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Sustainability of Soil Physical Properties Using Mushroom Residues and Surface,Subsurface Drip Irrigation Under Different Irrigation Water Levels and Their Impact on Growth and Yield of Maize (Zea mays L.)

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ABSTRACT

Soil physical properties are critical for agricultural productivity due to their direct and indirect effects on crop yield. Sustaining these properties requires scientific and practical approaches to maintain soil productivity and optimize irrigation efficiency. A field experiment was conducted on a clay-loam soil to study the sustainability of soil physical properties using mushroom residues and surface/subsurface drip irrigation under varying water levels and their impact on maize growth and yield during the autumn season of 2024 at the Agricultural Research Station, University of Kirkuk. The experiment included three factors: Irrigation method (surface drip, subsurface drip). Water stress levels (100%, 65%, 45% of net irrigation depth). Mushroom residue application (with/without 0.2% residue by experimental unit weight). The experiment followed a randomized complete block design (RCBD) with split-split plot arrangement and three replicates. Irrigation was applied at 50% depletion of available water. Key findings:

Subsurface drip irrigation reduced bulk density (1.37 Mg m^{-3}) and increased mean weight diameter (1.21 mm), total porosity (53.98%), cumulative infiltration (98.5 cm hr^{-1}), plant height (210.41 cm), leaf area (5671.87 cm^2 $plant^{-1}$), and total seed yield (11.86 Mg ha^{-1}) compared to surface drip. 100% irrigation level minimized bulk density and maximized soil structural indices and maize yield. Conversely, 45% irrigation increased bulk density and reduced growth parameters. Mushroom residues improved soil physical/hydraulic properties and maize growth: bulk density (1.01 Mg m^{-3}), total porosity (57.52%), mean weight diameter (1.60 mm), plant height (227.46 cm), leaf area (5839.84 cm^2 $plant^{-1}$), and yield (12.92 Mg ha^{-1}).

***Keywords*:** Physical properties, mushroom residues, subsurface drip irrigation, irrigation levels, total yield, maize.

INTRODUCTION

Amid escalating water and climatic stress in the Arab region—where renewable water resources are projected to decline by 15–50% by 2050 [1][2]—sustaining soil physical properties is vital for agricultural resilience. Soil degradation causes annual fertility losses of up to 30% in arid lands [3][4], threatening food security amid rapid population growth.[5]

Organic residues offer sustainable solutions for soil quality enhancement. Adding 2–5 tons ha^{-1} of residues increases micro-aggregate stability by 40–65% [6] and improves moisture retention through humification. Integrating this with subsurface drip irrigation reduces evaporative losses to 5% vs. 30% in surface irrigation; [7] and supports deficit irrigation strategies (RDI) saving 25–40% water while maintaining 90% crop productivity.[8]

Maize (*Zea mays* L.) is a strategic cereal crop used for human consumption (oil, starch), animal feed, and industrial products, driving its expanding cultivation [9][10]. This study aims to sustain soil physical properties using mushroom residues and drip irrigation methods under varied water levels to enhance maize productivity.

Research Methodology:

Study Area

The field experiment was conducted at Kirkuk University's Agricultural Research Station (35°23′12.3″N, 44°20′38.3″E; Figure 1) on clay-loam soil during autumn 2024. The field was plowed, leveled, and divided into three blocks.

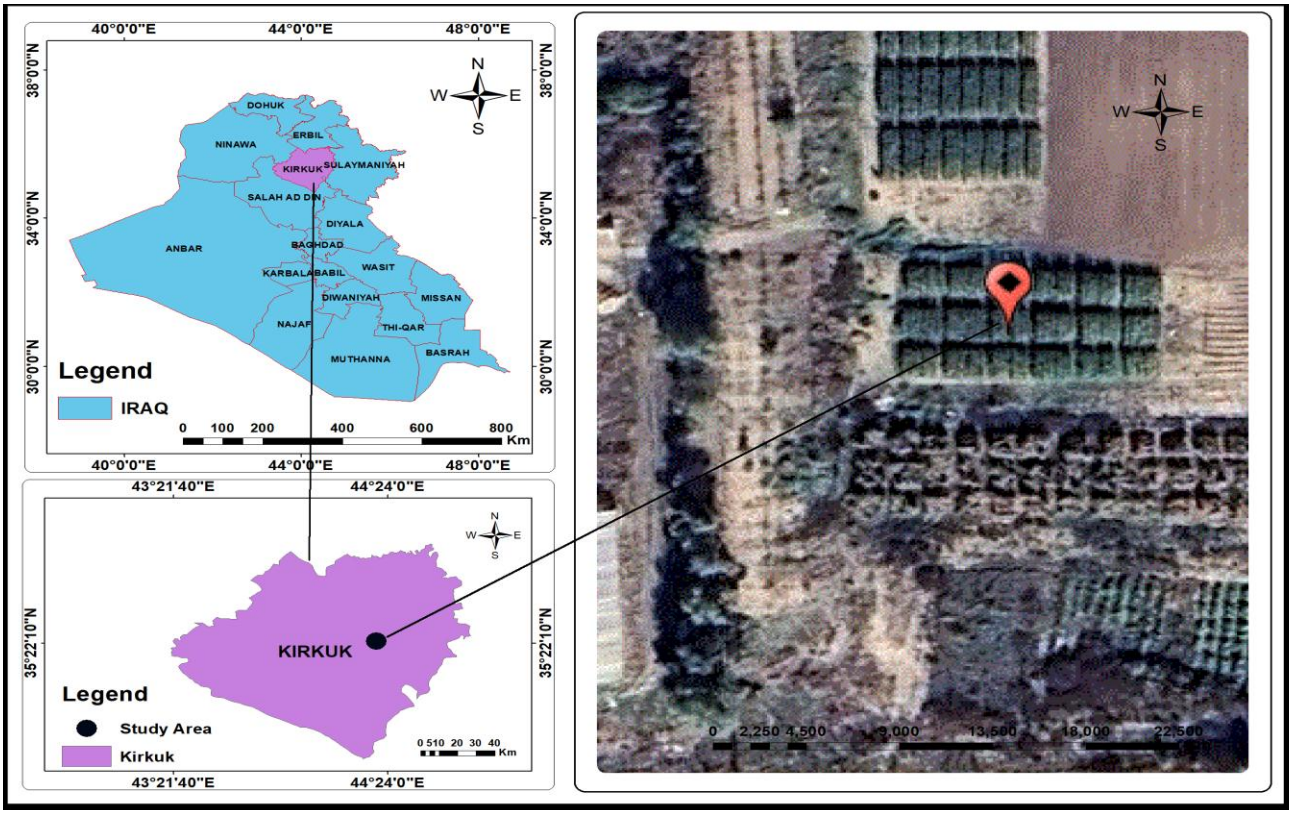


Figure 1. shows the location of field experiment implementation.

