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Full Length Research Paper

Effect of localized irrigation systems and humic compost fertilizer on water and fertilizer use efficiency of maize in sandy soil

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Irrigation water shortage, traditional irrigation systems and poor soils in arid regions and some other factors have their negative impacts on crops' production amount, energy used in processing, exportation and importation of fertilizers. Field experiments were carried out through the growing season (2012/2013) in sandy soil at the Experimental Farm of National Research Center (NRC), El-Noubaria Governor, Egypt, to study the effect of some localized irrigation systems (LIS) and humic fertilizer (HF) on water use efficiency (WUE), and fertilizer use efficiency (FUE) of maize crop. Three localized irrigation systems were used: mini-sprinkler irrigation system (MSIS), bubbler irrigation systems (BIS), and drip irrigation system (DIS). The humic fertilizer treatments used were: (HF100), (HF50), (HF0) and (50, 25 and 0 kg fed^{-1}, on ranking). N, P2O5 and K2O were applied via irrigation water (fertigation) at the rate of 60.71 and 69 kg fed^{-1} in doses according to growth stage. This research work concludes that farmers' interest should be shifted to agricultural activities that can produce more crops by choosing both irrigation system and humic fertilizers. Data obtained indicated that the bubbler irrigation system and humic fertilizer selection treatment (HF100) can positively affect some maize productivity parameters such as grain yield, stover yield, water use efficiency, fertilizer use efficiency, and physical nature of maize crop.

Key words: Localized irrigation systems (LIS), humic fertilizer (HF), water use efficiency (WUE), fertilizer use efficiency (FUE), sandy, maize.

INTRODUCTION

Water use efficiency (WUE) of maize is a function of multiple factors, including physiological characteristics of maize, genotype, soil characteristics such as soil water holding capacity, meteorological conditions and agronomic practices. To improve WUE, integrative measures should aim to optimize cultivar selection and agronomic practices. The most important management interaction in many drought-stressed maize environments is between soil fertility management and water supply. In areas subject to drought stress, many farmers are reluctant to economic loss risk by applying fertilizer, strengthening the link between drought and low soil fertility (Bacon, 2004). Ogola et al. (2002) reported that the WUE of maize was increased by application of nitrogen. They added that maize plants are especially sensitive to water stress because their root system is relatively sparse.

Humic compost is the final component of organic matter decomposition, and its benefits in agricultural system are its ability to capture more moisture content, which will increase water use efficiency in the amended

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sandy soil when compared with the unamended one. This could be due to the phenomenon of swelling and retention of water by the amended soil (Suganya and Sivasamy, 2006). Otherwise, humic substances are able to change into complex metal ions (Stevenson, 1982) which will decrease nutrients leaching with irrigation water, and increase fertilizers use efficiency. Humic substances are relatively stable products of organic matter (Mackowiak et al., 2001); they accumulate in the environmental systems to increase moisture retention and nutrient supply potentials of sandy soils (Suganya and Sivasamy, 2006). Laboski et al. (1998) found that maize yield responses to amount of water applied by trickle irrigation are therefore essential to achieve the best trickle irrigation management.

