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Soil moisture retention and performance of different irrigation practices for wheat crop grown on clay loam soil

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Abstract

An experimental field was carried out during the growing season of 2019/20 and 2020/21 at The Experimental Farm, Fac. of Agriculture, Assiut, Egypt (27° 12- 16.67= N latitude and 31° 09- 36.86= E longitude) in order to evaluate the change in soil moisture retention and wheat plant response to different irrigation practices as well as their performances and water productivity. The tested irrigation practices (border, furrow, alternative furrow, gated pipe and surface drip) were arranged as factorial in a completely randomized design with three replicates. The soil moisture retention decreased clearly with soil depth for all irrigation practices through both seasons. On average basis of both seasons, the soil water retained in 60 cm soil depth was 12.36, 12.17, 11.99, 11.91 and 11.75 cm water depth for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. It could be arranged the amount of retained water in descending order of basin > furrow > alternative furrow > gated pipe > drip irrigation practices. In general, it was noticed that the retained water in the top layer (0- 30 cm) was higher than that in sub layer (30- 60 cm). On average basis of both seasons, the relative increases in soil water retention in 60 cm soil depth were 3.79, 3.60, 2.00 and 1.40% for basin, furrow, alternative furrow and gated pipe, respectively compared to drip irrigation practice. The irrigation performance indices of gated pipe and drip irrigation were utmost the other irrigation practices. Water application efficiency, the non-beneficial water consumption, water storage efficiency and distribution uniformity was 84.15 and 85.29%, 18.85 and 17.25%, 58.04 and 56.15% and 90.68 and 90.90 for gated pipe and drip irrigation practices, respectively. The highest wheat grain and straw yield were attained at gated pipe and drip irrigation practices since grain yield was 3164.0 and 3113.0 kg/ fed. and straw yield was 3691.5 and 3646.0 kg/fed., respectively. It might be concluded that applying more irrigation water than can be stored in the top 60 cm of the soil profile will result in inefficient utilization of this water by winter wheat. Selection of a suitable irrigation method would depend on the specific conditions of water resources, crop types and management requirements.

Keywords: water retention, irrigation performance, wheat yield, actual evapotranspiration.

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1. Introduction

Soil moisture retention is a major soil hydraulic property that control soil functioning in ecology and greatly affects soil management. Soil moisture forms a major buffer against flooding, and water capacity in subsoil is a major steering factor for plant growth. The change effects in soil moisture retention depend on soil texture and the amount of soil organic carbon. Maintaining or even enhancing soil moisture retention capacity might positively mitigate the impacts of more frequent and severe droughts (Rawls *et al*., 2003). Kumar *et al*. (2002) revealed that land use and physiochemical properties (organic carbon, clay, water stable aggregate and mean weight diameter) play a significant and positive role in water retention. Forest soils had higher water retention, infiltration rate, and lower dispersion and erosion ratios than the cultivated and orchard soils. Amer and Amer (2010) stated that the desired water depth which the soil can keep in the root zone divides the area under the irrigation conditions into three divisions; the water stored in the root zone, the water of deep seepage beyond the root zone and the water deficit in the root zone. Soil moisture retention can be understood as the water retained by the soil after water runs through the soil pores to join its bodies. Water retention is mainly dependent on soil particle size. The finer the soil particles, the higher the chance of water molecules to hold on soil particles (clay). Soil water retention is critical for plants and acts as the chief source of moisture for it in almost all territories (Mariamma, 2010). Briggs (2016) revealed that soil moisture data can be used for water reservoir content and managing, early advice of deficiencies, irrigation planning, and crop yield estimation. Pinheiro *et al*. (2018) indicated that increasing the root density in upper soil layers may well be a more efficient strategy for ecosystems to acquire water in semi-arid regions. Stocker *et al*. (2018) revealed that soil moisture loss alone can reduce gross primary productivity by up to 40% at sites in sub-humid, semi-arid and arid regions. Li et al. (2019) found that irrigation water accounted for 0–22% (at 6% peak) of water absorbed by cherry roots at drip irrigation mode during the drought period. The soil water at these depths (from 0 to 100 cm) provided equal proportions of the total water absorption. In the surface irrigation mode, irrigation water accounted for 0–6% (at 6% peak) of water absorbed by cherry roots. Under drip irrigation in moist period, irrigation water accounted for 0–12% (at 4% peak) of the total water absorbed by cherry roots. Under surface irrigation, the irrigation water and the soil water at depths from 0 to100 cm contributed equally to the total water absorption. Wang *et al*. (2019) revealed that Soil moisture, evapotranspiration and atmospheric factors (e.g. vapour pressure deficit) are closely linked in transitional soil moisture regimes (ranging from dry to wet soil conditions), the identification of which is critical for quantifying these relationships under different soil moisture conditions. Demir and Sahin (2020) stated that drip irrigation over other irrigation methods improves efficiency in use of water and nutrients since it decreases water and nutrient loss through deep percolation, and declines total water requirements with more controlled irrigation. Cakmakci and Sahin (2021) found that the subsurface drip method saved 20.7 and 49% more irrigation water than the surface drip and furrow methods, respectively under fully irrigated conditions. The objective of this research is to evaluate the change in soil moisture retention and wheat plant response to different irrigation practices as well as their performances and water productivity.

