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EFFECT OF ZERO-TILLAGE FARMING SYSTEMS ON SOIL PHYSICAL PROPERTIES, GROWTH, AND YIELD OF WHEAT UNDER DIFFERENT IRRIGATION SYSTEMS IN AL-YUSUFIYA, CENTRAL IRAQ

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Abstract:
Rapid population growth in arid and semi-arid regions, coupled with rising living standards, has intensified the demand for food. Wheat (*Triticum aestivum* L.) is a strategic crop for food security in Iraq and other semi-arid countries, where efficient water and soil management are essential for sustainable production. A field experiment was conducted during the 2023–2024 growing season in a farmer's field located in the Yusufiyah region, approximately 15 km southwest of Baghdad, Iraq (33°07′84″ N, 44°18′75″ E, 34.1 m a.s.l.). The study evaluated the effects of three irrigation systems (sprinkler, drip, and surface), three seed rates (30, 40, and 50 kg/ha), and three tillage systems (disc opener, chisel opener, and broadcaster) on wheat growth, yield, soil physical properties, and irrigation efficiency. The results demonstrated that plant height was significantly influenced by irrigation and tillage, with the sprinkler–chisel combination producing the tallest plants. Grain yield, biological yield, and harvest index were not significantly affected, reflecting stability across treatments and offering management flexibility. Soil porosity improved significantly under sprinkler irrigation and chisel tillage, while soil penetration resistance remained unchanged, indicating minimal compaction differences. Irrigation efficiency analysis revealed that sprinkler performance increased with operating pressure, while drip irrigation achieved optimal efficiency at ~100 kPa. vegetative growth was more responsive to irrigation and tillage practices than yield components, which remained stable across management factors. Chisel tillage enhanced soil porosity without increasing compaction, and efficient irrigation management improved water use efficiency. It is recommended that farmers in semi-arid regions adopt sprinkler irrigation combined with chisel tillage to improve plant growth and soil structure, while drip irrigation should be managed at moderate pressure (~100 kPa) to optimize efficiency and conserve water resources.

Keywords: Wheat, Zero-Tillage, Irrigation Systems, Soil Properties

1. INTRODUCTION
About 15% of the world's population (~841 million) lives in arid and semi-arid regions, with 524 million in semi-arid areas (Barakat, 2009). Population growth and rising living standards have increased food demand, challenging food security where water and agricultural resources are limited (Millennium Ecosystem Assessment, 2005). Wheat (Triticum aestivum L.) is a key cereal for global and national food security, occupying significant cultivated land and contributing to international trade (FAO, 2003; FAOSTAT, 2013).

In Iraq, wheat underpins food security and rural livelihoods, with about one million hectares allocated for its cultivation. Al-Suwaira District, south of Baghdad, is a major wheat-producing area. However, wheat production faces challenges including drought, soil degradation, conventional tillage, and inefficient water use, contributing to declining yields and increased food insecurity (FAO, IFAD, WFP, 2015).

Problem Justification
Conventional tillage in Iraq disrupts soil structure, increases erosion and compaction, and reduces water and nutrient efficiency. Zero-tillage, a conservation agriculture practice, minimizes soil disturbance, improves soil structure and

moisture retention, and can enhance wheat productivity. Its adoption remains limited, and interactions with different irrigation systems are not well-studied. Efficient tillage and irrigation management are therefore essential for sustainable wheat production.

Research Objectives

General Objective:

To evaluate the effects of zero-tillage and irrigation systems on soil, wheat growth, and yield to improve productivity and resource use efficiency.

Specific Objectives:

1. Assess the impact of irrigation methods on soil properties, wheat growth, and yield.
2. Examine the effects of seed rates and planting methods on wheat performance.
3. Identify key factors influencing soil and plant characteristics.
4.

2. MATERIALS AND METHODS

2.1 Experimental Site

The field experiment was conducted during the 2023–2024 winter growing season at Al-Yusufiya, approximately 15 km southwest of Baghdad, Iraq (33°07′84″ N, 44°18′75″ E, 34.1 m a.s.l.). The region has a semi-arid climate with mild winters and limited rainfall during the growing season. The soil is classified as loam to clay loam with moderate fertility and good natural drainage.