Experimental Design and Treatments

The study employed a split-split plot design (RCBD) with three replicates:

- Main plots: Drip irrigation method (D):
  - D_1: Surface drip.
  - D_2: Subsurface drip (20 cm depth).
- Sub-plots: Water stress levels (S):
  - S_0: 100% of net irrigation depth.
  - S_1: 65%.
  - S_2: 45%.
- Sub-sub-plots: Mushroom residues (O):
  - O_0: No residues.

The leftover from the mushroom farm obtained from a mushroom farm in sulaymaniya , was incorporated into soil measuring 0.5 m in width and 5 m in length, added at rate of 0.2% (w/w) based on the dry soil mass, to a depth of 0.30 m inside the soil profile. The experiment was conducted in three replications following the randomized complete block design (RCBD) with a Split-Split Plot Design distribution, resulting in a total of 12 treatments for the study.

The soil samples of the field were taken randomly and to a depth of 0-0.3 m then mixed with each other and airy dried, then passed through a sieve with a diameter of 2 mm mesh, finally, the analysis and measurements were executed. Table (1) shows some physical and chemical properties of the study soil before cultivation. The grains of maize of the American cultivar DKC6777 were planted on July 31, 2024 at 5 cm depth, at a rate of two grains for each pit. The distance between one plant and another was 0.2 m with a space of 0.75 m between one agricultural line and another, bringing the total number of plants for the experiment to 2,700 plants equal to 66,665 plants ha^{-1} [16].

Table 1. specific properties (physical and chemical) of study soil before cultivation for depth 0-0.30 m

Trait		Value	Unit
Electrical Conductivity		0.42	dS m^{-1}
Potential of hydrogen		7.77	
Organic matter		14.6	g kg^{-1}
Lime		29	g kg^{-1}
Gypsum		0	
Sand		348	g kg^{-1}
Silt		252	
Clay		400	
Texture class		Clayey Loam	
Bulk density		1.45	Mg m^{-3}
Volumetric soil moisture at tension (kPa)	33	0.34	cm^3 cm^{-3}
	1500	0.16	
Available water		0.18	cm^3 cm^{-3}

Irrigation

Along the experiment period, the well water of the Sayyadah area was adopted as a source of irrigation for the maize crop table (2). An operational pressure of 0.5 bar was utilized for the irrigation system throughout the study duration. Irrigation was implemented during planting to establish moisture equilibrium in the soil, contingent upon the soil moisture at field capacity and the initial moisture prior to irrigation. This was based on the irrigation water depth, adopting a root zone depth of 0.20 m. Hydraulic deficit treatments commenced at the onset of the vegetative growth stage, applying 65% and 45% of the net irrigation depth following germination, starting on August 5, 2024, and continuing until the experiment concluded on December 2, 2024. Irrigation for all study treatments was scheduled based on the growth stages of maize, utilizing an evaporation basin (class A) in the field to ascertain irrigation timing as a primary indicator. This facilitated the collection of soil samples to estimate the actual remaining moisture in the soil using the weighted method. This process was repeated until 50% of the available water for the plant was depleted, at which point the actual soil moisture for irrigation was determined.

Table 2. Chemical properties of irrigation water

Trait	Value	Unit
EC	2	dS m^{-1}
pH	7.6	
Na^{+}	5.160	MEq L^{-1}
Ca^{+2}	11.544	
Mg^{+2}	10.65	
Cl-	30.53	
SO_4^{-2}	2.22	
HCO_3^{-}	6	
SAR	1.54	MEq L^{-1}
Class	C1S1	

Table 3. Stages and periods of growth of the maize plant, crop factors and root depths.

No.	Growth stages	Time period		Duration (day)	Crop Factor (KC)	Root Depth (cm)
		Form	To			
1.	Emergence of seedlings	31/7/2024	4/8/2024	5	0.94	20
2.	Vegetative growth and tillering	5/8/2024	28/9/2024	40	1.05	30
3.	Flowering and Composition of Ears	29/9/2024	12/11/2024	45	1.69	40
4.	Maturity	13/11/2024	2/12/2024	30	0.82	40

Studied Traits:

Bulk density (ρb)

ρb measured via paraffin wax method.[11]

$$\rho b = \frac{\rho w M s}{\dfrac{Msa - Msw - Mp - \rho w}{\rho b}} \ldots\ldots\ldots\ldots\ldots..1$$

porosity

It was calculated using the following equation [12]

$$F = \left(1 - \frac{\rho b}{\rho s}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Mean weight diameter (MWD):

$$M.W.D. = \sum_{i=1}^{n} \overline{X}_i \times W_i \ldots\ldots\ldots\ldots 3$$

Infiltration rate:

Measured using double-ring infiltrometer.[13]

Calculated via Kostiakov's equation:

$$D = Ct^m \ldots\ldots\ldots 4$$

Plant height (cm): At the completion of the flowering stage, ten plants were randomly selected from the middle-row cultivated plants. Their heights were measured from the ground surface to the lowest node of the male inflorescence."

Leaf area (cm² plant⁻¹): Leaf area was calculated at the 100% flowering stage for ten plants, and their average was determined using the following equation:

Leaf Area (cm^2) = (Length of leaf below the main cob)^2 × 0.75

Total grain yield TYG (Mg ha^{-1})

On 2/12/2024, at the full maturity stage of the maize crop, ten ears were harvested from the central row for each treatment. The grains were manually deseeded, air-dried, and subsequently weighed. The average grain yield per plant was calculated, and the total yield was determined by multiplying the average plant yield by the plant density of 66.665 plants per hectare. The grain moisture was assessed in the laboratory of the College of Agriculture at the University of Kirkuk, with the weight calibrated to a moisture content of 15.5%, and the total yield was evaluated as per the findings of .

