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THE EFFECT OF OPERATIONAL PRESSURE, DISTANCE BETWEEN FIELD PIPES, AND IRRIGATION LEVEL ON THE GROWT, YIELD, AND WATER USE EFFICIENCY OF WHEAT (TRITICUM AESTIVUM L.) UNDER A T-TAPE DRIP IRRIGATION SYSTEM

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Keywords
Triticum aestivum
Drip irrigation
Operational pressure
Pipe spacing
Irrigation level
Plant growth
Water use efficiency

Abstract
This study aimed to evaluate the effect of operational pressure, spacing between field pipes, and irrigation level on plant growth parameters (plant height, dry matter of vegetative parts, grain yield, and water use efficiency) under a T-tape drip irrigation system in wheat crop (Triticum aestivum L.). A field experiment was conducted during the winter season of 2024–2025 in Safwan district, Basrah Governorate, Iraq. The experiment included three operational pressures (0.75, 1.00, and 1.25 m), three distances between field pipes (20, 30, and 40 cm), and two irrigation levels (100% and 80% of cumulative pan evaporation). The experiment was arranged according to a split-split plot design using RCBD with three replicates. Results showed that the 20 cm spacing recorded the highest values of plant height, dry matter of vegetative parts, grain yield, and water use efficiency compared with wider spacing. Increasing operating pressure significantly increased the above growth and production parameters. Irrigation at 100%Ep significantly increased the growth and production parameters compared with 80% Ep. Except for water use efficiency, the superiority was at 80% Ep compared with 100% Ep. Provides a

1. Introduction

Drip irrigation is one of the most effective irrigation technologies that has significantly contributed to improving agricultural production and increasing water efficiency and use, especially in areas suffering from water scarcity and environmental challenges. This system relies on delivering water directly to the root zone through a network of pipes and emitters, while controlling the water flow rate and system operating time. This reduces losses due to evaporation, surface runoff, and deep seepage, thus enhancing crop water efficiency compared to surface and sprinkler irrigation methods (Hossain et al., 2017; Alsalami et al., 2023). Drip irrigation systems limit the physical and chemical processes that weaken soil aggregates or lead to their breakdown, surface compaction, and increased soil erosion (Arshad,2020). One of the most important limitations of drip irrigation systems is that the wetting front area depends on the water movement rate, and salt movement and accumulation occur at the wetting front boundaries, whether along the lateral front of the emitter line or between the emitters. Therefore, studies recommend increasing the overlap between wetting zones by reducing the distance between emitters and increasing their drainage, or by reducing the distance between field pipes in the case of strip drip irrigation (Montalvo et al., 2023). The T-tape drip irrigation system has recently emerged as a popular choice due to its ease of installation and low initial cost. It is used for cultivating large areas of field crops using thin plastic strips containing emitters arranged in longitudinal slits of equal spacing that are not prone to clogging (Rivulis, 2024). The operating pressure of the system and the discharge rate of the emitters are the main factors in the uniformity of water distribution in the soil, which in turn affects soil structure, porosity, bulk density, and water conductivity. Furthermore, the spacing between field pipes is a crucial design factor controlling the wetting front and increasing salt leaching efficiency, ultimately impacting plant growth and productivity (Radhi, 2023). A study conducted in China found that increasing the operating pressure leads to an increase in dripper discharge (2-10 L h^{-1}) using water of varying salinity, resulting in a significant increase in the dry weight yield of yellow corn grains under the irrigation system (Xiukang et al., 2014) . The reducing the distance between field pipes in a drip irrigation system improves water availability and increases the productivity of wheat in sandy soils the distance of (0.5m) and (0.6 m) achieved a significant advantage in growth and production indicators for wheat yield (Arafa et al. 2009). Choosing the appropriate irrigation level is also an important factor in providing the plant's water needs for different growth stages, as the level of irrigation water added affects the wetting front area, water use efficiency, and plant growth improvement (El-Hafedhet al., 2001). This study aims to evaluate the effect of operating pressure, the distance between field pipes, and the irrigation level on vegetative growth parameters, grain yield, and water use efficiency of wheat plants under the T-tape drip irrigation system

2. Materials and Methods

The field experiment was conducted during the winter growing season of 2024–2025 in Safwan district, southwest of Basrah Governorate, Iraq. The experimental field is located at latitude 30° 8′ 28″ N and longitude 47° 36′ 47″ E. Figure. (1) The soil of the study area was sandy loam texture and classified as Typic Quartzi Psamments .