Increasing the plant population density usually increases maize grain yield until an optimum number of plants per unit area is reached (Holt and Timmons, 1968). Fulton (1970) also reported that higher plant densities of maize produce higher grain yields. Plant densities of 90,000 plants ha^{-1} for maize are common in many regions of the world (Modarres et al., 1998). The use efficiency of plant nutrients depends upon various aspects of fertilizer application like rate, method, time, type of fertilizer, crop and soil in addition to other factors. Proper method and time of fertilizer application is inevitable to reduce the losses of plant nutrients and is important for a fertility program to be effective. Nitrogenous fertilizers should be applied in split doses for the long season crops. Similarly, nitrogen should not be applied to sandy soil in a single dose, as there are more chances for nitrate leeching (Bhatti and Afzal, 2001). Phosphate fertilizers applications are also of great concern. When applied to soil they are often fixed or rendered unavailable to plants, even under the most ideal field conditions. In order to prevent rapid reaction of phosphate fertilizer with the soil, the materials are commonly placed in localized band. To minimize the contact with soil, pelleted or aggregated phosphate fertilizers are also recommended (Brady, 1974). He also reported that much of the phosphate is used early in the plant's life for row crops. Similarly, data collected on the yield of maize showed that application of all phosphorus at sowing was better than its late application. Memon (1996) concluded that phosphorus uptake by plant roots depend on the phosphorus uptake properties of roots and the phosphorus supplying properties of soil. He also added that maximizing the uniformity of water application is one of the easier ways to save water at the farm level. The evaluation of the emission uniformity of the trickle system should be done periodically. In comparison, studies between different irrigation systems as observed by Mansour (2006) showed that the maximum increases in both water use efficiency and water utilization efficiency at the 2nd season relative to the 1st season were observed under drip irrigation system (42 and 43%, on ranking), followed by the low head bubbler irrigation system (40.7 and 37%, on ranking), while the minimum increases (30.6 and 32%, on ranking) were observed under the gated pipe irrigation system. Also, he found that the increases in fertilizers use efficiency of N, P_2O_5 and K_2O at the 2nd season relative to the 1st season were (24, 23 and 28%), (22, 21 and 27%) and (9, 8 and 14%) under drip irrigation system, low head bubbler irrigation system and gated pipe irrigation system, on ranking respectively. The aim of this work is to study the effect of the localized irrigation systems (LIS) used: 1) mini-sprinkler irrigation system (MSIS), 2) bubbler irrigation system (BIS), 3) drip irrigation system (DIS), and the humic fertilizer (HF) treatments: HF100 = 100 kg/fed, HF50 = 50 kg/fed, HF0 = 0 kg/fed on water use efficiency (WUE) and fertilizers use efficiency (FUE) of maize crop under Egyptian desert conditions.

MATERIALS AND METHODS

Field experiment was conducted at the Experimental Farm, Agricultural Division, National Research Center, El-Noubaria Governor, Egypt, using maize crop (Zea mays, L.) Gemizza 9 Variety, grown in Sandy soil through the growing season (2012/2013) to study the effect of localized irrigation systems (LIS) and humic fertilizer treatments (HF) on water use efficiency (WUE), fertilizers use efficiency (FUE) and cost analysis of maize production. Tables 1, 2 and 3 show the general characteristics of both soil and irrigation water. Localized irrigation systems used included the following treatments: mini-sprinkler irrigation system (MSIS), bubbler irrigation system (BIS) and drip irrigation system (DIS), while humic fertilizer treatments (HF) used were 100, 50 and 0 kg/fed [(HF100), (HF50); (HF0)]. The total experimental area was 504 m^2. Under each of the localized irrigation system (LIS), plot areas were 168 m^2 and under each humic fertilizers (HF) treatment, the plot area was 56 m^2 [(HF100)=100 kg/fed, (HF50)=50 kg/fed and (HF0)=0 kg/fed, on ranking]. The complete description of irrigation system was given by Mansour (2012) and Tayel et al. (2012a, b, c, d). The experiment design was split plot with three replicates. Maize grains were sown in rows 0.7 m apart and hills were 0.25 m apart along the rows on the 12th of May. Planting density was 24000 plant fed^{-1}. Each row was drip irrigated by single straight lateral line according to the daily reading of Class A pan evaporation. Irrigation frequency was 4 days. The amount of irrigation water required per irrigation was calculated according to the following equation:

$$IWA = \left[\frac{ET_o K_c K_r}{IE} + LR\right] 4.2 \quad (1)$$

Table (1): Some physical properties of the soil.*

Depth, cm	Particle Size distribution, %				Texture class	θ_S % on weight basis			HC (cmh^{-1})	BD (g/cm³)	P (cm³ voids /cm³ soil)
	C. Sand	F. Sand	Silt	Clay		F.C.	W.P.	AW			
0-15	8.4	77.6	8.5	5.5	Sandy	14.0	6.0	8.0	6.68	1.69	0.36
15-30	8.6	77.7	8.3	5.4	Sandy	14.0	6.0	8.0	6.84	1.69	0.36
30-45	8.5	77.5	8.8	5.2	Sandy	14.0	6.0	8.0	6.91	1.69	0.36
45-60	8.8	76.7	8.6	5.9	Sandy	14.0	6.0	8.0	6.17	1.67	0.37