The data were analyzed using the SAS (2000) program for analysis of variance (ANOVA), as well as for testing factor means using Duncan's multiple range test

Results And Discussion

Bulk density(Mg m^{-3})

Table (4) shows the effect of experimental treatments on bulk density values. The values differed significantly depending on the drip irrigation method, with the lowest bulk density value of 1.21 Mg m^{-3} recorded under subsurface drip irrigation (SDI), compared to 1.42 Mg m^{-3} under surface drip irrigation. This may be attributed to increased soil moisture content and the displacement of salts dispersing soil colloids, leading to enhanced root proliferation [14] and improved soil structure with increased porosity. Another contributing factor is that sustained soil moisture under SDI reduced the negative impact of wetting-drying cycles (which cause soil expansion and contraction), coupled with slower wetting rates during subsequent irrigations. This minimizes air entrapment effects and enhances soil aggregate stability, thereby preserving soil structure and increasing moisture retention.

Table (4) also shows the significant effect of irrigation level treatments on bulk density. The lowest bulk density value (1.26 Mg m^{-3}) was recorded at the 100% irrigation level, while values of 1.31 Mg m^{-3} and 1.39 Mg m^{-3} were observed at the 65% and 45% irrigation levels, respectively. This is due to higher moisture distribution uniformity at the 100% irrigation level, resulting in more effective leaching of salts beyond the root zone. This facilitates more extensive root growth within the soil profile, consequently influencing soil bulk density values – a finding consistent with.[15]

Table 4 . the impact of mushroom residues and hydraulic deficit on overall bulk density (Mg ha^{-1}) utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues O0	Mushroom residues O1	Hydraulic deficit * dripping method
D1	S0	1.55 c	1.14 h	1.34 c
	S1	1.65 b	1.18 g	1.41 b
	S2	1.75 a	1.26 f	1.50 a
D2	S0	1.32 e	1.03 j	1.17 f
	S1	1.35 e	1.06 ij	1.20 e
	S2	1.46 d	1.08 i	1.27 d
D * O		Average of mushroom residues (O) O0	O1	Average of drip irrigation method (D)
Drip irrigation method	D1	1.65 a	1.19 c	1.42 a
	D2	1.38 b	1.05 d	1.21 b
Average of mushroom residues (O)		1.51 a	1.01 d	
Hydraulic deficit * mushroom residues		Mushroom residues O0	O1	Average of hydraulic deficit (S)
Hydraulic deficit	S0	1.44 c	1.08 f	1.26 c
	S1	1.50 b	1.12 e	1.31 b
	S2	1.60 a	1.17 d	1.39 a

Table (4) further demonstrates the significant effect of spent mushroom substrate (SMS) on bulk density values. The lowest bulk density (1.01 Mg m^{-3}) was recorded with SMS application, compared to non-application treatments where bulk density reached 1.51 Mg m^{-3}. This reduction is attributed to SMS's beneficial properties: its organic matter has low density and high volume, increasing soil porosity while decreasing bulk density. Additionally, decomposition products of this organic matter—humic acids, gums, and waxes—enhance soil structure by improving particle cohesion and aggregate stability [16]. This results in slower wetting rates of soil aggregates during irrigation, reducing air entrapment effects. Aggregate stability is further improved because the hydrophobic nature of organic matter decreases adhesive forces between water molecules and soil particles, thereby increasing the soil-water contact angle.

Total soil porosity

Table (5) shows the effect of experimental treatments on total soil porosity values. Total porosity differed significantly between drip irrigation methods, with the highest value (53.98%) recorded under subsurface drip irrigation compared to surface drip irrigation (46.33%) – representing a 16.51% increase. This enhancement is attributed to increased soil moisture content and displacement of dispersive salts from soil colloids, which promotes extensive root proliferation and improves soil structure and porosity[14]

Table (5) also shows the significant effect of irrigation levels on total soil porosity values. Porosity differed significantly across irrigation treatments, with the highest value (52.35%) recorded at the 100% irrigation level, followed by 65% (50.56%) and 45% (47.54%) levels, respectively. The reduced porosity at 65% and 45% irrigation levels can be attributed to the detrimental effect of repeated wetting-drying cycles. Soil expansion during wetting and subsequent shrinkage during drying causes pore clogging, leading to increased bulk density and decreased total porosity. These findings align with those reported by [17]

Table5: the impact of mushroom residues and hydraulic deficit on overall Total porosity (%) utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues O0	Mushroom residues O1	Hydraulic deficit * dripping method
D1	S0	41.38 h	56.98 c	49.18 d
	S1	37.73 i	55.47 d	46.60 e
	S2	33.96 j	52.45 e	43.20 f
D2	S0	49.93 f	61.13 a	55.53 a
	S1	49.05 f	60 ab	54.52 b
	S2	44.65 g	59.12 b	51.88 c
D * O		Average of mushroom residues (O)		Average of drip irrigation method (D)
		O0	O1	
Drip irrigation method	D1	37.64 d	54.96 b	46.33 b
	D2	47.88 c	60.08 a	53.98 a
Average of mushroom residues (O)		42.78 b	57.52 a	
Hydraulic deficit * mushroom residues		Mushroom residues		Average of hydraulic deficit (S)
		O0	O1	
Hydraulic deficit	S0	45.66 d	59.05 a	52.35 a
	S1	43.39 e	57.73 b	50.56 b
	S2	39.30 f	55.78 c	47.54 c

Table (5) further demonstrates the effect of spent mushroom substrate (SMS) on total soil porosity. SMS application significantly outperformed the non-application treatment, with porosity values of 57.52% and 42.78% for SMS-amended and non-amended soils, respectively - representing a 34% increase. This enhancement is attributed to SMS organic matter improving soil structure and enhancing aggregate stability, which optimizes the soil pore system by increasing void space and interparticle porosity. These findings align with [18]and[19]

Weighted Mean Diameter (WMD, mm):

Table (6) demonstrates the effect of experimental treatments on Weighted Mean Diameter (WMD) values. WMD differed significantly between drip irrigation methods, with the highest value (1.37 mm) recorded under subsurface drip irrigation, compared to surface drip irrigation (0.93 mm).