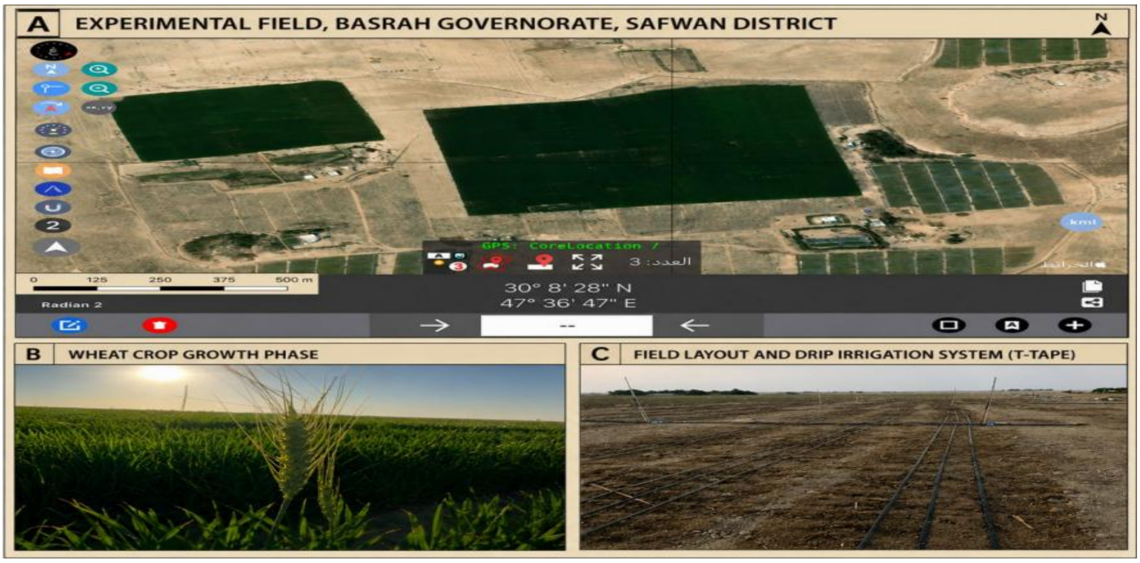

Figure 1. Geographical location and fieldwork preparations; (A) Experimental Field, Basrah Governorate, Safwan District (B) Plot preparation and surface irrigation pipe system, (C) Wheat crop growth

Soil Sampling and Analysis

Soil samples were collected before planting from three depths: 0–15, 15–30, and 30–45 cm. The collected samples were air-dried and passed through a 2-mm sieve before laboratory analysis. Physical and chemical soil properties were determined according to the standard procedures described by Black et al (1965), Page et al (1982). The measured soil properties are presented in Table 1.

Table 1. Physical and Chemical Properties of the Study Soil

Properties		**Soil depth (cm)**		
		0 – 15	**15-30**	**30-45**
Sand	gm. kg -1 soil	846	822	769
Silt		106	109	146
Clay		43	62	72
Soil texture		sandy loam	sandy loam	Sandy loam
Mean weight diameter (MWD)		0.120	0.105	0.98
Bulk density (mg.m-^{3})		1.72	1.64	1.47
Partical density (mg.m-^{3})		2.72	2.70	2.65
porosity %		36.76	39.25	44.52
field capacity% (pw%)		21.62	21.23	20.78
Wilting point (pw %)		9.8	9.2	8.9

Properties			Soil depth (cm)		
			0 – 15	**15-30**	**30-45**
Saturated water conductivity cm. minute^{-1})			20.6	19.3	19.8
Total carbonates (g.kg-1)			147.00	136.00	128.00
EC (Cmole m-^{1}) 1:1			4.14	2.79	2.69
pH 1:1			7.97	8.24	8.37
	Ca++	millimoles. L-1	6.312	4.125	3.825
	Mg++		5.875	4.125	3.45
dissolved ions	Na+		17.95	13.075	11.35
	K+		1.355	1.015	0.975
	HCO3-1		1.86	1.915	1.66
	SO_4^{-2}		11.7	10.965	8.115
	Cl-		27.25	1600	16.5
	CO_3^{-2}		0.0	0.0	0.0
Irrigation water		EC dSm^{-1}	6.39		
		pH	7.19		

3. Experimental Design

The experiment included three factors: operating pressure (P1 = 125 cm, P2 = 100 cm, and P3 = 75 cm), distance between field pipes (S1 = 20 cm, S2 = 30 cm, and S3 = 40 cm), and irrigation level (I1 = 100% Ep and I2 = 80% Ep). Irrigation water requirements were estimated using the us Class-A evaporation pan method. The experiment was arranged in a split–split plot design within a randomized complete block design (RCBD) with three replicates. Operating pressure treatments were assigned to the main plots, irrigation levels to the subplots, and distances between field pipes to the sub-sub plots. The total number of experimental units was 54. Each experimental unit was 7 m long, while plot widths varied according to field pipe spacing treatments.

Irrigation System and Crop Establishment

A T-tape drip irrigation system was used in all treatments. Each experimental unit contained three lateral lines. Operating pressure was controlled using piezometers and control valves installed at the beginning of each lateral line. Wheat (Triticum aestivum L.) was planted in November 2024.

4. Results and discussion

plant height

The results of the statistical analysis of the F-test (Table2) showed a significant effect of the spacing between field pipes on plant height at the end of the growing season, with significant differences between all treatments (Figure 2). The 20 cm treatment (S1) achieved the highest average plant height (65.97 cm), followed by the 30 cm treatment (S2) (64.21 cm), and then the 40 cm treatment (S3) (62.21 cm), with percentage decrease of 2.67% and 5.70%, respectively, compared to S1. The superiority of the 20 cm treatment is attributed to the efficiency of moisture distribution and the speed of the convergence of the wetting fronts, which enhanced water movement in the soil and increased the availability of water and nutrients. In contrast, the wider spacing led to a decrease in the efficiency of moisture distribution, a delay in the convergence of the wetting fronts, and an increase in moisture variability and salinity, which negatively impacted root growth and uptake efficiency, thus reducing plant height. These results are consistent with what was reported in (Zhau et al.,2018).

