60, 80 and 100 of water requirements. It was observed that 60% of water needs were the lowest values during the season, the highest moisture content was 10% in B60. However, 80% and 100% were almost similar highest in their values through the season.

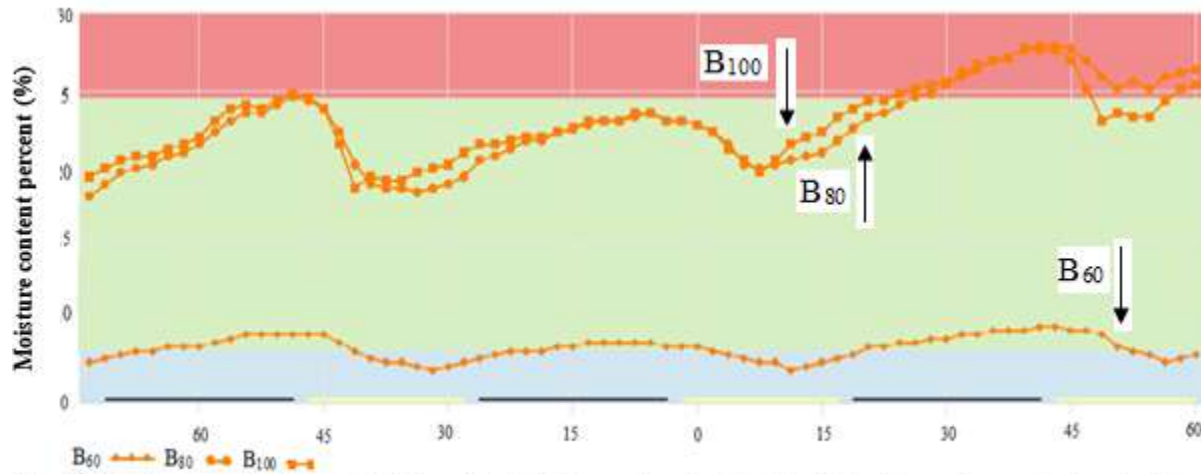


Fig. (9) Moisture content percent of soil profile with 25cm subsurface localized irrigation under varying levels of water application.

The highest value of moisture content was almost 27% by B80 and B100. Moisture content percent of soil profile with 50 cm subsurface localized irrigation under varying levels of water application in fig. 10. Explained that 60, 80 and 100 of water requirements were almost similar in their values through the season and the highest value was 20 % moisture content.

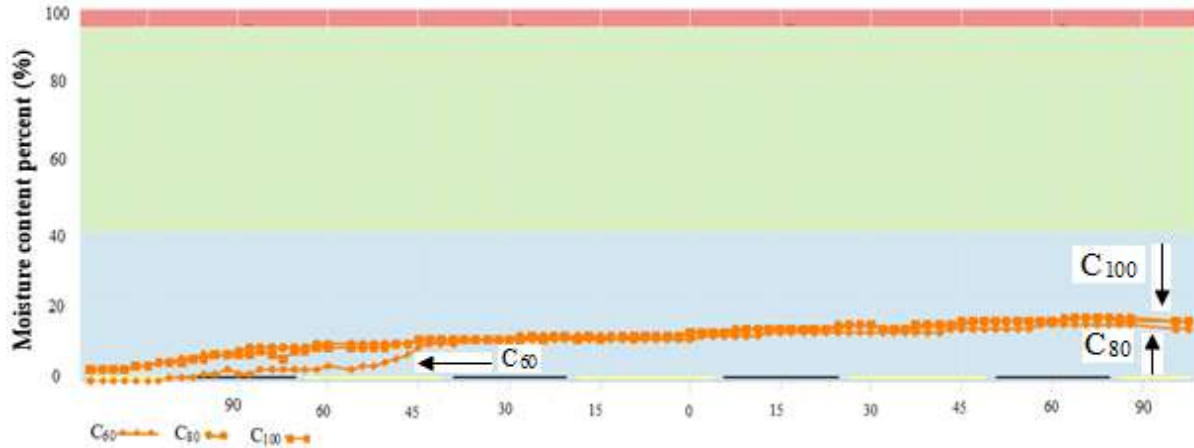


Fig. (10) Moisture content percent of soil profile with 50 cm subsurface localized irrigation under varying levels of water application

Yield productivity (Ton/fed.):

About feddan productivities, in figs. (11, 12 and 13) showed that the best treatment in productivity under surface localized irrigation with 100% water requirements which was 13.5 ton/fed compared with the same treatment of surface localized irrigation with 80% and 60% water requirements which increased by 1.8 and 6.3 ton/fed respectively, while, as is clear, it is possible to obtain the same productivity under the C80 treatment as with the C100 treatment 11 ton/fed. The highest values of productivity were 13.5 ton/fed with treatment under level of water application ET100%, for surface localized irrigation and The lowest values of productivity was 6.8 ton/fed with treatment under level of water application ET60%, for subsurface localized irrigation (25 cm).