This increase is attributed to subsurface irrigation maintaining higher soil moisture levels, resulting in slower wetting rates during irrigation events. Consequently, soils under subsurface irrigation exhibit reduced air entrapment effects, enhanced aggregate stability, and increased WMD. These findings align with [20] and [21]

The impact of wetting-drying cycles on soil aggregates lies in the rapid and sudden entry of water into soil aggregates, causing uneven swelling throughout all parts of the clods or aggregates. This leads to cracking and disintegration of these aggregates. Additionally, water absorption by fine capillary tubes compresses trapped air within the aggregates, resulting in air explosions inside these aggregates that exceed the cohesive forces between particles. These mechanisms align with the findings of [20] and [21], demonstrating how hydraulic processes during irrigation events fundamentally compromise soil structural integrity through differential swelling stresses and capillary-induced implosive failure when entrapped air pressure surpasses interparticle bonding strength, ultimately manifesting as reduced aggregate stability and degradation of soil pore architecture.

Table (6) shows the effect of experimental treatments on the weighted mean diameter (WMD). Soil WMD values differed significantly across irrigation levels, with the highest value (1.29 mm) recorded at the 100% irrigation level, followed by 65% (1.16 mm) and 45% (1.01 mm) levels, respectively. This enhancement is attributed to greater root system proliferation at the 100% irrigation level, including increased development of fibrous roots branching from secondary roots. This root growth improves soil structure and enhances aggregate stability [22]

Table6: the impact of mushroom residues and hydraulic deficit on overall WMD (mm) utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues O0	Mushroom residues O1	Hydraulic deficit * dripping method
D1	S0	0.64 j	1.53 d	1.08 d
	S1	0.47 k	1.38 e	0.92 e
	S2	0.33 l	1.24 f	0.78 f
D2	S0	1.07 g	1.94 a	1.50 a
	S1	0.93 h	1.86 b	1.39 b
	S2	0.76 i	1.70 c	1.23 c
D * O		Average of mushroom residues (O)		Average of drip irrigation method (D)
		O0	O1	
Drip irrigation method	D1	0.48 d	1.38 b	0.93 b
	D2	0.92 c	1.83 a	1.37 a
Average of mushroom residues (O)		0.70 b	1.60 a	
Hydraulic deficit * mushroom residues		Mushroom residues		Average of hydraulic deficit (S)
		O0	O1	
Hydraulic deficit	S0	0.85 d	1.73 a	1.29 a
	S1	0.70 e	1.62 b	1.16 b
	S2	0.55 f	1.47 c	1.01 c

Table (6) also demonstrates the effect of spent mushroom substrate (SMS) on the weighted mean diameter (WMD) of the study soil. SMS application significantly outperformed the non-application treatment, with values of 1.60 mm and 0.70 mm, respectively. This enhancement is attributed to organic matter increasing soil aggregate stability by penetrating between soil particles and acting as a binding agent that bonds particles together while resisting the detrimental impact of water movement during flow.[23]

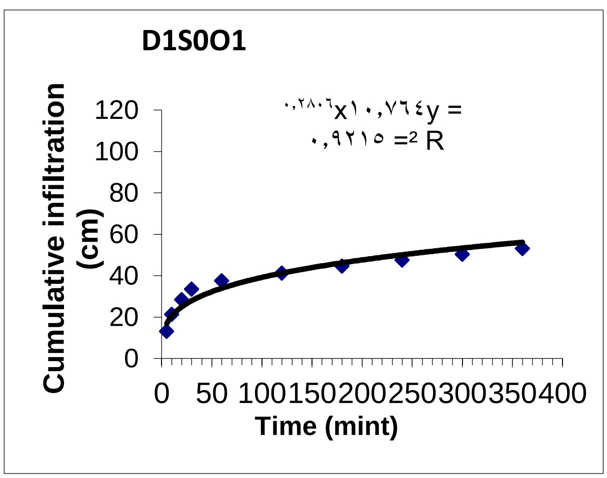
Water Infiltration

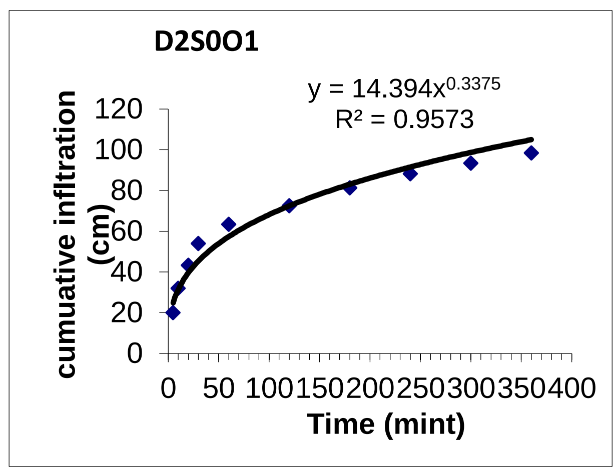
Figures (2) and (3) show the cumulative water infiltration curves in soil at experiment termination for drip irrigation methods, irrigation levels, and spent mushroom substrate (SMS) treatments. The figures depict the relationship between cumulative infiltration depth I (cm) and time (minutes). Data points represent actual measured water absorption depths, while the fitted curve represents the best-fit model for cumulative infiltration depth.

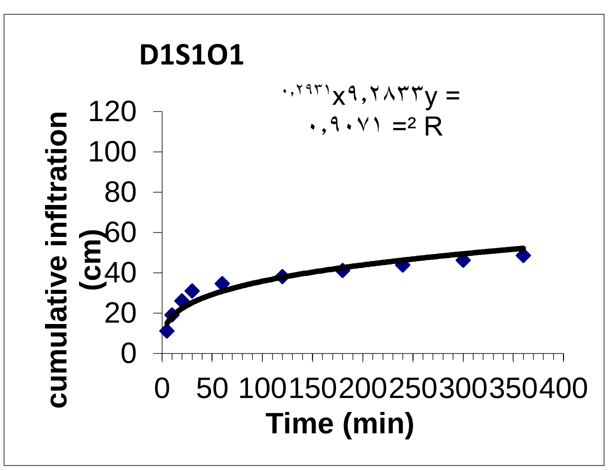
The highest infiltration rate was recorded in treatment D2S0O1, while the lowest value recorded in treatment D1S2O0 after 360 minutes of measurement initiation. This variation is attributed to differences in the physical properties of subsurface soil layers influenced by experimental treatments, including bulk density, total porosity, hydraulic conductivity, and soil aggregate stability. Treatment D2S0O1 exhibited superior physical characteristics compared to other treatments, as evidenced by its optimal soil structural parameters.