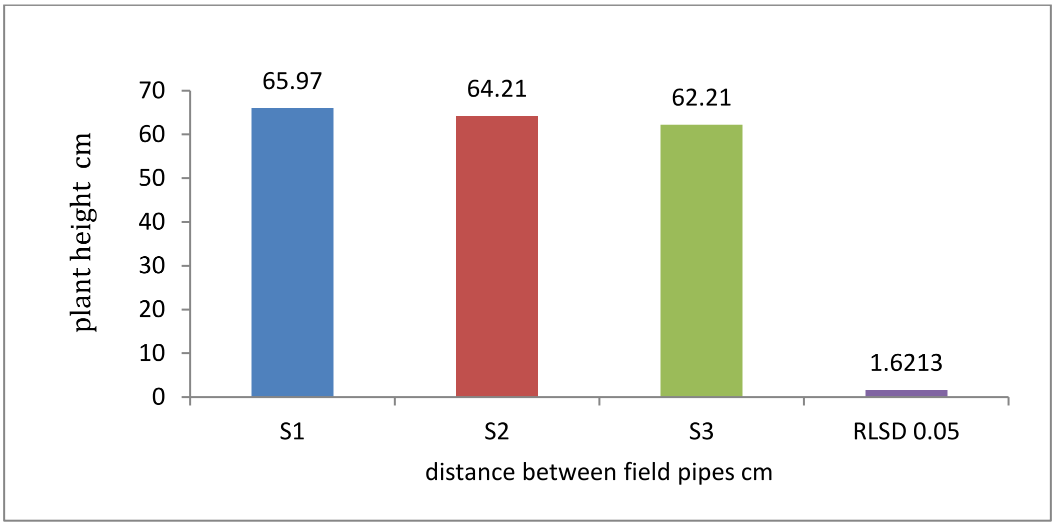

Figure 3. Effect of the distance between field pipes on plant height (cm)

The results of the statistical analysis of the F-test (Table 2) showed a significant effect of irrigation level on plant height at the end of the growing season (Figure 3). The full irrigation treatment (I1, 100% Ep) recorded the highest average height (65.02 cm), compared to the irrigation treatment (I2, 80% Ep), which reached (63.24 cm). This increase is attributed to the availability of sufficient moisture within the root zone, which enhanced water and nutrient absorption, improved salt leaching, and enhanced soil physical properties, positively impacting vegetative growth. Conversely, reducing the irrigation level subjected the plant to water stress, limiting absorption efficiency and resulting in a decrease in plant height. These results are consistent with those indicated by (Al-Obaidi, 2021).

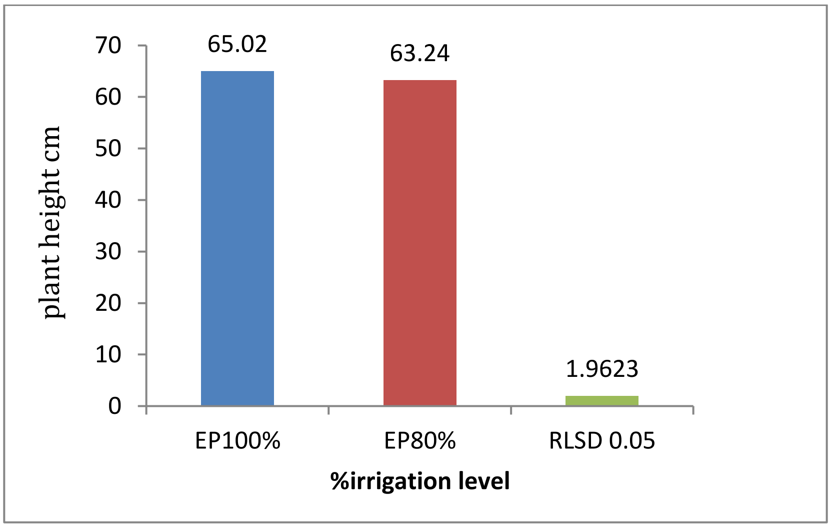

Figure 3. Effect of irrigation level on plant height (cm)

The results of the statistical analysis of the F-test (Table 2) showed a highly significant effect of operating pressure on plant height at the end of the growing season (Figure 4), with treatment (P1) recording the highest average height (65.06 cm), followed by (P2) (64.24 cm), while (P3) recorded the lowest value (63.09 cm). This is attributed to the fact that higher operating pressure improves drip drainage and widens the wetting front, which enhances the uniformity of moisture distribution within the root zone and increases the efficiency of water and nutrient absorption, in addition to improving salt leaching and some soil physical properties. Conversely, lower pressure leads to poorer uniformity of moisture distribution and reduced wetting front, which negatively impacts vegetative growth and plant height (karimi, 2021).

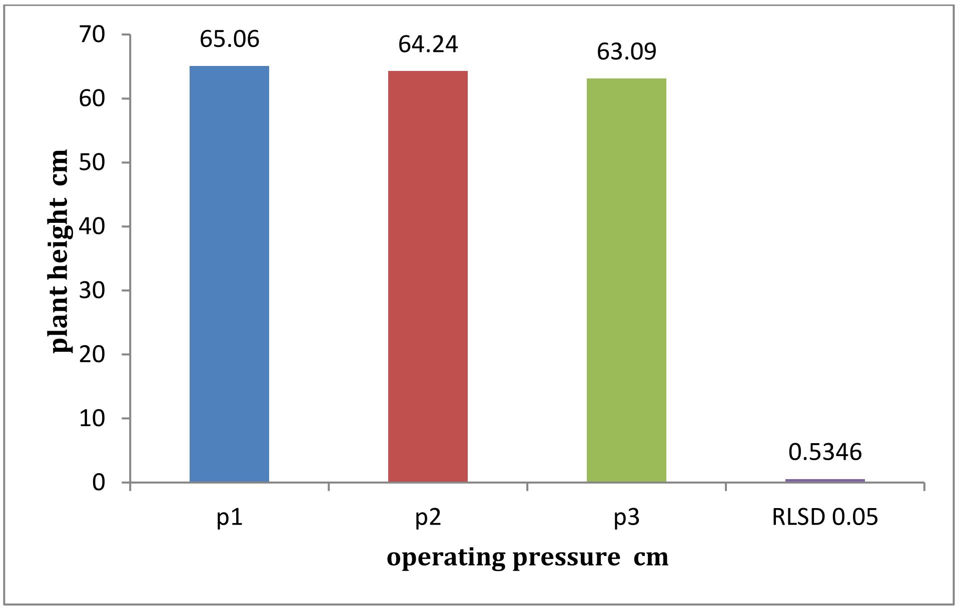

Figure 4. Effect of operating pressure on plant height (cm)