2. Materials and methods

An experimental field was carried out during the growing season of 2019/2020 and 2020/2021 at The Experimental Farm, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt (27° 12- 16.67= N latitude and 31° 09- 36.86= E longitude and at 51 m altitude above mean sea level). The meteorological data of the research area is present in Table (1). The chemical and physical properties of the investigated site as well as of used irrigation water were determined according to Page *et al*. (1982) and Klute (1986) (Table 2).

Table (1): The meteorological data of the studied area.

Year	Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Wind speed (km/ h)	Sunshine (h)	Evapotranspiration (ET_0 mm/day)
2014-2020	November	26.5	12.7	53.5	14.4	9.4	2.27
	December	21.8	8.1	57.7	15.5	9	1.67
	January	19.8	5.7	54.9	14.2	8.9	1.58
	February	23	8	48.8	15.3	9.7	2.17
	March	27.1	11.9	40.5	17.3	9.9	3.03
	April	31.6	15.5	34.2	17.7	10.3	3.86
	May	36.4	20.4	30.7	16.9	11.4	4.69

Source: Meteorology Station of Assiut, Egypt.

The tested irrigation practices (border, furrow, alternative furrow, gated pipe and surface drip) were arranged as factorial in a completely randomized design with three replicates. The surface drip irrigation is set up of GR polyethylene pipe 16 mm in diameter auto emitter every 30 cm with flow rate of 4 liter/hour at 1.5 bar. The gated pipe is perforated each 70 cm with 0.5 cm hole diameter along the gated pipe. The water supply to each irrigation treatment was regulated by adjusting the operating hours with the help of water meters and gate valves provided at the inlet end of each irrigation practice. Reference evapotranspiration (ETo) was determined using mean monthly meteorological data according to FAO (2012). To obtain the actual Evapotranspiration (ETa), the soil moisture content was measured in the middle of each treatment before irrigation and after 48 hours down to 60 cm depth with 15 cm increment. The amount of water retention or could be consumed (ETa) from the root zone between two successive irrigations as water depth in cm, was calculated according to Israelsen and Hansen (1962) using the following equation:

$$ET = \theta2\text{-}\theta1 / 100 \times Bd \times D / 100 \times 4200$$

Where: ET = evapotranspiration (m^3). θ2 and θ1 = soil moisture percent after and before irrigation, respectively. Bd = soil bulk density (g/ cm^3). D = soil depth (cm).