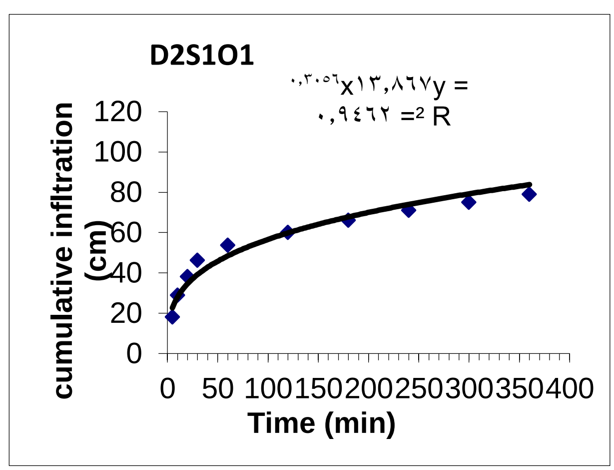
This effect is attributed to the positive role of spent mushroom substrate (SMS) in improving soil structure and enhancing aggregate stability. The organic matter in SMS acts as a binding agent for soil particles, improving the size distribution of soil pores and increasing total soil porosity. This positively influences water movement within the soil. Furthermore, the hydrophobic nature of organic matter reduces adhesive forces between water and soil particles, increasing the soil-water contact angle. This minimizes initial aggregate slaking, enhances aggregate stability, and improves water movement through the soil profile.

the organic matter in spent mushroom substrate (SMS) enhances the soil's water retention capacity. This reduces the wetting rate of soil aggregates during irrigation events. Slower wetting minimizes air entrapment effects within soil pores, thereby preventing localized micro-explosions that would otherwise disintegrate aggregates and degrade soil structure. These findings align with [25]and [26] confirming that controlled wetting through organic amendments preserves soil architectural integrity by mitigating hydraulic stresses during irrigation cycles.









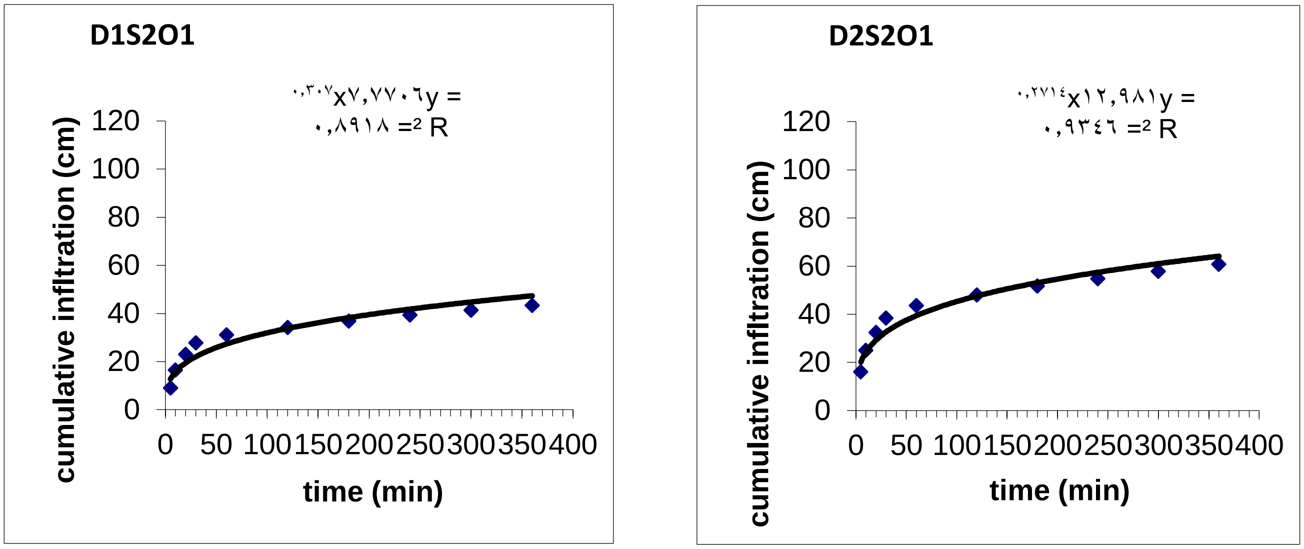
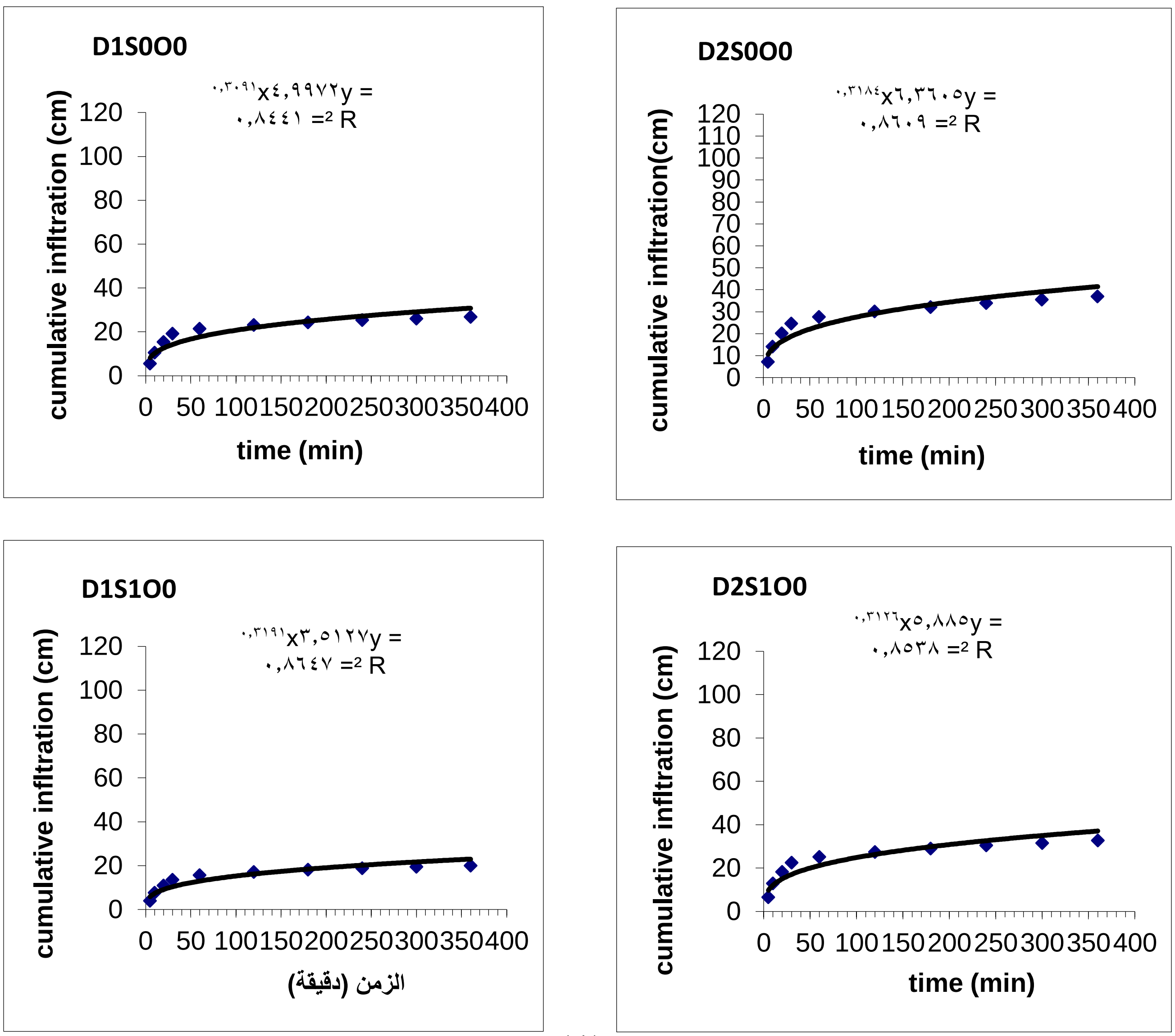
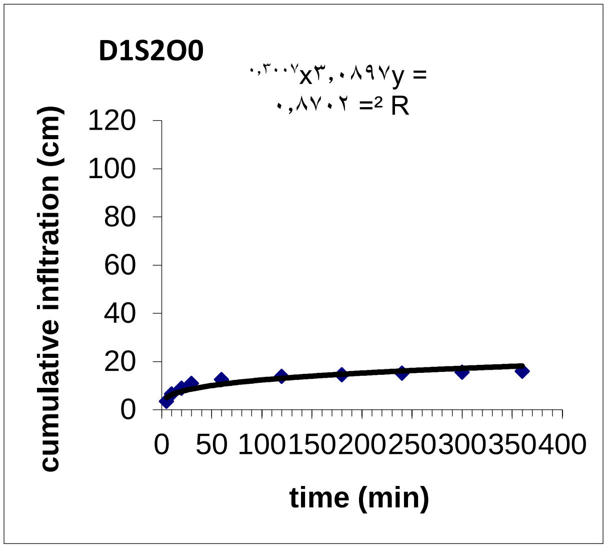