dry matter of the vegetative parts

The results of the statistical analysis of the F-test (see Table 2) showed a significant effect of the spacing between field pipes on the dry matter of the vegetative parts at the end of the growing season (Figure 5). The 20 cm treatment (S1) recorded the highest value (5.092 t ha^{-1}), followed by 30 cm (S2) (4.805 t ha^{-1}), and then 40 cm (S3) (4.737 t ha^{-1}). This superiority is attributed to the efficient distribution of moisture resulting from the overlap of wetting fronts at narrow spacings. This enhances the availability of water and nutrients and improves soil properties, positively impacting vegetative growth. Conversely, wider spacing leads to weaker wetting front overlap and lower moisture content, thus limiting absorption efficiency and resulting in a decrease in plant dry weight. These results are consistent with those reported by Kang et al. (2017) that the efficiency of water distribution in drip irrigation systems depends largely on the distance between field pipes, as optimal spacing contributes to improving soil moisture and increasing productivity.

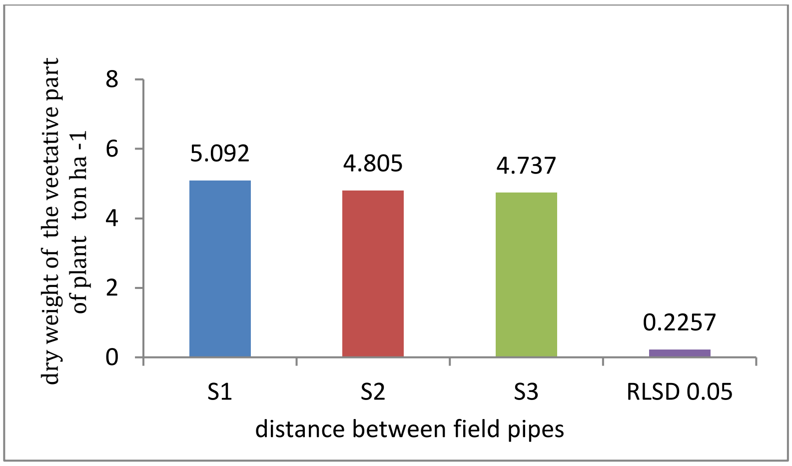

Figure 5. Effect of the distance between field pipes on the dry matter of the vegetative part of the plant (ton ha^{-1})

The results of the F-test (Table 2) statistical analysis showed a significant effect of irrigation level on the weight and dry matter of the vegetative parts at the end of the growing season (Figure 6). The full irrigation treatment (I1, 100% Ep) recorded the highest values (5.018 t ha^{-1}) compared to the irrigation treatment (I2, 80% Ep) (4.738 t ha^{-1}). This is attributed to the availability of sufficient moisture in the root zone, which enhances water and nutrient absorption and improves salt leaching, positively impacting vegetative growth and dry matter accumulation. Conversely, reducing the irrigation level leads to water stress, limiting absorption efficiency and physiological activity, which negatively affects plant biomass production. These results are consistent with what

Nayyef et al. (2026) indicated, namely that providing full water requirements promotes vegetative growth and increases dry matter accumulation efficiency, thus increasing productivity.

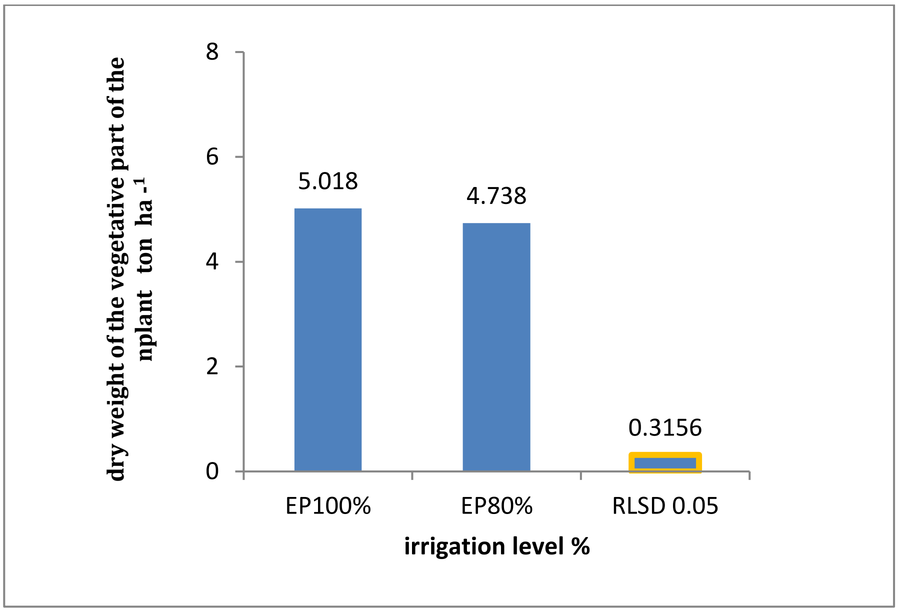

Figure 6. Effect of irrigation level on dry matter of the vegetative part of the plant (tons, ha^{-1})