In the winter season of 2019/20 and 2020/21, Wheat seeds (*Triticum aestivum vulgar*, CV Sids12) were broadcasting on 5th, December consumes 60 kg seeds/ feddan (feddan = 4200 m² = 0.420 hectares = 1.037 acres) for each irrigation practice. Wheat harvest was almost 150 days after planting. All wheat agricultural practices were applied according to the recommendations set by the Ministry of Agriculture. Nitrogen fertilizer was applied in the form of urea (46% N) at the rate of 200 kg/feddan in two equal doses; the first one was before the post planting irrigation and the second dose at the tillering stage (before the second irrigation). Phosphorus fertilizer in the form of calcium super phosphate (15.5% P_2O_5) was added at the rate of 200 kg/feddan in one dose during soil preparation. No potassium fertilizer was added due to the soil is alluvial which is rich in its potassium content. Four square meters (2 m × 2 m) from the centric area of each treatment were used to estimate the grain and straw yield then converted to yield/feddan.

Table (2): Some physical and chemical properties of the tested site.

Physical properties												
Soil depth (cm)	Particle size distribution (%)			Texture class	Organic matter (%)	$CaCO_3$ (%)	Field capacity (%)	Welting point (%)	Available water (%)	Bulk density (Kg/m^3)	Infiltration rate (cm/ h)	Hydraulic conductivity (m/day)
0-15	25.02	39.63	35.35	Clay loam	1.24	3.42	44.10	21.10	23.10	1.20	0.14	0.06
15-30	24.60	39.02	36.38	Clay loam	1.13	3.14	43.90	21.20	22.90	1.31		
30-45	25.85	38.76	35.39	Clay loam	0.99	2.62	43.20	20.60	22.60	1.33	--	
45-60	26.44	41.04	32.52	Clay loam	0.91	2.23	42.10	20.00	21.90	1.38	--	
Mean	25.48	39.61	34.91	Clay loam	1.07	2.85	43.33	20.73	22.63	1.31	--	--

Chemical properties													
Soil depth (cm)	Saturation percent (%)	pH(1:2.5)	EC_e (dS/m)	Soluble ions (meq./L)							Sodium adsorption ratio	Available nutrients (ppm)	
				CO_3 + HCO_3	Cl	SO_4	Ca	Mg	Na	K		N	P
0-15	86.00	7.92	1.08	2.45	1.27	6.20	2.65	1.42	5.83	0.13	4.08	84.00	11.18
15-30	85.00	7.94	1.01	2.25	1.19	6.05	2.54	1.23	5.55	0.25	4.04	75.50	11.01
30-45	84.00	7.98	0.98	2.14	1.28	5.60	2.38	1.18	5.32	0.21	3.98	64.20	10.84
45-60	83.00	7.99	1.12	3.38	3.03	6.15	3.17	1.34	7.82	0.28	5.20	53.50	10.16
Mean	84.50	7.96	1.05	2.56	1.69	6.00	2.69	1.29	6.13	0.22	4.33	69.30	10.80

Chemical composition of irrigation water										
pH	ECdS/m	Soluble ions (ppm)								
		CO_3 + HCO_3	Cl	Ca	Mg	Na	N	P	K	SAR
7.31	0.207	67.35	64.35	79.65	38.65	14.5	9.57	1.5	1.12	0.47

At harvest time, ten plants were chosen randomly from one square meter of each treatment to estimate the following parameters: Plant height (cm), Harvest index (weight as g/1000 grains), Nitrogen percentage in grain, Nitrogen percentage in straw. The obtained wheat plant data were statistically analyzed according to the methods described by Steel *et al*. (1997) using computer M-Stat program.

Wheat samples (grain and straw) from each treatment were collected, dried and milled. The milled samples were digested according to Thomas *et al.* (1967). Nitrogen content of wheat grains and straw were determined using Kjeldahl method as mentioned by FAO (1980). The technical performance of irrigation treatments was evaluated in terms of application efficiency is measured according to the formula proposed by Walker (1989) as follows:

$$Ea = (Dad / Dap) * 100$$

Where Ea is application efficiency (%), Dad is depth of water stored in the root zone (mm) and Dap is depth of water applied to the furrow (mm).