* Particle Size Distribution after (**Gee and Bauder, 1986**) and Moisture retention after (**Klute , 1986**). F.C.: Field Capacity, W.P.: Wilting Point, AW: Available Water, HC: Hydraulic conductivity(cmh^{-1}), BD: Bulck density(g/cm^3) and P: Porosity (cm³ voids/cm³ soil).

Table 2. Some chemical properties of the soil*.

Depth (cm)	pH 1:2.5	EC (dS/m)	Soluble cations (meq/L)				Soluble anions (meq/L)			
			Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^-
0-15	8.3	0.35	0.50	0.39	1.02	0.23	0	0.11	0.82	1.27
15-30	8.2	0.36	0.51	0.44	1.04	0.24	0	0.13	0.86	1.23
30-45	8.3	0.34	0.56	0.41	1.05	0.23	0	0.12	0.81	1.23
45-60	8.4	0.73	0.67	1.46	1.06	0.25	0	0.14	0.86	1.22

*Chemical properties after Rebecca (2004).

Table 3. Some chemical properties of irrigation water used.

pH	EC dS/m	Soluble cations (meq/L)				Soluble anions (meq/L)				SAR
		Ca^{++}	Mg^{++}	Na^+	K^+	CO_3^{--}	HCO_3^-	SO_4^{--}	Cl^{--}	
7.3	0.37	0.76	0.24	2.6	0.13	0	0.9	0.32	2.51	4.61

Where:
IWA = irrigation water applied (m^{3}fed^{-1}irrigation^{-1}),
ET$_o$ = potential evapotranspiration using Class A pan evaporation (mm day^{-1}),
Kc = crop coefficient,
Kr = reduction factor (Keller and Karmeli, 1974),
I = irrigation intervals (day),
I E = irrigation efficiency (90%), and
LR = leaching requirement = 10% of the total water delivered to the treatment.

The amounts of the recommended fertilizers used were: 70.5, 84.9 and 75.8 kg fed^{-1} of N, K_2O and P_2O_5, on ranking. The fertilizers were applied in doses according to the stage of growth via irrigation water. All plots were weeded and pest controlled according to the recommendation of Agriculture Ministry in Egypt. Maize was harvested on the 5th of September but irrigation season was ended 15 days before. The air-dried weights of both grains and stover (Kg fed^{-1}) were calculated.

Water use efficiency (WUE) was calculated following the study of Howell et al. (1995) using the following equations:

$$WUEg = \frac{grain\ yield(kgfed^{-1})}{Total\ water\ applied(m^3fed^{-1})} \quad (2)$$

Table 4. Effect of different irrigation circuits designs and different humic fertilizer treatments on WUE.