The results of the F-test (Table 2) showed a significant effect of operating pressure on the dry matter of the vegetative parts at the end of the growing season(see Figure7). The high-pressure treatment (P1) recorded the highest value (5.268 t ha^{-1}), followed by the medium-pressure treatment (P2) (4.828 t ha^{-1}), and then the low-pressure treatment (P3) (4.538 t ha^{-1}). This superiority is attributed to improved water distribution uniformity and increased wetting efficiency in the root zone at high pressures. This enhances water and nutrient uptake and improves salt leaching, positively impacting dry matter accumulation. Conversely, low pressure leads to poor drip drainage and uneven wetting, which limits root spread and absorption efficiency, resulting in reduced vegetative growth. These results are consistent with what was indicated by Akkamis & Caliskan (2023), namely that increasing the operating pressure within optimal limits improves the efficiency of the drip irrigation system and leads to better water distribution in the soil, while decreasing the pressure leads to a decline in irrigation efficiency and a decrease in plant growth and productivity.

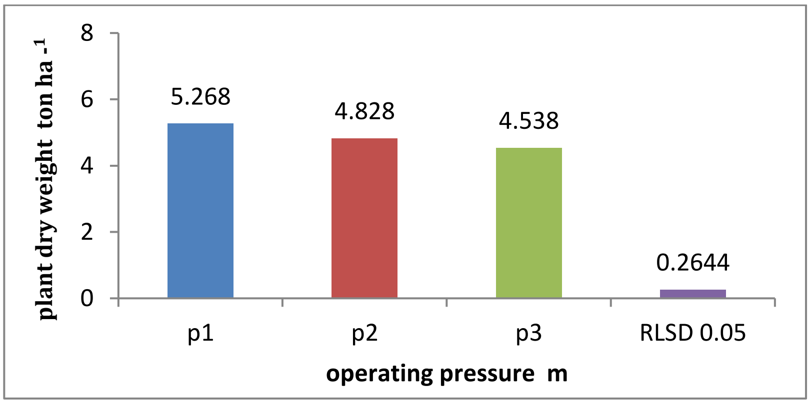

Figure 7. Effect of operating pressure on plant dry matter (tons ha^{-1})

The results of the statistical analysis of the F-test (Table2) showed a highly significant interaction effect between operating pressure and irrigation level on the dry matter of the vegetative parts at the end of the growing season (Figure 8). The interaction treatment (P1×I1) showed the highest value (5.562 tons ha^{-1}), followed by (P1×I2), then the treatments (P2×I1) and (P2×I2), while the lowest values were recorded with (P3×I2). This superiority is attributed to the synergy between high pressure and water availability, which improves moisture distribution and the speed of wetting front interaction, enhancing water availability and root spread, thus increasing uptake efficiency and dry matter accumulation. Conversely, low irrigation level or pressure leads to reduced distribution efficiency and increased water stress, negatively impacting plant growth. These results are consistent with those of Kang et al. (2017) that the efficiency of water use in drip irrigation systems depends on the interaction between the operating pressure and the level of water supply, as achieving a balance between them contributes to improving soil moisture and increasing growth and productivity, while any imbalance in one of them leads to a decrease in system efficiency and plant production.

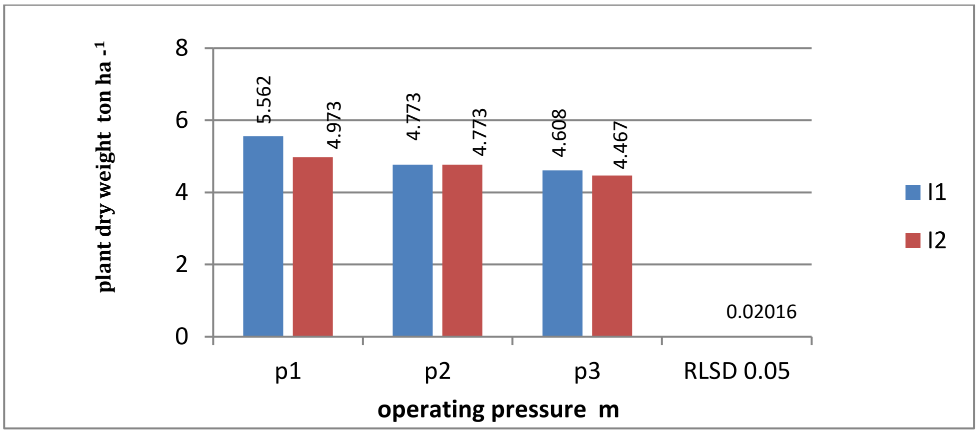

Figure 8. Effect of the interaction between operating pressure and irrigation level on plant dry matter (tons ha-1)

The results of the F-test (Table 2) showed a highly significant interaction between operating pressure and the spacing between field pipes on the dry matter of the vegetative parts at the end of the growing season (Figure 9). The (P1×S1) treatment showed the highest value (5.629 tons ha^{-1}), followed by (P1×S2), while the lowest values were recorded with (P3×S3). This superiority is attributed to the correlation between high pressure and optimal spacing, which improves water distribution and enhances the overlapping of wetting fronts. This increases water availability, root spread, and absorption efficiency, thus leading to dry matter accumulation. Conversely, wide spacing or low pressure leads to reduced water distribution efficiency, which limits plant growth. These results are consistent with what Kang et al. (2017) indicated, namely that an imbalance among the components of a drip irrigation system leads to reduced water use efficiency and decreased plant productivity.