Water storage efficiency has been defined by the equation proposed by Heermann *et al.* (1990) as follows:

$$Es = 100\ (Vs/ Vrz)$$

Where Es is the storage efficiency (%), Vs is the irrigation needed by the crop (m^3), Vrz is the root zone storage capacity (m^3).

Distribution uniformity (DU) was determined according to Micheal (1978) by using the following equation:

$$DU = \{1- (\hat{y} / đ) * 100\}$$

Where ŷ is the average numerical deviation from đ and đ is the average depth of water stored along during the irrigation.

Non beneficial water (%) was calculated according to the formula proposed by Zerihun et al. (1996) as:

$$RNC\% = (Wnbc/ Wc) *100$$

Where RNC is the Ratio of Non-beneficial Consumption, Wnbc is the non-beneficial consumption, Wc is the total consumption.

Irrigation water use efficiency (IWUE) and Crop water productivity (CWP) were calculated according to Du *et al.* (2017) using the following equations:

$$IWUE\ (kg/m^3) = 100\ (Y/I)$$
$$CWP\ (kg/m^3) = 100\ (Y/ET)$$

Where Y is the grain yield (kg/feddan) and I is the irrigation water applied (m^3/feddan), ET is the seasonal water requirement (m^3/feddan).

3. Results and Discussion

3.1 Retained soil moisture with different irrigation practices and soil depth

Soil moisture retention through the soil profile down to 60 cm depth for different irrigation practices at consequent irrigations for wheat crop growth in both winter seasons of 2019/2020 and 2020/2021 are shown in Table (3). In general, the soil moisture retention decreased clearly with soil depth for all irrigation practices through both seasons and it was higher in the 1st season than that in the 2nd one. On average basis of 4 irrigations, the soil water retained in 60 cm soil depth was 12.68, 12.40, 12.25, 12.23 and 12.18 cm water depth for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively in the 1st season (Figure 1). The corresponding value was 12.05, 11.94, 11.72, 11.59 and 11.32 cm water depth in the 2nd season (Figure 1).

Table (3): Soil moisture retention through soil profile for different irrigation practices at consequent irrigations for wheat crop growth in winter season of 2019/2020 and 2020/2021.

Irrigation practice	Soil depth (cm)	Soil water retention in the 1st season (cm depth)					Soil water retention in the 2nd season (cm depth)				
		1st irrigation	2nd irrigation	3rd irrigation	4th irrigation	Average	1st irrigation	2nd irrigation	3rd irrigation	4th irrigation	Average
Basin	15	4.97	4.76	4.91	4.89	4.88	4.52	4.40	4.42	4.38	4.43
	30	3.71	3.97	4.19	3.61	3.87	3.86	3.79	3.82	4.08	3.89
	45	2.39	2.68	2.60	2.40	2.52	2.31	2.51	2.00	2.60	2.35
	60	1.72	1.15	1.53	1.20	1.40	0.64	0.91	2.79	1.16	1.38
	All	12.79	12.56	13.23	12.12	12.68	11.33	11.62	13.03	12.22	12.05
Furrow	15	4.83	4.91	4.90	4.73	4.84	4.46	4.33	4.79	4.52	4.52
	30	4.01	4.12	4.02	3.78	3.98	3.91	3.59	3.89	3.73	3.78
	45	2.49	2.54	2.76	2.43	2.56	2.03	2.00	2.36	2.32	2.18
	60	1.01	1.09	1.20	0.79	1.02	0.88	1.49	2.09	1.38	1.46
	All	12.34	12.66	12.87	11.74	12.40	11.28	11.40	13.12	11.95	11.94
Alternative furrow	15	4.82	4.98	4.91	5.07	4.95	4.42	4.26	4.58	4.63	4.47
	30	3.82	3.92	3.42	3.88	3.76	3.62	3.83	3.74	3.53	3.68
	45	2.37	2.19	2.50	2.37	2.36	2.63	2.15	2.01	2.10	2.22
	60	1.24	1.15	1.23	1.14	1.19	1.25	1.39	1.49	1.27	1.35
	All	12.25	12.25	12.05	12.46	12.25	11.92	11.64	11.82	11.52	11.72
Gated pipe	15	4.86	4.97	4.81	4.94	4.89	4.34	4.12	4.77	4.46	4.42
	30	3.64	4.29	3.95	4.08	3.99	2.98	3.68	3.57	3.56	3.45
	45	2.06	2.36	2.37	2.43	2.31	2.28	2.44	2.48	2.98	2.54
	60	0.98	1.03	1.03	1.13	1.04	0.80	0.98	1.26	1.67	1.18
	All	11.54	12.64	12.16	12.57	12.23	10.41	11.23	12.08	12.67	11.59
Drip	15	4.79	5.01	5.03	4.97	4.95	4.39	4.46	4.57	4.42	4.46
	30	3.52	3.50	4.05	3.71	3.69	3.70	3.41	3.47	3.51	3.52
	45	2.26	2.43	2.51	2.67	2.46	2.24	2.57	2.09	2.19	2.27
	60	0.70	1.09	0.99	1.51	1.07	1.22	1.11	0.88	1.05	1.06
	All	11.27	12.02	12.58	12.85	12.18	11.55	11.55	11.01	11.16	11.32