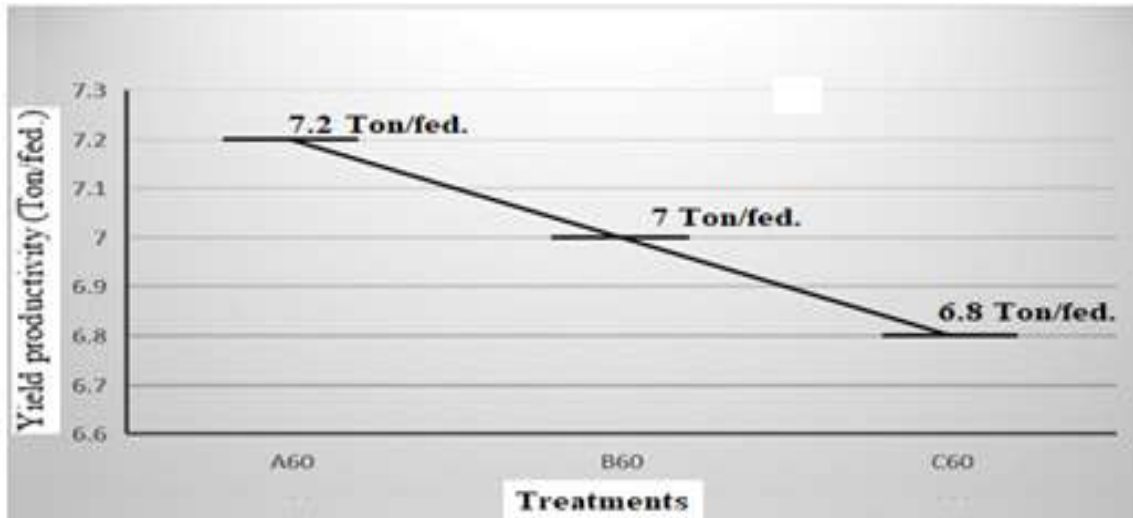


Fig. 11 . Yield productivity (Ton/fed.) for 60% of water requirements.

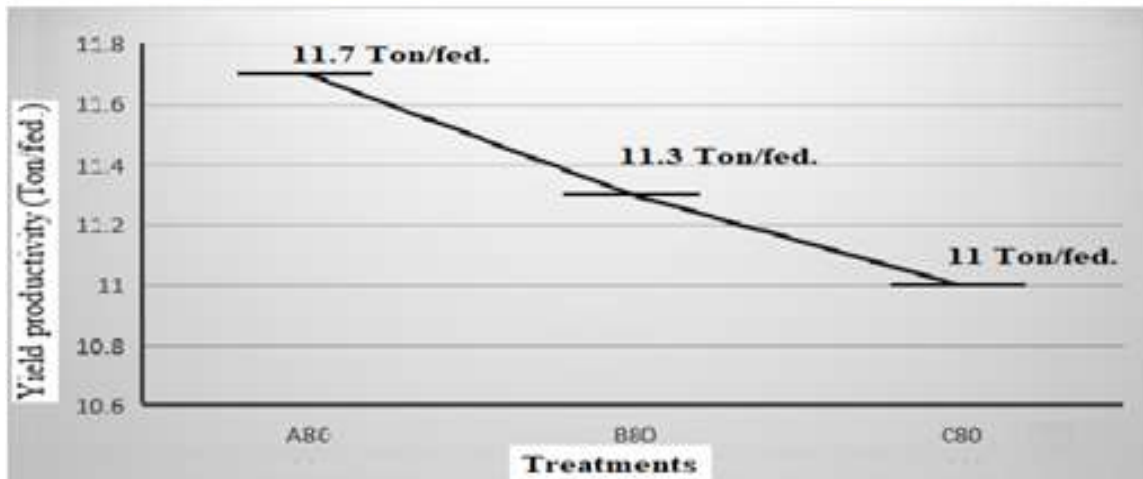


Fig. 12 . Yield productivity (Ton/fed.) for 80% of water requirements.