2.2 Experimental Design and Treatments

The experiment was arranged in a factorial randomized complete block design (RCBD) with three replications. Treatments consisted of:

- Irrigation systems: sprinkler irrigation, drip irrigation, and surface irrigation;
- Planting methods (zero tillage): disc opener, chisel opener, and broadcasting;
- Seeding rates: 30, 40, and 50 kg dunam^{-1}.

Standard agronomic practices for wheat production in the region were followed throughout the growing season.

2.3 Data Collection

Measured parameters included plant height, number of tillers per plant, biological yield, grain yield, and harvest index. Soil physical properties, including penetration resistance and soil porosity, were determined at appropriate growth stages. Irrigation system performance indicators—coefficient of uniformity (CU), application efficiency (AE), distribution uniformity (DU), and coefficient of variation (CV)—were evaluated according to standard irrigation assessment procedures (Allen et al., 1998).

2.4 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) to evaluate the effects of the studied factors and their interactions, and treatment means were compared using the least significant difference (LSD) test at a probability level of $p \leq 0.05$, following standard statistical procedures (Gomez and Gomez, 1984; Steel et al., 1997

RESULTS AND DISCUSSION

The results in Table 1 show that wheat plant height was significantly influenced by irrigation systems (IS) and seed rate (SR), while no-tillage planting systems (M) did not have a significant effect. The interaction between IS and SR was also significant, indicating that the effect of seed rate on plant height differed among the irrigation systems. However, the three-way interaction (IS × SR × M) and other two-way interactions (IS × M, SR × M) were not significant.

Wheat plants grown under sprinkler irrigation recorded the tallest plants (average 105.24 cm), followed by drip irrigation (94.10 cm), while surface irrigation produced the shortest plants (79.42 cm). This suggests that sprinkler irrigation provided more favorable soil moisture distribution and aeration, promoting vegetative growth and internode elongation. Similar results were reported by Ahmed et al. (2018), who found that sprinkler irrigation enhanced plant growth in wheat compared to traditional surface irrigation due to improved water-use efficiency.

Regarding seed rate, plants grown with 40 kg/dunam had the greatest average height (96.09 cm), compared with 30 kg/dunam (92.68 cm) and 50 kg/dunam (89.99 cm). This indicates that moderate seeding density allowed optimal resource utilization without excessive competition, while higher seed rate (50 kg/dunam) reduced plant height due to increased intra-specific competition for nutrients and light. This finding is in line with Hussein et al. (2020), who reported that excessive seed density may restrict individual plant growth in cereals.

The non-significant effect of planting systems (M) shows that plant height was not strongly affected by the method of sowing (disc, chisel, or scattering). This suggests that water availability and seed rate were more decisive factors for vertical growth than the physical placement of seeds under no-tillage conditions.

The experimental precision was high, as reflected by the low coefficient of variation (CV = 2.5%) and SE ± (1.34), indicating reliability and accuracy of the results.

Table 1. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Plant Height(cm) (H.P) .

		no-tillage planting systems (M)	IS* SR

Irrigation systems(IS)	Seed rate(SR) kg/dunam	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	109.16	103.27	94.84	102.42	
	40	121.91	113.05	103.68	112.88	
	50	102.76	102.36	96.15	100.42	
Drip	30	100.31	90.91	90.14	93.79	
	40	92.05	97.81	90.28	93.38	
	50	99.68	92.79	92.90	95.12	
Surface	30	83.76	82.75	79.00	81.84	
	40	89.74	80.97	75.34	82.02	
	50	74.04	76.16	73.04	74.41	
LSD I*SR*M			N.S		LSD I*SR	4.726
SE ±			1.34			
CV %			2.5%			

IS*M

Irrigation system	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler	111.27	106.22	98.22	105.24	
Drip	97.35	93.84	91.11	94.10	
Surface	82.51	79.96	75.79	79.42	
LSD IS*M		N.S		LSD IS	2.729

SR*M

Seed rate(SR)		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems
30		97.74	92.31	87.99	92.68
40		101.23	97.27	89.77	96.09
50		92.16	90.43	87.37	89.99
LSD SR	2.729		N.S		LSD SR*M

M

No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	97.05	93.34	88.38
LSD M	2.729		

The results in Table 2 indicate that the number of tillers (NO.T) in wheat was significantly influenced by the irrigation systems (IS) and seed rate (SR), while the planting systems (M) showed no significant effect. The interaction between irrigation systems and seed rate (IS × SR) was also significant, suggesting that the response of tiller production to seed rate varied depending on the irrigation system used. However, the other interactions (IS × M, SR × M, and IS × SR × M) were not significant.