It could be arranged the amount of retained water in descending order of basin > furrow > alternative furrow > gated pipe > drip irrigation practices. In general, it was noticed that the retained water in the top layer (0- 30 cm) was higher than that in sub layer (30-60 cm). On average basis of both seasons, the relative increases in soil water retention in 60 cm soil depth were 3.79, 3.60, 2.00 and 1.40% for basin, furrow, alternative furrow and gated pipe, respectively compared to drip irrigation practice. This might indicate that drip irrigation frequency has some beneficial effect on soil water storage and plant water consumption. These findings are evident from the values of soil water storage (DS) and irrigation water compensation for plant water consumption (WC). The values of DS were generally higher in higher frequency treatments than in low frequency treatments and vice versa for WC values. This is probably due to the low irrigation frequency having the highest probability of more deep percolation and the amount of water that percolated at lower depth was not depleted by roots. Souza *et al*. (2009) indicated that there is a relation between the storage and the volume of water applied to the wetted soil volume (agreeing with conservation of mass). Hence, increasing the volume applied causes the storage of water to descend to the deepest layer of the soil profile.

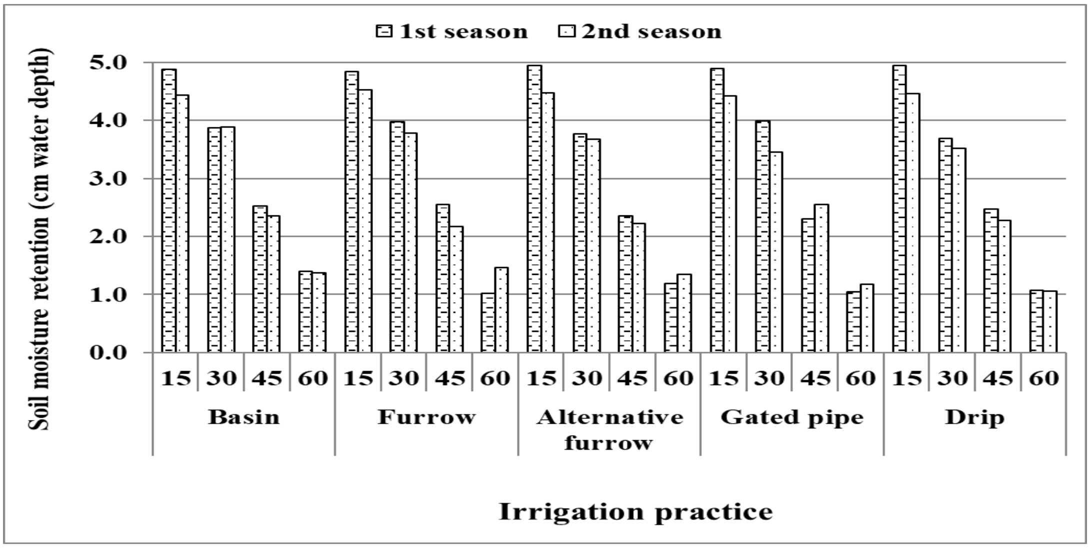

Figure (1): Soil moisture retention for soil depth and with different irrigation practices through the growing season of 2019/2020 and 2020/2021.

3.2 Irrigation performance

Performance terms measure how close an irrigation event is to an ideal one. Various terms are used to describe how efficiently irrigation water is applied and/ or used by the crop. In general, the performance of a furrow irrigation event can be fully evaluated from three distinct but complementary perspectives as application efficiency, water requirement efficiency and distribution uniformity (Irmak *et al*., 2011). Water application efficiency of both growing seasons (2019/20 and 2020/2021) is presented in Table (4). For both seasons, water application efficiency changed from 60.30 to 85.86% at different irrigation practices. In the 1st season, water application efficiencies were 62.06, 73.97, 79.59, 84.82 and 85.86% for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. They were 60.30, 72.58, 77.19, 83.47 and 84.72% for the corresponding irrigation practices