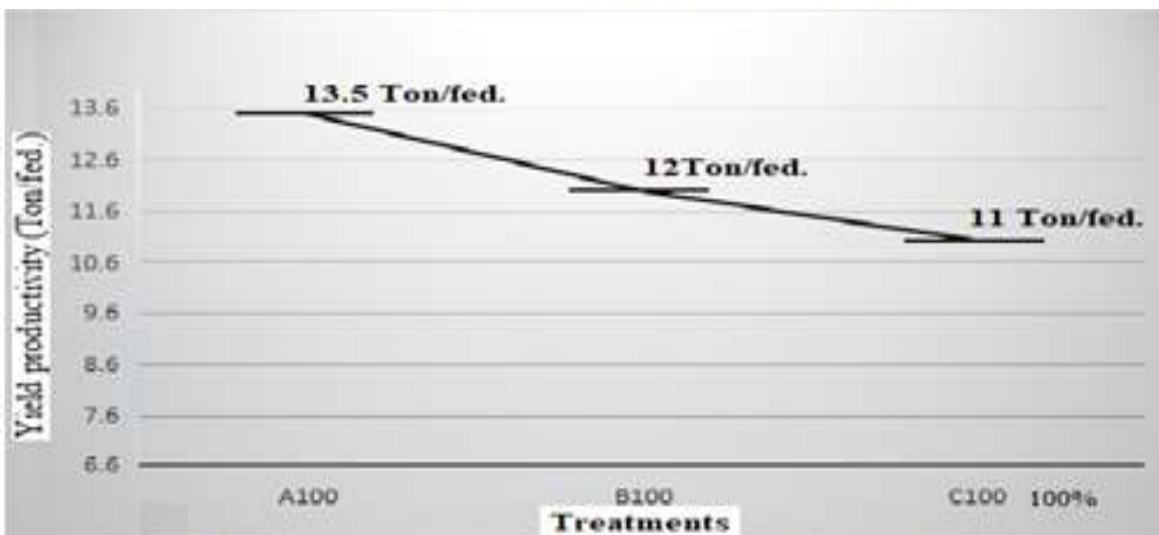


Fig. 13 . Yield productivity (Ton/fed.) for 100% of water requirements.

Water use efficiency (Water productivity):

Table (3) showed that the highest water productivity was obtained in the treatments A80 (4.7 kg/m³) than treatments B80, C80 and A100 since the water productivity were 4.5 kg/m³ 4.4 kg/m³ and 4.3 kg/m³ respectively, meanwhile data showed that the lowest water productivity was obtained in the treatment C100 which was 3.5 kg/m³.

Table 3: Water productivity (kg/m³) for all treatments.

Treatments	Water applied (m ³ /fed)	Production yield (kg/fed.)	Water productivity (kg/m ³)
A ₆₀	1872	7200	3.8
A ₈₀	2496	11700	4.7
A ₁₀₀	3120	13500	4.3
B ₆₀	1872	7000	3.7
B ₈₀	2496	11300	4.5
B ₁₀₀	3120	12000	3.8
C ₆₀	1872	6800	3.6
C ₈₀	2496	11000	4.4
C ₁₀₀	3120	11000	3.5

The results of water productivity of crop for 80% and 100% of water requirements were higher than 60 % of water requirements respectively, with surface localized irrigation compared with subsurface localized irrigation.

Some physiological indicators of crop:**Plant length(cm)**

Physiological indicators of crop for 60% of water requirements were explained in table (4), plant length was the highest (80 cm) with surface localized irrigation and 60 % of water requirements (A60), compared with subsurface localized irrigation at level 25 cm with 60 % (75 cm) and subsurface localized irrigation at level 50 cm with 60 % was (70 cm) of water requirements (C60).

Table 4: Some physiological indicators of crop for 60% of water requirements

Treatments	Plant length (cm)	Number of branches	Number of horns	Number of seeds	Plant weight (gm)	Feddan productivity (Ton)
A ₆₀	80	4.4	15	41	34	7.2
B ₆₀	75	4	13.6	36.7	32	7
C ₆₀	70	3.6	12.4	32.3	30	6.8

The results of physiological indicators of crop for 80% of water requirements were explained in table (5), plant length was the highest with surface localized irrigation and 80 % of water requirements (88 cm), compared with subsurface localized irrigation at level 25 cm (84 cm) and subsurface localized irrigation at level 50 cm with 80 % of water requirements (80 cm). In table (6), plant length was the highest with surface localized irrigation and 100 % of water requirements (100 cm), compared with subsurface localized irrigation at level 25 cm (95 cm) and subsurface localized irrigation at level 50 cm with 100 % of water requirements (90 cm).