The higher number of tillers under drip and surface irrigation systems compared to sprinkler irrigation may be attributed to the more efficient soil moisture distribution and availability of water in the root zone. This steady moisture supply enhances tiller initiation and survival, as reported by Singh et al. (2015), who found that consistent soil moisture promotes better vegetative growth in cereals.

Regarding seed rate, increasing seeding density generally improved tiller numbers, particularly under drip irrigation, where seed rates of 40–50 kg/dunam produced higher tiller counts. This agrees with findings by Abdalla et al. (2019), who noted that higher seed rates can enhance plant population and tiller production up to an optimum threshold, beyond which intra-specific competition may reduce effectiveness.

The non-significant effect of planting systems (M) indicates that the method of seed placement (disc, chisel, or scattering) did not play a decisive role in tiller production under the conditions of this study. This may be due to the overriding influence of water availability and seed density, which are the primary drivers of tiller initiation in wheat.

The low values of CV% (4.0) and SE ± (0.3) demonstrate high experimental precision, confirming the reliability of the observed differences among treatments.

Table 2. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Number of Tiller (NO.T) .

Irrigation systems(IS)	Seed rate (SR) kg/dunam	no-tillage planting systems (M)			IS* SR	
		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	10.33	11.00	10.67	10.67	
	40	11.67	10.67	11.00	11.11	
	50	12.33	13.67	12.33	12.78	
Drip	30	14.33	13.33	12.67	13.44	
	40	14.33	14.67	15.00	14.67	
	50	14.67	15.33	14.67	14.89	
Surface	30	13.00	13.67	15.00	13.89	
	40	14.67	14.33	14.67	14.56	
	50	14.67	15.33	14.00	14.67	
LSD I*SR*M		N.S			LSD I*SR	0.615
SE ±		0.3				
CV %		4.0 %				
IS*M						

Irrigation system	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler	111.27	106.22	98.22	105.24	
Drip	97.35	93.84	91.11	94.10	
Surface	82.51	79.96	75.79	79.42	
LSD IS*M	N.S			LSD IS	0.615

SR*M

Seed rate(SR)		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems
30		97.74	92.31	87.99	92.68
40		101.23	97.27	89.77	96.09
50		92.16	90.43	87.37	89.99
LSD SR	0.615	N.S			LSD SR*M

M

No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	97.05	93.34	88.38
LSD M	N.S		

The results presented in Table 3 demonstrate significant differences in grain yield as influenced by irrigation systems, seed rates, and no-tillage planting systems. Regarding irrigation systems (IS), sprinkler irrigation achieved the highest average grain yield (7.422 kg/dunam), followed by drip irrigation (7.138 kg/dunam), while surface irrigation produced the lowest yield (6.763 kg/dunam). This pattern highlights the importance of uniform water distribution and efficient water use, as sprinkler irrigation provides better soil moisture coverage and reduces water losses through evaporation and runoff, compared to surface irrigation.

Concerning seed rate (SR), the results indicate that a moderate rate of 40 kg/dunam produced the highest grain yield (7.221 kg/dunam), compared to 30 kg/dunam (7.179 kg/dunam) and 50 kg/dunam (6.923 kg/dunam). The decrease in yield at the higher seed rate may be attributed to increased competition among plants for water, nutrients, and light, which negatively affects individual plant growth and final productivity.

Regarding no-tillage planting systems (M), the disc planting system (M1) resulted in the highest average yield (7.319 kg/dunam), followed by chisel planting (M2, 7.138 kg/dunam), whereas scattering seeds randomly (M3) produced the lowest yield (6.866 kg/dunam). The higher yields of organized planting systems can be explained by better seed placement, soil aeration, and root development, which collectively enhance crop establishment and growth.

Although the three-way interaction (IS × SR × M) was not statistically significant (N.S.), indicating that each factor independently influences grain yield, the two-way interactions provide valuable insights. The interaction between irrigation system and planting system (IS × M) was significant (LSD = 0.148), showing that sprinkler irrigation combined with disc planting (M1) produced the highest yield, while surface irrigation with scattered planting yielded the lowest. Similarly, the interaction between seed rate and planting system (SR × M) suggests that a seed rate of 40 kg/dunam combined with disc or chisel planting maximizes productivity.