in the 2nd season. Water application efficiency of both growing seasons could be arranged in the descending order of drip > gated pipe > alternative furrow > furrow > basin irrigation practice. In general, water application efficiencies in the 1st season were higher than those of the 2nd season. It was noticed that water application efficiency under gated pipe and drip irrigation realized the utmost ones compared to the other irrigation practices. This might be attributed to less surface water evaporation at the same time minimum water loss by either runoff or deep percolation. These findings are in harmony with those obtained by Fang et al. (2018) who found drip irrigation (DI) changed the infiltration form of soil moisture, the moist area under DI was almost elliptical and should have been so smaller than that under traditional basin irrigation (BI). However, great increases the soil wetting proportion and thus the soil evaporation (E). Moreover, the hardening of soil under BI hindered the E of water to some extent (Jha *et al.*, 2019). Yang *et al.* (2020) explained the main reason that DI reduced soil E was that DI reduced the irrigation amount, thus reducing the water evaporated during irrigation and the average moisture content of the soil. With decreasing soil moisture content, soil E can decrease. However, there was little difference in soil E between DI and BI when the irrigation amounts were similar.

Table (4): Wheat water relationship and irrigation performance at different irrigation practices through 2019/2020 and 2020/2021 growing season.

Growing season	Treatments	Irrigation water applied (m^3/feddan)	Consumptive use (m^3/feddan)	Grain yield (kg/feddan)	Field water use efficiency (kg/m^3)	Crop water productivity (kg/m^3)	Water application efficiency (%)	Non beneficial water (%)	Storage efficiency (%)	Distribution uniformity (%)
2019/20	Basin	3658	2270	2812	0.77	1.24	62.06	61.15	62.12	88.93
	Furrow	3008	2225	2789	0.93	1.25	73.97	35.19	60.67	91.76
	Alternative furrow	2764	2200	2937	1.06	1.34	79.59	25.64	59.72	90.30
	Gated pipe	2576	2185	3128	1.21	1.43	84.82	17.89	60.93	91.50
	Drip	2489	2137	3097	1.24	1.45	85.86	16.47	59.27	91.19
2020/21	Basin	3572	2154	2861	0.80	1.33	60.30	65.83	58.32	88.57
	Furrow	2943	2136	2914	0.99	1.36	72.58	37.78	56.71	87.77
	Alternative furrow	2696	2081	2953	1.10	1.42	77.19	29.55	55.57	88.49
	Gated pipe	2487	2076	3097	1.25	1.49	83.47	19.80	55.16	89.85
	Drip	2396	2030	3129	1.31	1.54	84.72	18.03	53.03	90.60

