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Effect of Some Soil Physical and Hydrogical Properties on Water Consumption use of Maize Plant

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ABSTRACT

Since the world is experiencing a series of climate changes that either directly or indirectly impact the amount of usable water, there is now a global need to save water. Thus, the purpose of this study was to ascertain how certain physical and water characteristics of two types of soil (loam and sand) affected the amount of water that maize plants used and the ensuing variations in crop quality and yield. Lysimeters set up in the greenhouse of the Department of Soils and Water, Faculty of Agriculture, Ain Shams University, was used for the experiment. Water stress gradients were created based on the field moisture capacity of maize plants in order to examine the effects of different levels of drought on the growth of maize plants. The gradients listed below were applied 3 Coefficients of moisture drain, the following are included: W1, 40% ± 5% of field moisture capacity, normal water supply; W2, 60% ± 5% of field moisture capacity, moderate drought; and W3, 80% ± 5% of field moisture capacity, severe drought. Plant metrics including plant height and corn cob were found to significantly decrease when the 80% moisture drain treatments was used, however the results indicated no significant differences when the 60-80% moisture drain treatment was used.

Keywords: Soil physical, hydraulic properties, maize plant, water requirements, and Lysimeters

1. Introduction

Egypt as an arid country relying on the Nile River, which provides 95% of its water resources, is suffering from water stress due to the limited supplies and growing population and increased competition on water from the upper Nile basin countries. Besides, there are many challenges such as water pollution, lack of financial resources, lack of harmonized legislations, and significant decline in Nile stream flow under climate change (Mohamed, 2013).

In general, the farmers over irrigate resulting in water loss and low irrigation efficiencies, and thus creating drainage and salinity problems. With fertigation system, water and nutrients can be applied directly to the crop at the root level, having positive effects on yield and water savings and increasing the irrigation performance. For these reasons, drip irrigation system has seen widespread use in the world in recent years. Scheduling of irrigation is very critical to make the most efficient use of drip irrigation system, as excessive irrigation can reduce yield, while inadequate irrigation causes water stress and reduces production (Yuan *et al.,* 2006).

On the other hand, extensive areas in Egypt have a shallow water table created by indiscriminate use of irrigation water, non-functional drainage systems and also seepage from rice fields, which are covered with water for long periods of time, thus can result in further water table rise leading to water logging and secondary salinity problems. Water logging and salinity are potentially serious problems for the agricultural industry, because of the significant negative impact on crop yield and long-term impact on agricultural productivity; they can reduce the potential yield by as much as 30-80 percent for many crops (McFarlane and Williamson, 2002).

Lysimeter is a large container filled with soil, generally located in the field to represent field environment, with bare or vegetated surface (Crop or grass). It used to measure the amount of water

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used in evapotranspiration (ET) by a vegetated surface (agronomic crops or natural vegetation. Lysimeters are the most accurate method for determining evapotranspiration (Meissner *et al.,* 2020).

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice. It is a dominate crop in the farming system because it is a stable food crop for most of rural population. Due to short growing period, maize is grown twice a year both for grain and fodder purposes (El- Sayed, 2013). In addition to this, corn plant has a significant response to both water and soil factors (Mueller *et al.,* 2005). Water deficit can limit maize yield; therefore, appropriate choices of irrigation schemes or water-saving irrigation strategies to maximize WUE are needed for sustainable agriculture in response to environmental challenges and climate change.

In arid regions, irrigated agriculture is a crucial development strategy that aims to use water resources efficiently and employ appropriate irrigation techniques to increase crop yields and maintain food security (Rosa *et al.,* 2020; Ding *et al.,* 2021; Ward, 2022). Water use efficiency (WUE) refers to the crop yield obtained per unit of water consumption for evaluating agricultural water use or irrigation efficiency and can be used to detect water-stressed areas of farms composed of a variety of crop species with different physiology (Chai *et al.,* 2015; Xing *et al.,* 2022). Drip irrigation that allows farmers to decrease irrigation amounts based on irrigation quota and water availability has been practiced for many years for its effectiveness in reducing soil surface evaporation and increasing crop yield and WUE (Ajaz *et al.,* 2020; Zou *et al.,* 2021).