The statistical reliability of the experiment is supported by a low coefficient of variation (CV = 3%) and an acceptable standard error (SE ± = 0.08), indicating consistency among replicates.

Table 3. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Grain Harvest (Kg) (G.H) .

<table>
<tr><td rowspan="2">Irrigation systems(IS)</td><td rowspan="2">Seed rate (SR) kg/dunam</td><td colspan="3">no-tillage planting systems (M)</td><td rowspan="2" colspan="2">IS* SR</td></tr>
<tr><td>Disc vacuoles (M1)</td><td>Chisel vacuoles (M2)</td><td>scattering wheat seeds (M3)</td></tr>
<tr><td rowspan="3">Sprinkler</td><td>30</td><td>7.990</td><td>7.327</td><td>7.117</td><td colspan="2">7.478</td></tr>
<tr><td>40</td><td>8.140</td><td>7.677</td><td>7.237</td><td colspan="2">7.684</td></tr>
<tr><td>50</td><td>7.197</td><td>7.130</td><td>6.987</td><td colspan="2">7.104</td></tr>
<tr><td rowspan="3">Drip</td><td>30</td><td>7.350</td><td>7.220</td><td>7.073</td><td colspan="2">7.214</td></tr>
<tr><td>40</td><td>7.307</td><td>7.207</td><td>6.993</td><td colspan="2">7.169</td></tr>
<tr><td>50</td><td>7.163</td><td>6.990</td><td>6.940</td><td colspan="2">7.031</td></tr>
<tr><td rowspan="3">Surface</td><td>30</td><td>6.993</td><td>6.963</td><td>6.577</td><td colspan="2">6.844</td></tr>
<tr><td>40</td><td>6.957</td><td>6.997</td><td>6.480</td><td colspan="2">6.811</td></tr>
<tr><td>50</td><td>6.773</td><td>6.730</td><td>6.393</td><td colspan="2">6.632</td></tr>
<tr><td colspan="2">LSD I*SR*M</td><td colspan="3">N.S</td><td>LSD I*SR</td><td>0.148</td></tr>
<tr><td colspan="3">SE ±</td><td colspan="4">0.08</td></tr>
<tr><td colspan="3">CV %</td><td colspan="4">3 %</td></tr>
<tr><td colspan="7">IS*M</td></tr>
<tr><td colspan="2">Irrigation system</td><td>Disc vacuoles (M1)</td><td>Chisel vacuoles (M2)</td><td>scattering wheat seeds (M3)</td><td colspan="2">Average irrigation systems</td></tr>
<tr><td colspan="2">Sprinkler</td><td>7.776</td><td>7.378</td><td>7.113</td><td colspan="2">7.422</td></tr>
<tr><td colspan="2">Drip</td><td>7.273</td><td>7.139</td><td>7.002</td><td colspan="2">7.138</td></tr>
<tr><td colspan="2">Surface</td><td>6.908</td><td>6.897</td><td>6.483</td><td colspan="2">6.763</td></tr>
<tr><td colspan="2">LSD IS*M</td><td colspan="3">0.148</td><td>LSD IS</td><td>0.086</td></tr>
<tr><td colspan="7">SR*M</td></tr>
<tr><td colspan="2">Seed rate(SR)</td><td>Disc vacuoles (M1)</td><td>Chisel vacuoles (M2)</td><td>scattering wheat seeds (M3)</td><td colspan="2">Average irrigation systems</td></tr>
<tr><td colspan="2">30</td><td>7.444</td><td>7.170</td><td>6.922</td><td colspan="2">7.179</td></tr>
<tr><td colspan="2">40</td><td>7.468</td><td>7.293</td><td>6.903</td><td colspan="2">7.221</td></tr>
<tr><td colspan="2">50</td><td>7.044</td><td>6.950</td><td>6.773</td><td colspan="2">6.923</td></tr>
<tr><td>LSD SR</td><td>0.086</td><td colspan="3">0.148</td><td colspan="2">LSD SR*M</td></tr>
<tr><td colspan="7">M</td></tr>
</table>

No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	7.319	7.138	6.866
LSD M	0.086		

The results in Table 4 demonstrate that biological harvest of wheat was significantly affected by irrigation systems (IS), seed rate (SR), and their interactions. The three-way interaction (IS × SR × M) was highly significant, which indicates that the effect of seed rate and planting system varied across irrigation methods.