LIS (1)	Applied HF (kg/fed) (2)	Applied water (m^3fed^{-1})	Grain yield		Stover yield	
			($kgfed^{-1}$)	WUE_g ($kg\ m^{-3}$)	($kgfed^{-1}$)	WUE_s (kgm^{-3})
	100		4832.6a	1.58a	4943.5a	1.61a
BIS	50	3066.2	4459.8c	1.45c	4787.4c	1.56c
	0		4370.5e	1.43e	4637.5e	1.51e
	100		4623.7b	1.51b	4817.4b	1.58b
MSIS	50	3054.8	4357.3f	1.43fe	4564.2f	1.49f
	0		4206.9g	1.38g	4520.9g	1.48h
	100		4373.1d	1.44d	4696.2d	1.55d
DIS	50	3035.4	3855.1h	1.27h	4525.0h	1.49gf
	0		3701.3i	1.22i	4415.3i	1.45i
1 X 2	$LSD_{0.01}$		**5.52**	**0.02**	**4.54**	**0.01**
Means (1)	BIS		4554.3a	1.49a	4789.5a	1.56a
	MSIS		4396.0b	1.44b	4634.2b	1.52b
	DIS		3976.5c	1.31c	4545.5c	1.50cb
	$LSD_{0.01}$		**6.41**	**0.03**	**4.48**	**0.03**
Means (2)	100		4609.8a	1.51a	4819a	1.58a
	50		4224.1b	1.38b	4625.5b	1.52b
	0		4092.9c	1.34c	4524.5c	1.48c
	$LSD_{0.01}$		**6.53**	**0.05**	**3.37**	**0.03**

LIS: Localized irrigation system, **HF:** Humic Fertilizer added, **(HF100)**: Humic amount added = 100 kg/fed, **(HF50)**: Humic amount added = 50 kg/fed, **(HF0)**: Humic amount added = 0 kg/fed **BIS**: Bubbler irrigation system, **MSIS**: Mini-sprinkler irrigation system, **DIS**: Drip irrigation system, **WUE_g:** grain water use efficiency **WUE_s** : Stover water use efficiency.

$$WUEs = \frac{Stover\ yield\ (kgfed^{-1})}{Total\ water\ applied(m^3fed^{-1})} \quad (3)$$

Treatments mean were compared using the technique of analysis of variance (ANOVA) and the least significant difference (L.S.D) between systems at 1% (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Grain and stover water use efficiency (WUE_g and WUE_s)

Table 4 shows the effect of both localized irrigation systems (LIS) and humic fertilizer (HF) treatments used on grain water use efficiency (WUE_g) and stover water use efficiency (WUE_s). One could infer that the changes in WUE_g and WUE_s took the same trend of the vegetative growth parameters under investigation, that is, leaf area, plant height, leaf length and number of leaves per plant. This could be due to the positive effect of LIS and HF treatments on the vegetative growth parameters mentioned above.

According to WUE_g and WUE_s values, LIS could be put in the following descending orders: BIS > MSIS > DIS and BIS ≥ MSIS ≥ DIS, on ranking. Differences in WUE_g only among LIS were significant at the 1% level.

In respect to the WUE_g and WUE_s values, the HF could be illustrated in the following descending orders: (HF100) > (HF50) > (HF0) and (HF100) ≥ (HF50) ≥ (HF0), on ranking. Differences in WUE_g among HF treatments were significant at the 1% level. On the other hand, difference in WUE_s was significant at the 1% level only between (HF100) and (HF0).

The effect of the interaction: LIS × HF on WUE_g were significant at the 1% level, except those among the interactions: BIS × (HF0), MSIS × (HF50) and DIS × (HF100). The effect of interaction: LIS × HF on WUE_s was not significant at the 1% level in most cases. The highest WUE_g and WUE_s (1.58 and 1.61 kg m^{-3}) and the lowest one (1.22 and 1.45 kg m^{-3}) were obtained in the interactions: BIS × (HF100) and DIS × (HF0), on ranking

Table 5. Effect of different trickle irrigation circuits designs and humic fertilizer treatments on FUE.