Regulated deficit irrigation (RDI) is an efficient water-saving irrigation technique for ensuring optimal crop water status in phenological phases that are most sensitive to water stress by restricting irrigation during the most resistant crop phases (Rop *et al.,* 2016; Galindo *et al.,* 2018). The principle of RDI is that the water demand of plants and the effects of water deficit on plants at different growth stages are different, and the key point of this method is how to determine the water requirement of the target plant in different phenological stages and the effect of water shortage (Yang *et al.,* 2022a). In the non-critical stages, the amount of irrigation water for plants was less than that required, which could avoid not only ineffective and excessive vegetative growth but also promoted reproductive growth under mild stress (Ju *et al.,* 2019; Sun *et al.,* 2020). For instance, Li et al. (2019) found that RDI increased sugar yield at 30 % and 50 % of FC during three growth stages (canopy development, storage root development, and sugar accumulation) of sugar beet. Nevertheless, some studies have shown that RDI reduces fruit yield if the stage of RDI is not selected properly, such as olive oil production might not meet the demand because the growth of crops would be limited by RDI and no clear benefit of RDI over sustained deficit irrigation was found (Ben-Gal *et al.,* 2021; Lu *et al.,* 2019). Therefore, it is necessary to assess in advance what the key economic indicators of the crop include, and not all plants are suitable for this RDI method. In addition, the construction and maintenance of water control, drip irrigation, and water measurement equipment require a certain cost, which brings difficulties to large-scale promotion.

Studies have shown that conducting RDI before the maize tasseling stage can mitigate the negative effects of water scarcity on plant development (Liang *et al.,* 2013; Cheng *et al.,* 2021). Drought is one of the main environmental factors that inhibit maize yield and growth (Shemi *et al.,* 2021).

Understanding and evaluating a plant's ability to cope with water stress in specific/localized environments will lead to better-informed decisions on the suitability of irrigation management practices, and our results can help develop proper field management and save water resources.

2. Materials and Methods

2.1. Experimental site

The experimental site was at the Faculty of Agriculture, Ain Shams University, and Shoubra El-Khima, Egypt which situated 30 º at 16ˈ N Latitude and 31º 15ˈ longitude, while the altitude is 95 m above the mean sea level. This study was established during the one season of 2023 to put a spotlight on the contribution of water table to meet the water requirements of maize crops.

2. 2. Experimental design

The experiment was carried out in twenty double walls concrete lysimeters of the size 1.25m x 1.25 m in and 1.25 m deep using the cultivar maize (*Zea mays* L.), respectively as a test plants. Each lysimeter consists of a drain a of the lysimeter. The soil of the different lysimeters had different properties. Horizons were of sand and loam texture extending from surface to 60 cm depth. Some physical and chemical properties of the investigated soil. Soil sample was collected from three successive soil depths (0-20, 20-40, and 40-60 cm) after and before either corn plan cultivation. Soil samples were air dried and pulverized to pass through al mm sieve. Fine earth was taken to determine physical and chemical characteristics of the experimental soil as follows.

2.3. Lysimeter experiment

2.3.1. Irrigation treatment.

Due to their varying water-holding capacities and leakage characteristics, the soils with varied textures had significantly different irrigation schedules and total irrigation amounts during the crop-growing season. We created three irrigation treatments for every type of soil for pragmatic reasons. Since the irrigation interval durations varied for each type of soil, the irrigation time for each type of soil was determined by the moisture content of the soil. In order to conveniently manage irrigation for each soil type, the irrigation treatments were arranged into three replicates. The total amount of irrigation applied during the maize growth period was therefore determined by multiplying a single irrigation amount by the number of irrigation times for each treatment of each soil type.

The maize water stress experiment was carried out at a plant plantation in Egypt starting in June 2023. Water stress gradients were created based on the field moisture capacity of maize plants in order to examine the effects of different levels of drought on the growth of maize plants. The gradients listed below were applied. 3. Coefficients of moisture drain W1, 40% ± 5% of field moisture capacity, with normal water supply; W2, 60% ± 5% of field moisture capacity, under moderate drought; and W3, 80% ± 5% of field moisture capacity, under severe drought. From day 1 to day 10, enough water was supplied to guarantee the maize's smooth emergence. The sole variable in the experiment was the amount of watering; the growth conditions, such as temperature and light, were maintained constant for every maize plant.

The Single Cross 368 maize (*Zea mays* L.) hybrid was grown on June 18, 2023, with nine plants per lysimeter, with planting spacing of 20 cm and rows separated by 30 cm. As advised by the Ministry of Agriculture, 400 kg of ammonium nitrate (33.5%), 120 kg of super phosphate (15.5% P2O5), and 100 kg of potassium sulphate (48% K2O) were added to each feddan prior to planting in order to nourish the experimental plants.