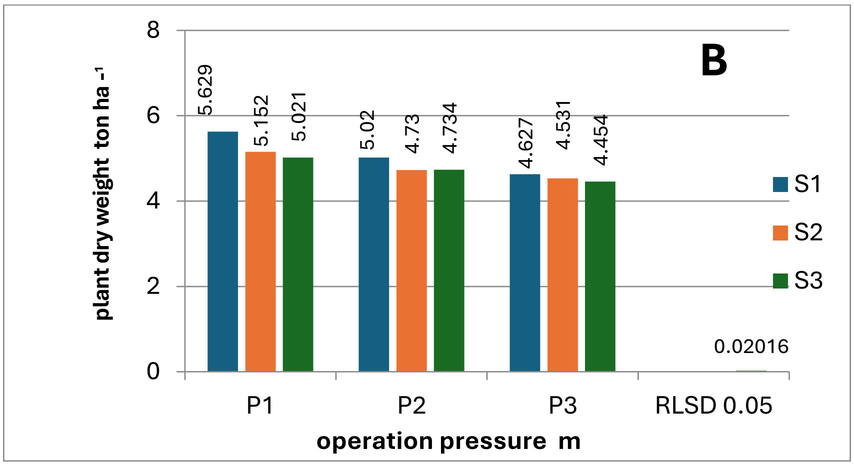

Figure 9. Effect of the interaction between operating pressure and the distance between field pipes on plant dry matter (ton ha^{-1})

grain yield

The results of the statistical analysis of the F-test (Table2) showed a significant effect of the distance between field pipes on grain yield (Figure 10). The 20 cm treatment (S1) recorded the highest yield (6.636 t ha^{-1}), followed by 30 cm (S2) (6.231 t ha^{-1}), and then 40 cm (S3) (6.084 t ha^{-1}), with percentage decreases of 6.10% and 8.31%, respectively, compared to S1. This superiority is attributed to improved uniformity of moisture distribution resulting from the effective overlap of wetting fronts, which enhances water and nutrient uptake and increases growth efficiency and grain formation. Conversely, a wider distance leads to weaker overlap of wetting fronts and the emergence of relatively dry areas, causing partial water stress and negatively impacting productivity. These results are consistent with those of Li et al. (2018) that choosing the optimal distance between drip irrigation lines contributes to improving moisture distribution in the soil and increasing water use efficiency, leading to improved plant growth and increased grain yield, while inappropriate spacing reduces system efficiency and productivity.

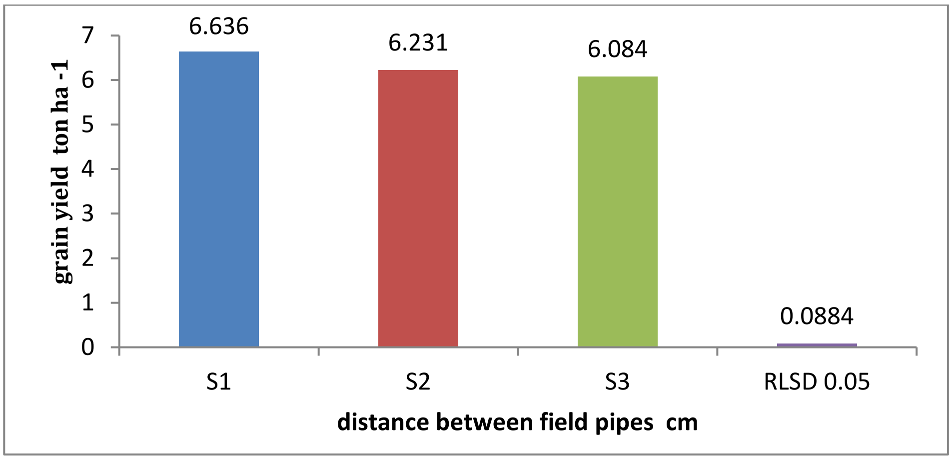

Figure 10. Effect of distance between field pipes on grain yield (ton ha- 1)

The results of the statistical analysis of the F-test (Table 2) showed a significant effect of irrigation level on grain yield(Figure11) The full irrigation treatment (I1, 100% Ep) recorded the highest yield (6.478 tons ha^{-1}), compared to the irrigation treatment (I2, 80% Ep) which yielded (6.156 tons ha^{-1}), with percentage decrease of 4.97%.This superiority is attributed to the availability of sufficient water, which improves soil properties and enhances the efficiency of physiological processes and nutrient absorption, thus positively impacting grain formation. Conversely, reducing the irrigation level leads to water stress, limiting growth and photosynthetic efficiency, which negatively affects productivity. These results are consistent with the findings of Fereres and Soriano (2007), who stated that reducing irrigation levels leads to decreased crop productivity due to the impact of water stress on physiological processes, while providing sufficient water promotes growth and increases grain yield.