Figure (2): Effect of Experimental Treatments on Cumulative Infiltration After Planting





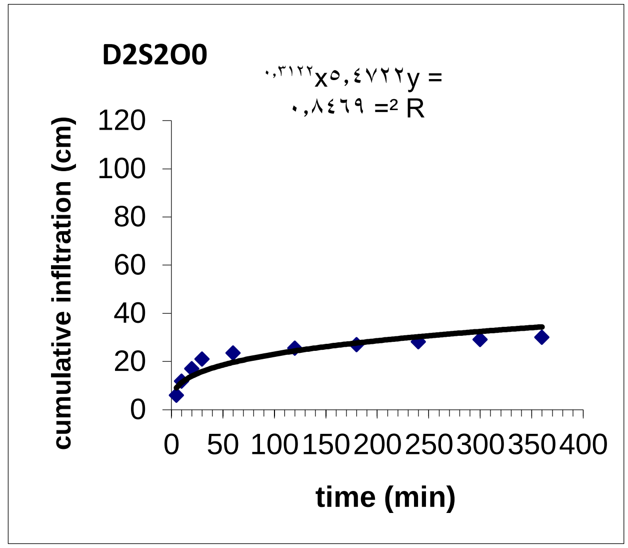


Figure (3): Effect of Experimental Treatments on Cumulative Infiltration After Planting

Plant Height (cm plant^{-1}):

Table (7) shows the effect of experimental treatments on plant height values. Heights differed significantly between drip irrigation methods, with the highest value recorded under subsurface drip irrigation (210.41 cm plant^{-1}) compared to surface drip irrigation (175.22 cm plant^{-1}), representing a 16.72% increase. This increase in plant height is attributed to subsurface drip irrigation achieving superior moisture distribution homogeneity within the root zone, while optimizing irrigation water use through balanced hydraulic conditions at appropriate rooting depths. Conversely, surface drip irrigation fails to maintain adequate root zone moisture, negatively impacting NPK nutrient uptake and mobility from soil to plant. This fundamentally compromises morphological development, including plant height. Furthermore, soil moisture deficit in the root zone reduces cellular water content, directly limiting stem elongation and consequently reducing plant height compared to subsurface treatments.[24]

Table (7) shows the effect of irrigation levels on plant height values. Plant heights differed significantly, with the highest value (203.95 cm) recorded at the 100% irrigation level and the lowest (181.95 cm) at the 45% irrigation level. This reduction is attributed to prolonged soil moisture deficit, which inhibits cell division and elongation, reduces nutrient uptake and translocation, and lowers stem water potential below the threshold required for cell elongation. Consequently, internodes shorten, reducing overall plant height.[25] Deficit irrigation negatively impacts maize growth and physiological processes by suppressing meristematic activity under hydraulic tension, ultimately decreasing plant height [26]