2.3.2. Water use efficiency (WUE)

Water use efficiency (g/L) was calculated for different treatments according to the following equation:

Water use efficiency = Yield (gm/plant) Amount of water consumed (L/plant)

2.4. Growth and Yield measurements

Some parameters of growth and development of maize plants were measured at harvest, on 25september, 2023, (98) days after planting plant height, corn cob length, weight of 100 seeds, and final crop productivity.

2.5. physical and Chemical analyses

2.5.1 Soil, and water analyses

Representative soil samples were collected at 0-30 cm depth from the experimental area before cultivation for some physical and chemical analyses. Soil physical characteristics (i.e. SP, FC and PWP, $CaCO_3$, Real particle density (P_d), bulk density (B_d) and soil texture were determined using the methods described by Black *et al.* (1965). Soil organic matter (OM) was determined based on the Walkley-Black chromic acid wet oxidation method as described by Walkley (1947). Electrical conductivity was determined in soil paste water extract using an EC meter (Model YSI 32). In the soil paste water extract, pH, water soluble K^+, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, HCO_3^- and $CO_3^=$ were determined using the standard methods of analysis as described by Jackson (1973). The soil in this area was not saline and almost light alkaline. The results were presented in Tables 1, 2 and 3.

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Table 1: Some soil physical properties of the experimental area

Parameter	Unit	Sandy soil	Loam soil
PD	g/cm^3	2.63	2.26
BD		1.62	1.21
F	%	38.36	46.41
SP		39.32	48.00
FC		11.43	39.00
WP		1.31	17.20
TAW		10.12	21.80
Ksat	cm/hr.	490.4	20.8
Particle size distribution, %			
Sand		92.81	42.59
Silt		3.11	41.33
Clay		4.08	16.08
Textural class		Sand	loam

Table 2: Some soil chemical properties of the experimental area

Parameter	Unit	Sandy soil	Loam soil
pH		8.26	8.10
Ece	dS/m	0.71	1.67
Soluble cations			
Ca^{++}	meq/l	3.60	8.47
Mg^{++}		2.71	6.37
K^+		0.11	0.26
Na^+		0.58	1.36
Soluble anions			
HCO_3-	meq/l	0.10	4.00
$CO_3^=$		ND	ND
Cl^-		6.40	11.50
$SO_4^=$		0.40	0.88
$CaCO_3$	%	3.52	5.67
OM		0.2	2.4

Table 3: Irrigation water analysis

Parameter	Unit	Value
pH		7.36
ECe	dS/m	0.71
Soluble cations		
Ca^{++}	meq/l	1.00
Mg^{++}		1.20
K^+		0.03
Na^+		5.52
Soluble anions		
HCO_3-	meq/l	4.80
$CO_3^=$		ND
Cl^-		1.68
$SO_4^=$		1.28

2.5.2 Determination of N, K, and P contents

The collected samples of maize leaves was prepared for chemical analysis. Plant samples were dried in a drying oven at 70°C for 24 h and digested with a mixture of H_2SO_4/H_2O_2. The nitrogen, potassium, calcium and magnesium contents were determined using the methods described by Walinga *et al.* (2013); Chapmann and Pratt (1961).

2.6. Statistical analysis

The obtained data were undergo to homogeneity test (Levene, 1960) and Anderson–Darling normality test (Scholz and Stephens, 1987) prior to analysis of variance (ANOVA). The outputs proved that the homogeneity and normality of the data are satisfied for running further ANOVA. Thus, data of each season were subjected to ANOVA according to Casella (2008), using Costat software program, Version 6.303, 2004. At P<0.05, LSD was used for distinguishing among the treatment means. The trail design was a one Way Randomized Blocks

3.Results and Discussion

3.1. Modeling of water requirements and soil physical characteristics

It is generally accepted that poor soil structure, or aggregation and porosity, is a key barrier to water infiltration, redistribution, and storage in a soil profile. This can result in increased run off and erosion, less water accessible for plants, and decreased crop yields. A valuable tool for assessing the relationships between crop development, management, climate, and soil physical state is a soil-crop system model. Usually employed for in-depth simulations of soil water dynamics and solute mobility, mechanistic models were more intricate than functional models. No one modeling approach or model is suitable for every application; the features and complexity required depend on the problem the model is intended to answer. The data in Table 4 demonstrated that statistical analysis was done on all of the soil's hydrological and physical characteristics.