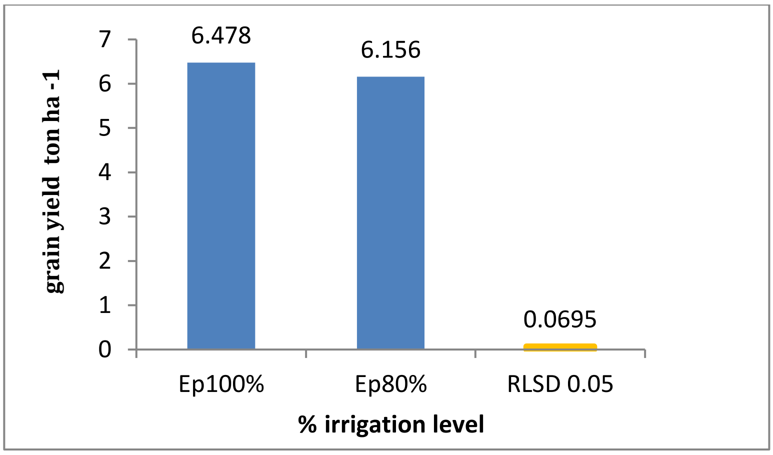

Figure 11. Effect of irrigation level on grain yield (ton ha- 1)

The results of the statistical analysis of the F-test (Table 2) showed a significant effect of operating pressure on grain yield (Figure 12). The high-pressure treatment (P1) recorded the highest yield (6.952 t ha^{-1}), followed by (P2) (6.206 t ha^{-1}), and then (P3) (5.793 t ha^{-1}), with percentage decreases of 10.7% and 16.67%, respectively, compared to P1. This superiority is attributed to improved drip irrigation, increased uniformity of moisture distribution, and more effective salt leaching, which enhances water and nutrient uptake and root spread, positively impacting plant growth and grain formation. Conversely, low pressure leads to poor water distribution and uneven moisture distribution, causing water stress and negatively affecting productivity. These results are consistent with those of Burt et al. (1997). Choosing the appropriate operating pressure in drip irrigation systems improves the hydrological and physical properties of the soil, reduces moisture stress, and increases the efficiency of water and nutrient absorption, which is reflected in the physiological processes of the plant, such as vegetative growth and grain yield.

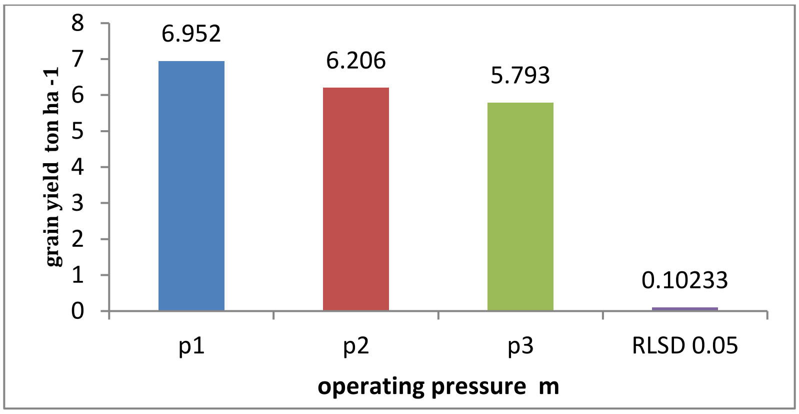

Figure 12. Effect of operating pressure (m) on grain yield (tons, ha-1)

water use efficiency

The results of the statistical analysis of the F-test (Table 2) showed a significant effect of the spacing between field pipes on water use efficiency (Figure 13), with treatment (S1) recording the highest value (0.757 kg m^{-2} mm^{-1}), followed by (S2) (0.7124 kg m^{-2} mm^{-1}), and then (S3) (0.6945 kg m^{-2} mm^{-1}), with percentage decreases of 5.89% and 8.26%, respectively, compared to S1. This superiority is attributed to increased overlap of wetting fronts and improved uniformity of moisture distribution, which enhances water availability for uptake and reduces plant water stress. It also improves salt leaching and soil properties, positively impacting growth, productivity, and water use efficiency. Conversely, a wider spacing leads to decreased distribution efficiency and increased water stress, thus limiting water use efficiency. These results are consistent with what (Radi, 2023) indicated: that growth indicators such as grain yield, plant height, and water use efficiency increase with a decrease in the distance between field pipes.

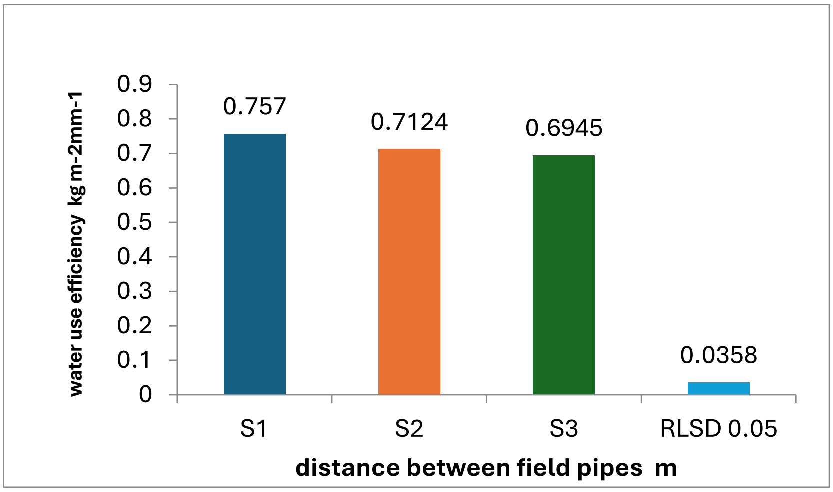

Figure 13. Effect of the distance between field pipes on water use efficiency kg m-2 mm-1

The results of the F-test (Table 2) statistical analysis showed a significant effect of irrigation level on water use efficiency (Figure 14). The 80% Ep irrigation level recorded the highest value (0.7818 kg m^{-2} mm^{-1}) compared to the 100% Ep level (0.6607 kg m^{-2} mm^{-1}), with an increase of 18.33%. This is attributed to the fact that increasing the irrigation level improves water availability and supports physiological processes. However, the increase in water use efficiency is not directly proportional to the increase in yield due to the influence of growth-specific factors such as genetic characteristics and the interaction of environmental factors. Therefore, the yield response to increased irrigation is non-linear, despite improvements in growth and production indicators. These results are consistent with those reported by Sahouki et al. (2013) and Dheyab et al. (2024).