Number of branches

In table (4), number of branches were the largest (4.4) with surface localized irrigation and 60 % of water requirements (A60), compared with subsurface localized irrigation at level 25 cm with 60 % (4) and subsurface localized irrigation at level 50 cm with 60 % was (3.6) of water requirements (C60). The results of physiological indicators of crop for 80% of water requirements were explained in table (5), number of branches was the largest with surface localized irrigation and 80 % of water requirements (6.2), compared with subsurface localized irrigation at level 25 cm (5.6) and subsurface localized irrigation at level 50 cm with 80 % of water requirements (6). In table (6), number of branches was the largest with surface localized irrigation and 100 % of water requirements (6.3), compared with subsurface localized irrigation at level 25 cm (6) and subsurface localized irrigation at level 50 cm with 100 % of water requirements (5.7).

Number of horns

In table (4), number of horns were the largest (15) with surface localized irrigation and 60 % of water requirements (A60), compared with subsurface localized irrigation at level 25 cm with 60 % (13.6) and subsurface localized irrigation at level 50 cm with 60 % was (12.4) of water requirements (C60). The results of physiological indicators of crop for 80% of water requirements were explained in table (7), number of horns was the largest with surface localized irrigation and 80 % (A80) of water requirements (18.9), compared with subsurface localized irrigation at level 25 cm (17.5) and subsurface localized irrigation at level 50 cm with 80 % of water requirements (17). In table (6), number of horns was the largest with surface localized irrigation and 100 % (A100) of water requirements (21.7), compared with subsurface localized irrigation at level 25 cm (20.3) and subsurface localized irrigation at level 50 cm with 100 % of water requirements (19).

Number of seeds

In table (4), number of seeds were the largest (41) with surface localized irrigation and 60 % of water requirements (A60), compared with subsurface localized irrigation at level 25 cm with 60 % (36.7) and subsurface localized irrigation at level 50 cm with 60 % was (32.3) of water requirements (C60). The results of physiological indicators of crop for 80% of water requirements were explained in table (7), number of seeds was the largest with surface localized irrigation and 80 % (A80) of water requirements (56.6), compared with subsurface localized irrigation at level 25 cm (53.4) and subsurface localized irrigation at level 50 cm with 80 % of water requirements (50.2). In table (6), number of seeds was the largest with surface localized irrigation and 100 % (A100) of water requirements (64.7), compared with subsurface localized irrigation at level 25 cm (62.5) and subsurface localized irrigation at level 50 cm with 100 % of water requirements (60).

Plant weight (gm)

In table (4), plant weight was the highest (34 gm) with surface localized irrigation and 60 % of water requirements (A60), compared with subsurface localized irrigation at level 25 cm with 60 % was (32 gm) and subsurface localized irrigation at level 50 cm with 60 % was (30 gm) which water requirements (C60). The results of physiological indicators of crop for 80% of water requirements were explained in table (5), plant weight was the highest with surface localized irrigation and 80 % (A80) which water requirements (50.5 gm), compared with subsurface localized irrigation at level 25 cm was (49.5 gm) and subsurface localized irrigation at level 50 cm with 80 % of water requirements was (48 gm). In table (6), plant weight was the highest with surface localized irrigation and 100 % (A100) of water requirements (58.6 gm), compared with subsurface localized irrigation at level 25 cm (56.6 gm) and subsurface localized irrigation at level 50 cm with 100 % of water requirements (54.6 gm).

Table 5: Some physiological indicators of crop for 80% of water requirements

Treatments	Plant length (cm)	Number of branches	Number of horns	Number of seeds	Plant weight (gm)	Feddan productivity (Ton)
A ₈₀	88	6.2	18.9	56.6	50.5	11.7
B ₈₀	84	5.6	17.5	53.4	49.5	11.3
C ₈₀	80	5	17	50.2	48	11

Table 6: Some physiological indicators of crop for 100% of water requirements

Treatments	Plant (cm) length	Number of branches	Number of horns	Number of seeds	Plant weight (gm)	Feddan productivity (Ton)
A ₁₀₀	100	6.3	21.7	64.7	58.6	13.5
B ₁₀₀	95	6	20.3	62.5	56.6	12
C ₁₀₀	90	5.7	19	60	54.6	11

Conclusion:-

According to the variables have been studied to achieve the objectives of this research, the results showed no significant difference between the treatments of surface localized irrigation with 100% water requirements and subsurface localized irrigation with 80% water requirement. Consequently, using subsurface localized irrigation with only 80% of irrigation requirements will achieve almost the same results with less irrigation water

consumption. On the same regard, results showed that, the highest water productivity was obtained in the treatments A80 (4.7 kg/m³) compared to the treatments B80, C80 and A100 where the water productivity were 4.5 kg/m³ 4.4 kg/m³ and 4.3 kg/m³ respectively, meanwhile the lowest water productivity was obtained in the treatment C100 which was 3.5 kg/m³.

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