Among irrigation systems, sprinkler irrigation achieved the highest average biological harvest (18.56 kg), followed by drip irrigation (17.36 kg), while surface irrigation produced the lowest (16.14 kg). The superiority of sprinkler irrigation can be attributed to its uniform water distribution, better soil moisture management, and enhanced nutrient uptake, which collectively improved biomass accumulation. These results agree with Al-Karaki (2011) and Kahlown and Ashraf (2005), who reported that sprinkler irrigation enhances water-use efficiency and plant biomass in cereals compared with conventional surface irrigation.

With respect to seed rate, using 40 kg/dunam resulted in the highest average biological harvest (17.14 kg), compared with 30 kg/dunam (17.02 kg) and 50 kg/dunam (16.84 kg). This indicates that moderate seeding density maximized biomass production by balancing plant population and resource availability. Lower seed rate reduced total biomass due to fewer plants per unit area, while higher density increased competition among plants for water, nutrients, and light, thereby reducing individual growth and total harvest. Similar findings were observed by Hussein et al. (2020) in wheat production under semi-arid conditions.

Regarding no-tillage planting systems (M), although the differences were smaller, the disc vacuoles system (M1) produced slightly higher biomass (17.62 kg) compared with chisel vacuoles (17.43 kg) and scattering method (17.00 kg). This trend suggests that disc planting ensured better seed-soil contact and early establishment, which translated into higher dry matter accumulation.

The very low coefficient of variation (CV = 0.43%) and small standard error (SE ± = 0.076) indicate high precision and reliability of the experiment.

Table 4. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Biological harvest (Kg) (B.H)

Irrigation systems(IS)	Seed rate (SR) kg/dunam	no-tillage planting systems (M)			IS* SR	
		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	18.76	18.32	17.96	18.34	
	40	19.49	19.65	18.45	19.20	
	50	18.33	18.15	17.94	18.14	
Drip	30	17.46	17.23	17.14	17.27	
	40	18.10	17.72	17.23	17.68	
	50	17.37	17.17	16.78	17.11	
Surface	30	16.27	16.21	15.96	16.15	
	40	16.68	16.35	15.74	16.26	
	50	16.15	16.09	15.81	16.02	
LSD I*SR*M		0.2629 ***			LSD I*SR	0.1518
SE ±		0.076				
CV %		0.43%				

IS*M					
Irrigation system	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler	18.86	18.71	18.12	18.56	
Drip	17.64	17.37	17.05	17.36	
Surface	16.37	16.22	15.84	16.14	
LSD IS*M	0.1518			LSD IS	0.0876

SR*M					
Seed rate(SR)		Disc vacuoles(M1)	Chisel vacuoles(M2)	scattering wheat seeds (M3)	Average irrigation systems
30		17.49	17.25	17.02	17.02
40		18.09	17.91	17.14	17.14
50		17.28	17.14	16.84	16.84
LSD SR	0.0876	0.1518			LSD SR*M

M			
No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	17.62	17.43	17.00
LSD M	0.0876		

The results in Table 5 indicate that harvest index (H.I), representing the efficiency of the crop in partitioning biomass into grain, was influenced by irrigation systems, seed rates, and no-tillage planting methods, although the three-way interaction (IS × SR × M) and the two-way interaction between irrigation and seed rate (IS × SR) were not statistically significant.
Among irrigation systems (IS), the highest average harvest index was observed under surface irrigation (42.21–42.51%) with disc or chisel planting, followed closely by drip irrigation (41.07–41.23%), and slightly lower values under sprinkler irrigation (39.27–41.21%). This suggests that while sprinkler irrigation may maximize absolute grain yield (as shown in Table 3), surface and drip irrigation can be slightly more efficient in converting total biomass into grain under certain planting systems.
For seed rates (SR), a clear trend was observed: the lowest seed rate (30 kg/dunam) produced the highest harvest index (41.63%), followed by 40 kg/dunam (40.81%), and the highest seed rate (50 kg/dunam) resulted in the lowest harvest index (40.55%). This pattern indicates that excessively high plant densities may increase vegetative growth relative to grain formation, thereby reducing the proportion of biomass allocated to grain.
Regarding no-tillage planting systems (M), disc vacuoles (M1) achieved the highest average harvest index (41.55%), followed by chisel vacuoles (M2, 41.01%), while scattering seeds (M3) recorded the lowest value (40.42%). This highlights the importance of organized planting systems in enhancing biomass partitioning efficiency.
The two-way interaction between irrigation system and planting system (IS × M) was significant (LSD = 0.8407), indicating that surface irrigation combined with disc or chisel planting resulted in the highest harvest index, whereas sprinkler irrigation with scattered planting produced the lowest. In contrast, interactions involving seed rate (SR × M) were not significant, suggesting that planting system effects on H.I are relatively consistent across different seed rates. Statistical reliability is supported by a low coefficient of variation (CV = 1.25%) and a standard error of SE ± 0.0876, indicating high consistency among replicates.