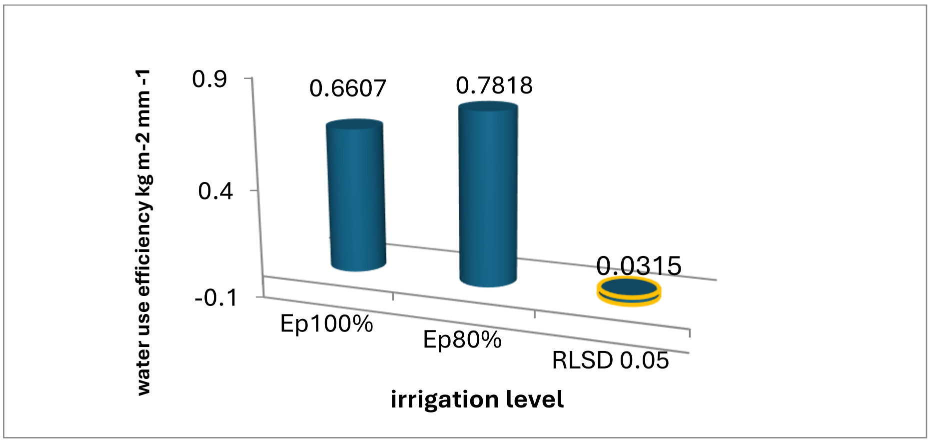

Figure 14. Effect of irrigation level on water use efficiency kg m-2 mm-1

The results of the statistical analysis of the F-test (Table 2) showed a significant effect of operating pressure on water use efficiency (Figure 15), with the high-pressure treatment (P1) registering the highest value (0.794 kg m^{-2} mm^{-1}), followed by (P2) (0.7081 kg m^{-2} mm^{-1}), and then (P3) (0.6618 kg m^{-2} mm^{-1}), showing percentage decreases of 10.82% and 16.65%, respectively, compared to P1. This superiority is attributed to improved dripper discharge, increased uniformity of moisture distribution, and a wider wetting front, which enhances water availability and nutrient uptake, as well as improving salt leaching and soil properties. Conversely, low pressure leads to poor water distribution and uneven moisture distribution, thus limiting water use efficiency. These results are consistent with what was indicated by (Radi, 2023) regarding the increase in water use efficiency values with increased dripper discharge due to increased efficiency in leaching and removing salts away from the root zone distribution area, and an increase in the size and area of the wetting fronts with increased dripper discharge.

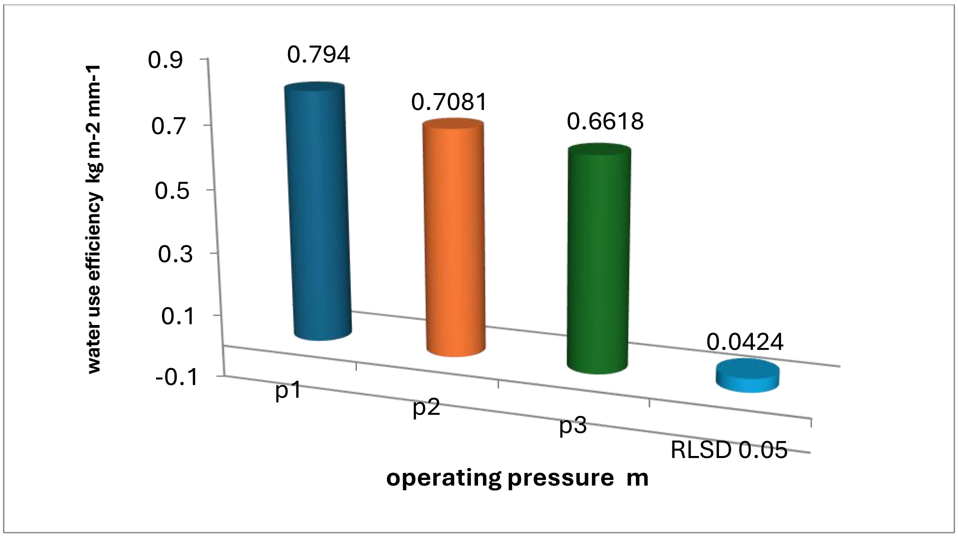

Figure 15. Effect of operating pressure on water use efficiency kg m-2 mm-1

Table 2. Statistical analysis of the f-test for plant growth indicators

Factor	Degrees of Freedom d.f	Plant height	Dry matter of the Vegetative Part	grain Yield	Water use Efficiency WUE
P	2	3.64**	104.16**	117.53**	81.00**
I	1	8.80**	45.43**	26.36**	198**
S	2	13.12**	27.43**	27.76**	18.6**
P.I	2	0.62 ns	13.79**	0.48ns	0.08 ns
P.S	4	0.22 ns	3.94**	1.28 ns	1. 0 ns

I.S	2	0.95^{ns}	1.09^{ns}	1.53^{ns}	0.6^{ns}
P.I.S	4	0.25^{ns}	1.69^{ns}	0.55^{ns}	0.5^{ns}

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