Table7: the impact of mushroom residues and hydraulic deficit on overall plant height utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues O0	Mushroom residues O1	Hydraulic deficit * dripping method
D1	S0	151.300 j	221.73 d	186.51 d
	S1	138.30 k	210.83 e	174.36 e
	S2	128.33 l	200.83 f	164.58 f
D2	S0	188.90 g	253.90 a	221.40 a
	S1	177.100 h	243.96 b	210.53 b
	S2	165.13 i	233.50 c	199.31 c
D * O		Average of mushroom residues (O)		Average of drip irrigation method (D)
		O0	O1	

Drip irrigation method	D1	139.31 d	211.13 b	175.22 b
	D2	177.04 c	243.78 a	210.41 a
Average of mushroom residues (O)		159.17 b	227.46 a	
Hydraulic deficit * mushroom residues		Mushroom residues		Average of hydraulic deficit (S)
		O0	O1	
Hydraulic deficit	S0	170.10 d	237.81 a	203.95 a
	S1	157.7 e	227.40 b	192.55 b
	S2	146.7 f	217.16 c	181.95 c

The same table (7) shows the effect of spent mushroom substrate (SMS) on plant height. The SMS application treatment significantly outperformed the non-application treatment, with values of 227.46 cm plant^{-1} and 159.17 cm plant^{-1}, respectively—representing a 42.9% increase. This enhancement is attributed to SMS increasing nutrient availability and uptake, thereby elevating absorbed element quantities. Additionally, organic matter stimulates the formation of organic compounds and promotes auxin production in plants. It further enhances protein synthesis, nucleic acids, protoplasmic construction, and DNA/RNA formation, essential for activating cell division and elongation, ultimately increasing plant height .[27]

Leaf Area (cm² plant^{-1}):

Table (8) shows the effect of experimental treatments on leaf area values. Leaf area differed between drip irrigation methods, with subsurface drip irrigation yielding the highest value (5671.87 cm² plant^{-1}) compared to surface drip irrigation (536.62 cm² plant^{-1}) – a 957% increase. This substantial enhancement is attributed to the superior efficiency of subsurface drip irrigation in maintaining optimal root zone moisture, thereby increasing nutrient availability and enhancing overall plant growth compared to surface drip methods. These results align with.[28]

Table (8) shows the significant effect of irrigation levels on leaf area values. The 100% irrigation level yielded the highest leaf area (5625.86 cm² plant^{-1}), compared to the lowest value (5409.79 cm² plant^{-1}) at the 45% irrigation level—representing a 3.99% increase. This reduction under deficit irrigation is attributed to limited leaf expansion, which critically constrains photosynthetic capacity. Reduced leaf area serves as an early adaptive response to water stress, alongside declining leaf turgor as an initial biophysical indicator of hydraulic tension. These findings align with [29] and [30]

Table8: the impact of mushroom residues and hydraulic deficit on overall leaf area utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues		Hydraulic deficit * dripping method
		O0	O1	
D1	S0	5129.39 hi	5769.58 cd	5449.48 d
	S1	5049.66 ij	5665.95 de	5357.81 e
	S2	4984.82 j	5564.34 ef	5274.58 f
D2	S0	5455.87 f	6148.61 a	5802.24 a
	S1	5326.93 g	6009.82 b	5668.37 b
	S2	5209.24 h	5880.77 c	5545 c
D * O		Average of mushroom residues (O)		Average of drip irrigation method (D)

		O0	O1	
Drip irrigation method	D1	5054.62 d	5666.62 b	5360.62 b
	D2	5330.68 c	6013.06 a	5671.87 a
Average of mushroom residues (O)		5192.65 b	5839.84 a	
Hydraulic deficit * mushroom residues		Mushroom residues		Average of hydraulic deficit (S)
		O0	O1	
Hydraulic deficit	S0	5292.63 d	5959.09 a	5625.86 a
	S1	5188.29 e	5837.89 b	5513.09 b
	S2	5097.03 f	5722.55 c	5409.79 c

The same table (8) shows a significant effect of spent mushroom substrate (SMS) on leaf area. SMS application yielded the highest leaf area (5839.84 cm^2 $plant^{-1}$), compared to the lowest value (5192.65 cm^2 $plant^{-1}$) without SMS—representing a 12.46% increase. This enhancement is attributed to SMS organic matter improving chemical, physical, and biological soil properties, thereby promoting vegetative growth. Additionally, SMS supplies essential nutrients that activate key physiological processes, enhances carbon assimilation, and stimulates cell division and elongation. Collectively, these factors increase plant height, leaf number, and leaf area [31]

Total grain yield (TGY) (Mg ha-1):

Table (9) demonstrates the impact of experimental treatments on TYG, indicating notable differences attributed to the drip irrigation approach. The subsurface drip irrigation treatment attained the maximum output of 11.86 Mg ha-1, whereas the surface drip irrigation yielded the minimum at 9.87 Mg ha-1, leading to a 20.16% enhancement. The rise in TYG is due to the subsurface drip irrigation method's ability to sustain adequate soil moisture, therefore improving nutrient availability and absorption by the plant. This corresponds with [28] findings, which demonstrated that heightened soil moisture content is associated with augmented overall output. Furthermore, the physical properties of the soil (bulk density, total porosity, mean weighted diameter, and hydraulic conductivity) were enhanced with the application of subsurface drip irrigation.

Table (9) presents the effect of irrigation water levels on TYG values, which varied significantly across different irrigation levels. The maximum grain yield was recorded at 11.54 Mg ha-1 for the 100% irrigation water level, while the minimum yields were observed at the 65% and 45% irrigation levels, with values of 10.87 and 10.19 Mg ha-1, respectively. The rise in irrigation water levels has augmented the moisture content and availability of water for plants, which reduced the exposure to hydraulic deficits by plant, reducing the potential exerted by the plant to absorb water to complete its vital processes. Hydraulic deficit also causes a significant decline in grain yield. The percentage of reduction in the grain yield depends on the intensity of deficit and the progressive stage of plant's life and duration [32], with the leaching of salts from rhizosphere, which is a determining factor for plant growth. These findings are consistent with [29] finding

Table 9. the impact of mushroom residues and hydraulic deficit on overall grain yield (Mg ha^{-1}) utilizing surface and subsurface drip irrigation.