Table 5. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Harvest Index (%) (H.I) .

Irrigation systems(IS)	Seed rate(SR) kg/dunam	no-tillage planting systems (M)			IS* SR	
		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	42.60	40.00	39.63	40.75	
	40	41.76	39.05	39.22	40.01	
	50	39.26	39.27	38.95	39.16	
Drip	30	42.10	41.91	41.26	41.76	
	40	40.35	40.66	40.59	40.53	
	50	41.25	40.70	41.35	41.10	
Surface	30	42.98	42.95	41.20	42.38	
	40	41.72	42.78	41.17	41.89	
	50	41.93	41.81	40.43	41.39	
LSD I*SR*M		N.S			LSD IS*SR	N.S
SE ±		0.0876				
CV %		1.25				

IS*M					
Irrigation systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler	41.21	39.44	39.27	18.56	
Drip	41.23	41.09	41.07	17.36	
Surface	42.21	42.51	40.94	16.14	
LSD IS*M		0.8407		LSD IS	0.4854

SR*M					
Seed rate(SR)		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems
30		42.56	41.62	40.70	41.63
40		41.28	40.83	40.33	40.81
50		40.81	40.59	40.24	40.55
LSD SR	0.4854	N.S			LSD SR*M

M			
No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	41.55	41.01	40.42
LSD M	0.4854		

The results in Table 6 indicate that soil penetration resistance (SPR) was significantly affected by both irrigation systems (IS) and no-tillage planting methods (M), while interactions with seed rate (SR × M) and the three-way interaction (IS × SR × M) were less pronounced. The standard error (SE ±) for the measurements is 0.021 kPa, and the coefficient of variation (CV%) is 2.63%, reflecting high reliability and consistency of the data.
Among irrigation systems, sprinkler irrigation recorded the highest average SPR (2.676 kPa), followed by drip irrigation (2.207 kPa), and surface irrigation showed the lowest value (2.069 kPa). The elevated resistance under sprinkler irrigation can be attributed to localized soil compaction from water droplets impacting the soil surface, whereas surface irrigation allows gradual water distribution, reducing compaction.
Regarding planting systems, disc vacuoles (M1) and chisel vacuoles (M2) had higher SPR values (2.454 and 2.433 kPa, respectively) compared to scattering seeds (M3, 2.064 kPa). Structured planting concentrates mechanical pressure along planting rows, increasing penetration resistance, while scattered planting distributes pressure more evenly, reducing SPR.
Seed rate effects showed a moderate increase in SPR with higher seed rates, from 2.203 kPa at 30 kg/dunam to 2.377 kPa at 50 kg/dunam, indicating that denser plant populations slightly increase soil compaction.
The interaction between irrigation system and planting system (IS × M) was significant (LSD = 0.099), with sprinkler irrigation combined with disc vacuoles showing the highest SPR, and surface irrigation with scattering seeds the lowest. The SR × M interaction was not significant, indicating that the influence of planting systems on SPR is consistent across seed rates.

Table 6. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on soil penetration resistance (kPa)(NO.T) .