Table 4: Simple linear regression of relation between the concerned soil physical properties and water requirement

Parameter	Parameter estimate	Sig	P-value
Clay	-510.271**	0.002	-1.771
W.H.P	265.039*	0.031	3.356
W.P	-472.459*	0.05	-2.49
Constant	6489.653***	0.001	
F	352.323**	0.003	
R^2 adj.	0.999		

W.H.P: Water Holding Pores**, W.P:** Wilting Point

3.2. Total irrigation requirements

The data in Table 5 showed that the total irrigation requirements vary according to the soil texture. Irrigation periods varied depending on the kind of soil, however in this study, the amount of irrigation was regulated at each irrigation time, and each soil was treated with both full irrigation and water-saving irrigation (medium and low irrigation). The table's findings demonstrate that, depending on the plant's growth stage, the amount of water used by the plant during its various growth periods in loamy and sandy soils was higher, and that the plant required more irrigations in sandy soils than in loamy soils. The total amount of irrigation per acre in loamy soils was as follows (4057, 2117 and 1848) according to the irrigation treatments used in the research, while in sandy soils it was as follows (5880, 4469 and 3675) respectively.

3.3 Plant growth parameters

The results presented in Table (6) showed that the plant height was affected by the lack of water quantity, as well as the quantity of corn cobs after harvest, and this effect became clear in the case of cultivation in sandy soil. Therefore, insufficient irrigation led to a decrease in the morphological characteristics of the plant, especially the height of the plant, through its effect on the growth, development and physiology of the yellow corn plant, and thus reducing the vegetative mass.

Table 5: Total irrigation volume in the maize growth period in different soil types.

Growth period days	Initial (8 days)	Development (40 days)	Mid (20 days)	Late (30 days)	Total water irrigation $m^3.fed^{-1}$
			Loam soil		
LW 1	1	8	3	2	4057
LW 2	1	7	2	1	2117
LW 3	1	6	2	1	1848
			Sandy soil		
SW 1	4	22	8	6	5880
SW 2	4	21	7	6	4469
SW 3	4	20	6	5	3675

W1= water after draining 40% ± 5% of field moisture capacity; **W2**= water after draining 60% ± 5% of field moisture capacity, and **W3**, 80% ± 5% of field moisture capacity, **L**= loam soil, **S** = sandy soil

Table 6: Effect of applied water regimes on plant growth parameters of maize plant.

Water trt.	Plant Height cm	Cob length cm	Cob number No.
		Loam soil	
LW 1	3.00 a	32.7 a	18 a
LW 2	2.60 b	27.7 b	16 b
LW 3	2.10 c	20.6 c	12 c
		Sandy soil	
SW 1	1.84 d	20.0 c	9 d
SW 2	1.71 d	18.0 d	9 d
SW 3	1.50 e	15.0 e	9 d
LSD $_{(0.05)}$	0.123	1.87	1.34

W1= water after draining 40% ± 5% of field moisture capacity; **W2**= water after draining 60% ± 5% of field moisture capacity, and **W3**, 80% ± 5% of field moisture capacity, **L**= loam soil , **S** = sandy soil

Result in Table (6) showed that ear length was significantly affected by irrigation intervals. Irrigation in clay soils gave the highest of ear length under the influence of water stress treatments.

3.4. Grain yield

The results in table 7 showed that water stress at the cob formation stage caused a significant decrease in the number of cobs per square meter, the number of grains per ear, grain yield, biological yield, and water use efficiency of grain yield, while water stress at the grain filling stage caused a significant decrease in the weight of 100 grains and the amount of plant per acre. The effect of water stress as a treatment followed in both clayey and sandy soil resulted in a decrease in plant height, number of grains, and leaf area, which resulted in a decrease in the photosynthesis process, a decrease in dry weight, and a reduction in the growth period to cob formation, and thus incomplete grains. The results showed a clearer effect of water stress as a treatment followed in this research in the case of application on sandy soil and its reflection on corn productivity per acre, as it was much lower in sandy soil than in clayey soil with different water treatments. The result indicated that the maize grain yield was higher under the full irrigation treatment than under the medium and low irrigation treatments for all soil types, and the differences were significant with the exception. The grain yield decreases due to the decrease in the number and weight of grains in the ear, as the decrease in the soil water content leads to a decrease in the soil water potential, so the difference in the water gradient potential (WPG) decreases, which is the driving force for water transfer, so the amount of water absorbed by the root group decreases, and becomes insufficient to compensate for the water lost through evaporation and transpiration, so the plant cells are exposed to water deficit, which leads to a decrease in the filling potential inside the plant cells, which is the physical force that drives the walls of the plant cells to elongate, so the elongation of the plant cells stops, and growth stops accordingly (Cossgrove, 1989). This is consistent with (Sammis *et* *al.,* 1988; Pandey *et al.,* 2000a; Stone *et al.,* 2001). In Egypt and Yemen, one of the most significant grain crops, maize (*Zea mays* L.), is grown mostly in the summer. In Yemen, the growing area of maize reached 43467 and 37402 hectares, respectively, while in Egypt it was 820274 and 835000 hectares during the 2008 and 2009 seasons. Egypt and Yemen produced an average of 7977 and 8143 kg/ha and 1514 and 1499 kg/ha, respectively (F.A.O, 2008 and 2009).