LIS	HF (kg/fed)	Applied fertilizers (kgfed^{-1})			Grain yield (kg fed^{-1})	FUE (kg yield kg fertilizer^{-1})		
		N	P_2O_5	K_2O		FUE_N	FUE_{P2O5}	FUE_{K2O}
	100				4832.6a	68.6a	56.9a	64.0a
BIS	50				4459.8c	63.3c	52.5c	59.1c
	0				4370.5e	62.0d	51.5d	57.9d
	100				4623.7b	65.6b	54.5b	61.2b
MSIS	50	70.5	84.9	75.8	4357.3f	61.8f	51.3f	57.7f
	0				4206.9g	59.7g	49.6g	55.7g
	100				4373.1d	62.0ed	51.5ed	57.9ed
DIS	50				3855.1h	54.7h	45.4h	51.1h
	0				3701.3i	52.5i	43.6i	49.0i
LSD $_{0.01}$					**5.5**	**2.8**	**1.4**	**2.5**
Means	BIS				4554.3a	64.6a	53.6a	60.3a
	MSIS				4396.0b	62.4b	51.8b	58.2b
	DIS				3976.5c	56.4c	46.8c	52.7c
LSD $_{0.01}$					**6.4**	**2.2**	**1.5**	**1.9**
Means	100				4609.8a	65.4a	54.3a	61.1a
	50				4224.1b	59.9b	49.8b	55.9b
	0				4092.9c	58.1c	48.2c	54.2c
$LSD_{0.01}$					**6.5**	**1.5**	**1.3**	**2.4**

LIS: Localized irrigation system, **HF:** Humic Fertilizer added**, FUE =** Fertilizers use efficiency**, (FUE)$_N$ =** Nitrogen use efficiency, **(FUE)$_{P2O5}$** = Phosphorous use efficiency, **(FUE)$_{K2O}$** = Potassium use efficiency, **(HF100)**: Humic amount added = 100 kg/fed, **(HF50)**: Humic amount added = 50 kg/fed, **(HF0)**: Humic amount added = 0 kg/fed **BIS**: Bubbler irrigation system, **MSIS**: Mini-sprinkler irrigation system, **DIS**: Drip irrigation system.

Fertilizers use efficiency (FUE)

Table 5 shows the effect of LIS and HF treatments on (N, P_2O_5 and K_2O) fertilizers use efficiency (FUE_N, FUE_{P2O5} and FUE_{K2O}). According to the FUE values of the three fertilizers used, the LIS and HF treatments used could be ranked in the following ascending orders: DIS < MSIS < BIS and (HF0) < (HF50) < (HF100). Differences in FUE among LIS between any two LIS treatments and/or HF ones were significant at the 1% level except differences between (BIS; MSIS) and (HF50; HF0) in the case of $(FUE)_N$.

The effects of the interactions: LIS × HF treatments on FUE were significant at the 1% level among some interactions and not among the others. The highest values of nitrogen use efficiency FUE_N, phosphate use efficiency FUE_{P2O5} and potassium use efficiency FUE_{K2O} (68.6, 56.9; 64.0 kg yield.kg fertilizer^{-1}) and the lowest ones (52.5, 43.6; 49.0 kg yield.kg fertilizer^{-1}) were achieved in the interactions: BIS × (HF100) and DIS × (HF0), on ranking. These data are supported by Baligar and Bennett (1986).

The obtained results indicated that FUE took the same trend of vegetative growth parameters, yield and WUE. This finding may be attributed to the direct linear relation between WUE and FUE found by Tayel et al. (2006).

Conclusion

At present, the world is facing very big challenges of food insecurity and malnutrition are widespread due to the limited water resources, and the continuing increase in population , and adverse climate changes, environmental pollution, and not relying on bio-fuel energy. Dehydration is one of the most important reasons that lead to poor crop yield. In order to avoid the occurrence of drought and water stress to crops, we must use modern irrigation methods, which are called localized irrigation systems (LIS) and for the major crops such as maize, because we are able to perform a well-managed process of irrigation, and thus avoid the occurrence of drought, which affects positively on maize crop productivity and food security.

In addition, we must use organic fertilizers such as humic fertilizer (HF) which is one of the organic fertilizers recently known to have positive effect on agricultural production in general and maize crop in particular. Finally, it can be recommended from the results mentioned that the optimal quantity of (HF = 100 kg fed^{-1}) with bubbler irrigation system (BIS) should be used since their impact was positive on the water and fertilizer use efficiencies (WUE and FUE), and maize crop productivity.

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