Irrigation systems(IS)	Seed rate(SR) kg/dunam	no-tillage planting systems (M)			IS* SR	
		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	2.410	2.587	2.173	2.390	
	40	3.187	2.843	2.197	2.742	
	50	3.373	3.153	2.157	2.894	
Drip	30	2.263	2.210	2.157	2.210	
	40	2.233	2.253	2.087	2.191	
	50	2.257	2.210	2.193	2.220	
Surface	30	1.987	2.170	1.870	2.009	
	40	2.183	2.377	1.983	2.181	
	50	2.190	2.093	1.763	2.016	
LSD I*SR*M		0.172			LSD IS*SR	0.099
SE ±			0.021			
CV %			2.63%			

IS*M					
Irrigation systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler	2.990	2.861	2.176	2.676	
Drip	2.251	2.224	2.146	2.207	
Surface	2.120	2.213	1.872	2.069	
LSD IS*M	0.099			LSD IS	0.057

SR*M					
Seed rate(SR)		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems
30		2.220	2.322	2.067	2.203
40		2.534	2.491	2.089	2.371
50		2.607	2.486	2.038	2.377
LSD SR	0.057	0.099			LSD SR*M

M			
No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	2.454	2.433	2.064
LSD M	0.057		

The results presented in Table 7 show that soil porosity was significantly influenced by irrigation systems and no-tillage planting methods, while interactions involving seed rate (SR × M) and the three-way interaction (IS × SR × M) were not significant. The calculated standard error (SE ±) is 0.0065, and the coefficient of variation (CV%) is 4.39%, indicating high precision and reliability of the measurements.

Among irrigation systems (IS), drip irrigation showed the highest average porosity (0.443%), followed by sprinkler irrigation (0.382%), whereas surface irrigation resulted in the lowest porosity (0.368%). This indicates that localized water application in drip irrigation helps maintain soil pore spaces and reduces compaction, while surface irrigation may slightly compress the soil.

Regarding no-tillage planting systems (M), chisel vacuoles (M2) and disc vacuoles (M1) had higher porosity (0.368–0.457%) compared to scattering seeds (M3, 0.359–0.444%). Structured planting likely preserves soil pores along planting rows, while scattered planting distributes mechanical pressure more randomly, slightly reducing porosity.

For seed rates (SR), the lowest rate (30 kg/dunam) resulted in slightly higher porosity (0.400%), while the highest rate (50 kg/dunam) reduced porosity (0.392%). This suggests that higher plant density slightly increases soil compaction, reducing pore space.

The interaction between irrigation system and planting system (IS × M) was significant (LSD = 0.009), with drip irrigation combined with disc or chisel planting showing the highest porosity, and surface irrigation with scattered planting the lowest. Other interactions, including SR × M, were not significant, indicating consistent planting system effects across different seed rates.

Table 7. Effects of different combinations of Irrigation systems (IS), Seed rate (SR), and no-tillage planting systems (M) on Soil porosity(%) (NO.T) .

		no-tillage planting systems (M)	IS* SR

Irrigation systems(IS)	Seed rate(SR) kg/dunam	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)		
Sprinkler	30	0.383	0.377	0.380	0.380	
	40	0.393	0.383	0.393	0.390	
	50	0.370	0.367	0.387	0.374	
Drip	30	0.443	0.460	0.467	0.457	
	40	0.430	0.453	0.443	0.442	
	50	0.407	0.457	0.423	0.429	
Surface	30	0.383	0.360	0.343	0.362	
	40	0.387	0.367	0.357	0.370	
	50	0.360	0.377	0.377	0.371	
LSD I*SR*M		N.S			LSD IS*SR	0.016
SE ±		0.0065				
CV %		4.39%				
IS*M						
Irrigation systems		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
Sprinkler		0.382	0.376	0.387	0.382	
Drip		0.427	0.457	0.444	0.443	
Surface		0.377	0.368	0.359	0.368	
LSD IS*M		0.009			LSD IS	0.016
SR*M						
Seed rate(SR)		Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)	Average irrigation systems	
30		0.403	0.399	0.397	0.400	
40		0.403	0.401	0.398	0.401	
50		0.379	0.400	0.396	0.392	
LSD SR	N.S	N.S			LSD SR*M	
M						

No-till farming systems	Disc vacuoles (M1)	Chisel vacuoles (M2)	scattering wheat seeds (M3)
Average farming systems	2.454	2.433	2.064
LSD M	N.S		

Table 8 illustrates the effect of operating pressure on the uniformity coefficient (CU), application efficiency (AE), and overall efficiency (OE) of the sprinkler irrigation system. The results clearly show that irrigation performance improved consistently with increasing operating pressure.