The combined analysis of variance for irrigation intervals shown in Tables 5, 6, and 7 showed that, with the exception of N and P percentage in grains, irrigation intervals significantly impacted the number of days to 50% tasseling, ear length, grains weight/ear, 100-grain weight, grain yield/fed. and K percentage in grains.

Table 7: Effect of applied water regimes on productivity of maize plant.

Water trt.	Grain yield ton.fed^{-1}	wt. of 100 grains g
	loam soil	
LW 1	6580 a	47 a
LW 2	5250 b	43 b
LW 3	4321 c	35 c
	Sandy soil	
SW 1	3990 c	30 d
SW 2	2450 d	26.7 e
SW 3	1772 e	20.6 f
LSD (0.05)	**435.748**	**2.833**

W1= water after draining 40% ± 5% of field moisture capacity; **W2**= water after draining 60% ± 5% of field moisture capacity, and **W3**, 80% ± 5% of field moisture capacity, **L**= loam soil, **S** = sandy soil

3.5. Macronutrients: N, P and K

The type of irrigation treatment was found to have no significant effect on the N and P content of the maize from the various soil types of Fang and Su, (2019 but the type of irrigation was found to have significant effect on the K content. Potassium has an active role in opening and closing of stomata (Ibrahim, 2013). Potassium being the most mobile plant nutrient it plays role in osmotic regulation (Beg and Sohrab, 2012) and improves drought tolerance by maintaining water balance (Cakmak, 2005).

Table 8: Effect of applied water regimes on total concentration of nitrogen, phosphorus and potassium of shoot of maize plant.

Water trt.	N	P %	K
		Loam soil	
LW 1	3.48 a	0.13 a	3.47 a
LW 2	3.45 a	0.13 a	3.43 b
LW 3	3.40 a	0.13 a	3.39 b
		Sandy soil	
SW 1	2.18 b	0.05 b	2.32 c
SW 2	2.17 b	0.05 b	2.30 cd
SW 3	2.06 b	0.05 b	2.20 c
LSD (0.05)	**0.178**	**0.168**	**0.103**

W1= water after draining 40% ± 5% of field moisture capacity; **W2**= water after draining 60% ± 5% of field moisture capacity, and **W3**, 80% ± 5% of field moisture capacity, **L**= loam soil , **S** = sandy soil

3.6. Water use efficiency

Data in table 9 showed that effects of irrigation treatments and soil properties on water use efficiency were found to significantly between (W 1) and (W 2,3) in loam soil but between (W 1) and (W 2) no significantly, In sand soil was found to significantly between (W 1) and (W 2),(W 3).

Table 9: Effects of irrigation volume and soil properties on water use efficiency (WUE).

Water trt.	Sand soil	Loam soil
W 1	0.68 c	1.62 a
W 2	0.55 cd	2.48 b
W 3	0.47 d	2.33 b
LSD $_{(0.05)}$	0.14	0.11

W1= water after draining 40% ± 5% of field moisture capacity; **W2**= water after draining 60% ± 5% of field moisture capacity, and **W3**, 80% ± 5% of field moisture capacity.

4. Conclusion

A deeper understanding of the effects of soil on crop and irrigation water requirements is an essential prerequisite to accurately assessing regional irrigation water needs and water-saving potential. The results of this study show that water-saving irrigation (medium and low irrigation treatments) reduces maize yields. In this study, soil properties had a clear influence on maize yield. Differences in soil texture affect the physical properties of the soil, including pores and hydraulic conductivity .Thus, it affects the movement of water, the spread of active roots in the soil, the amount of water and evapotranspiration, and the efficiency of water use of the crop. The use of different soil types led to significant differences in the amounts of water used during the growing season as well as ear length, grains weight/ear, 100-grain weight, grain yield /fed. and K percentage in grains was significantly affected by irrigation intervals, except N, P percentage in grains were insignificant.

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