Drip irrigation method (D)	Hydraulic deficit (S)	Mushroom residues		Hydraulic deficit * dripping method
		O0	O1	
D1	S0	8.40 j	12.59 d	10.49 d
	S1	7.82 k	11.91 e	9.86 e
	S2	7.29 l	11.23 f	9.26 f

D2	S0	10.52 g	14.63 a	12.58 a
	S1	9.81 h	13.94 b	11.87 b
	S2	9.07 i	13.19 c	11.13 c
D * O		Average of mushroom residues (O)		Average of drip irrigation method (D)
		O0	O1	
Drip irrigation method	D1	7.83 d	11.91 b	9.87 b
	D2	9.80 c	13.92 a	11.86 a
Average of mushroom residues (O)		8.82 b	12.92 a	
Hydraulic deficit * mushroom residues		Mushroom residues		Average of hydraulic deficit (S)
		O0	O1	
Hydraulic deficit	S0	9.46 d	13.61 a	11.54 a
	S1	8.81 e	12.93 b	10.87 b
	S2	8.18 f	12.21 c	10.19 c

Table (9) indicates a significant effect of mushroom farm residue on total grain yield. The use of mushroom residue led to a maximum TYG of 12.92 Mg ha-1, compared to a minimum yield of 8.82 Mg ha-1, indicating a 46.48% increase. The improvement of soil physical, chemical and fertility properties can be attributed to organic residues. This enhancement increases the availability of plant nutrients, facilitating root growth and expansion. Consequently, this positively influences other plant characteristics, such as height and leaf area, ultimately leading to an increase in the plant's dry weight. The findings align with the work of [33].

Recommendations

1. Subsurface drip irrigation significantly improved soil physical/hydraulic properties and enhanced growth indices and total seed yield compared to surface drip irrigation.
2. At the 100% irrigation level, bulk density decreased while weighted mean diameter, total porosity, cumulative infiltration, plant height, leaf area, and total seed yield increased. Conversely, the 45% irrigation level reduced soil physical/hydraulic properties, growth parameters, and yield of maize.
3. Applying spent mushroom substrate (SMS) at 0.2% of experimental unit weight enhanced soil physical/hydraulic sustainability, improved growth indices, and increased total seed yield.

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استدامة الخصائص الفيزيائية للتربة باستخدام مخلفات الفطر والري بالتنقيط السطحي وتحت السطحي لمستويات ماء ري مختلفة وأثر ذلك في نمو وحاصل الذرة الصفراء Zea mays L.

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الخلاصة

تعتبر الخصائص الفيزيائية للتربة من خصائص التربة المهمة لما لها من تاثير مباشر وغير مباشر في انتاجية المحاصيل الزراعية وان استدامتها من الامور المهمة والواجب صيانتها من خلال اتباع اساليب علمية وعملية متميزة من اجل الحفاض على قدرة التربة الانتاجية لمختلف المحاصيل الحقلية ، فضلا عن دورها في ادارة عمليات الري بشكل كفوء لرفع انتاجية المياه، وبناء على ما تقدم فقد نفذت تجربة حقلية في تربة ذات نسجة مزيجة طينية لدراسة استدامة الخصائص الفيزيائية للتربة باستخدام مخلفات الفطر والري بالتنقيط السطحي وتحت السطحي لمستويات ماء ري مختلفة وأثر ذلك في نمو وحاصل الذرة الصفراء خلال الموسم الخريفي 2024 في محطة البحوث والتجارب الزراعة – جامعة كركوك. تضمنت التجربة ثلاث عوامل وهي العامل الاول: اسلوب نظام الري بالتنقيط وشمل (التنقيط السطحي والتنقيط تحت السطحي) ، العامل الثاني: الاجهاد المائي وتضمن (100 ، 65 و 45)% من صافي عمق الارواء ، العامل الثالث: اضافة مخلفات مزرعة الفطر وتضمن (الاضافة وبدون الاضافة). نفذت التجربة بثلاثة مكررات وفقاً لتصميم القطاعات الكاملة المعشاة (***RCBD)*** وبتوزيع القطع المنشقة – المنشقة (***Split-Split Plot Design).*** تم الري عند استنفاد 50% من الماء الجاهز. اعطى الري بالتنقيط تحت السطحي اقل قيمة للكثافة الظاهرية واعلى قيمة لكل من معدل القطر الموزون والمسامية الكلية والغيض التجميعي وارتفاع النبات والمساحة والورقية والحاصل الكلي للبذور اذ بلغت القيم (1.37 ميكاغرام م-3 ، 53.98 % ، 1.21 مم ، 98.5 سم ساعة-1 ، 210.41 سم نبات-1 ، 5671.87 سم2 نبات-1 و 11.86 ميكاغرام هكتار-1) ، مقارنة باستخدام نظام الري بالتنقيط السطحي. اعطى مستوى ماء الري 100% اقل قيم للكثافة الظاهرية واعلى قيم لكل من معدل القطر الموزون والمسامية الكلية والغيض وارتفاع النبات والمساحة الورقية والحاصل الكلي للبذور ، مقارنة بمعاملات مستوى ماء الري 45% التي ارتفعت فيها الكثافة الظاهرية وانخفضت باقي الصفات ، ادت اضافة مخلفات الفطر الى تحسين الخصائص الفيزيائية والمائية للتربة وارتفاع مؤشرات النمو والحاصل الكلي لبذور محصول الذرة الصفراء ، اذا بلغت القيم (1.01 ميكاغرام م-3 ، 57.52% ، 1.60 مم ، 227.46 سم نبات-1 ، 5839.84 سم2 نبات-1 و 12.92 ميكاغرام هكتار-1) ، لكل من (الكثافة الظاهرية ، المسامية الكلية ، معدل القطر الموزون ، ارتفاع النبات ، المساحة الورقية وحاصل البذور الكلي) ، على الترتيب.

الكلمات المفتاحية: الخصائص الفيزيائية ، مخلفات الفطر ، تنقيط تحت سطحي ، مستويات ماء الري، الحاصل الكلي ، الذرة الصفراء.