The uniformity coefficient increased from 46.93% at 200 kPa to 53.61% at 300 kPa, reaching a maximum of 81.80% at 400 kPa, indicating that higher pressures enhanced water distribution uniformity and reduced spatial variability across the field. Similarly, application efficiency showed a marked improvement, rising from 34.52% at 200 kPa to 69.62% at 300 kPa and 78.52% at 400 kPa, suggesting more effective use of applied water and reduced losses through runoff and deep percolation.

Overall efficiency, which integrates both uniformity and application efficiency, increased substantially from 16.20% at 200 kPa to 64.23% at 400 kPa. These findings confirm that operating pressure is a key determinant of sprinkler irrigation performance, with higher pressures significantly enhancing water use efficiency and minimizing irrigation losses.

Table.8 Effect of Different Operating Pressures on Uniformity Coefficient (CU), Application Efficiency (AE), and Overall Efficiency (OE) in Sprinkler Irrigation System.

Efficiency (%)	Operating Pressure (kPa)		
	200	300	400
Uniformity (CU)	46.93	53.61	81.80
Addition Efficiency (AE)	34.52	69.62	78.52
Overall Efficiency (OE)	16.20	37.32	64.23

Table 9 illustrates the effect of different operating pressures on the uniformity coefficient (CU), low-quarter distribution uniformity (DU), and coefficient of variation (CV) in a drip irrigation system. The results indicate that operating pressure influences water distribution, although drip systems maintain relatively high uniformity across all pressures.

Uniformity Coefficient (CU):

CU increased from 92.79% at 50 kPa to 97.45% at 100 kPa, and slightly decreased to 96.80% at 150 kPa.

These values suggest that moderate operating pressure (100 kPa) achieves optimal water distribution, while further increases do not significantly improve CU, likely due to system design constraints.

Low-Quarter Distribution Uniformity (DU):

DU followed a similar trend, increasing from 88.50% at 50 kPa to 95.82% at 100 kPa, and slightly decreasing to 92.72% at 150 kPa.

This indicates that water application in the least-watered quarter of the field is maximized at 100 kPa, ensuring more uniform crop water availability.

Coefficient of Variation (CV):

CV decreased from 24% at 50 kPa to 16% at 100 kPa, and further to 14% at 150 kPa.

Lower CV values indicate reduced variability in emitter discharge along the lateral lines, contributing to consistent soil moisture and better crop performance.

Table 9. Effect of Different Operating Pressures on Uniformity Coefficient (CU), Low-Quarter Distribution Uniformity (DU), and Coefficient of Variation (CV, qm) in Drip Irrigation System.

Operating Pressure (kPa)	CU (%)	DU (%)	CV (%)
50	92.79	88.50	24
100	97.45	95.82	16
150	96.80	92.72	14

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The results of this study demonstrated that irrigation systems, seed rates, and no-tillage planting systems significantly affected wheat growth, yield, and soil physical properties under the conditions of Baghdad. Sprinkler irrigation produced the highest plant height, biological yield, and grain yield compared with drip and surface irrigation systems. A seed rate of 40 kg/dunam achieved the best balance between plant density and resource utilization, resulting in improved growth and productivity. Among the planting systems, disc vacuoles (M1) provided better seed placement and crop establishment, leading to higher yield performance. Drip irrigation improved soil porosity and reduced soil penetration resistance compared with other irrigation systems. Irrigation system performance also improved with increasing operating pressure, where 400 kPa for sprinkler irrigation and around 100 kPa for drip irrigation produced the best irrigation efficiency and water distribution. Overall, appropriate irrigation management combined with optimal seed rate and planting method can enhance wheat productivity under Baghdad conditions.

RECOMMENDATIONS

1. Sprinkler irrigation is recommended for wheat production due to its superior performance in plant growth and grain yield.
2. Use a seed rate of 40 kg/dunam to achieve optimum plant density and higher productivity.
3. Apply the disc vacuoles planting system (M1) under no-tillage conditions for better crop establishment.
4. The combination sprinkler irrigation + disc planting (M1) + 40 kg/dunam is the most suitable practice for maximizing wheat yield.
5. Operate sprinkler irrigation systems at about 400 kPa to improve water distribution and irrigation efficiency.
6. Operate drip irrigation systems at around 100 kPa to obtain the best uniformity and reduce water loss

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