Water storage efficiency of both growing seasons (2019/2020 and 2020/2021) is presented in Table (4). For both seasons, water storage efficiency varied from 53.03 to 66.12% at different irrigation practices. In the 1st season, water storage efficiencies were 62.12, 60.67, 59.72, 60.93 and 59.27% for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. They were 58.32, 56.71, 55.57, 55.16 and 53.03% for the corresponding irrigation practices in the 2nd season. Water storage efficiency of both growing seasons could be arranged in the ascending order of drip < gated pipe < alternative furrow < furrow < basin irrigation practice (Table 4). In general, water storage efficiencies in the 1st season were higher than those of the 2nd season. It was noticed that water storage efficiency under drip irrigation realized the least ones compared to the other irrigation practices. This might be attributed to the crop root zone may not need to be refilled with each irrigation under drip irrigation practice. These results agreed with those obtained by Howell (2003) who revealed that the storage efficiency has little utility for sprinkler or micro-irrigation because these irrigation methods seldom refill the root zone, while it is more often applied to surface irrigation method. The non-beneficial water consumption of both growing seasons (2019/2020 and 2020/2021) is presented in Table (4). For both seasons, the non-beneficial water consumption varied from 16.47 to 65.83% at different irrigation practices. In the 1st season, the non-beneficial water consumption was 61.15, 35.19, 25.64, 17.89 and 16.47% for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. They were 65.83, 37.78, 29.55, 19.80 and 18.03% for the corresponding irrigation practices in the 2nd season. In general, the non-beneficial water consumption in the 2nd season was higher than those of the 1st season. The non-beneficial water consumption of both growing seasons could be arranged in the ascending order of drip < gated pipe < alternative furrow < furrow < basin irrigation practice. These findings are in combatable with those obtained by Jägermeyr (2017) who found that irrigation water consumption is calculated to be 1257 m^3, of which 608 m^3 are non-beneficially consumed, *i.e.* lost through evaporation, interception, and conveyance and is indicative of the substantial water saving potentials associated with irrigation improvements. Replacing surface systems by sprinkler or drip systems could reduce the non-beneficial consumption at river basin level by 54 and 76%, respectively while maintaining the current level of crop yields. Miao *et al*. (2018) found that a smaller non-beneficial water use (NBWU) is achieved in level basin projects with a length of up to 200 m and for graded basins (GB) with 0.5‰ slopes when the length does not exceed 100 m. Naturally, a smaller NBWU corresponds to projects whose beneficial water use fraction (BWUF) is higher and irrigation water productivity (IWP) is also higher. Distribution uniformity (DU) of both growing seasons (2019/2020 and 2020/2021) is presented in Table (4). For both seasons, the distribution uniformity varied from 87.77 to 91.76% at different irrigation practices. In the 1st season, the DU were 88.93, 91.76, 90.30, 91.60 and 91.19% for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. They were 88.58, 87.77, 88.49, 89.85 and 90.60% for the corresponding irrigation practices in the 2nd season. In general, the distribution uniformities in the 1st season were higher than those of the 2nd season. It was noticed that the distribution uniformity under both gated pipe and drip irrigation realized the utmost ones compared to the other irrigation practices. The distribution uniformity of both growing seasons could be arranged in the ascending order of basin < alternative furrow < furrow < gated pipe < drip irrigation practice. Badr and Abuarab (2013) revealed that the uniformity of soil moisture distribution and its variation from one site to another is due to soil matric potential at the same soil depth as well as to the total hydraulic potential at different soil depths because of the soil moisture movement direction.

3.3 Field water use efficiency and crop water productivity

Field water use efficiency (FWUE) and crop water productivity (CWP) of both growing seasons (2019/2020 and 2020/2021) are shown in Table (4). For both seasons, IWUE values varied from 0.77 to 1.31 kg/m^3 at different irrigation practices. On the average basis of both seasons, the FWUE were 0.78. 0.96, 1.08, 1.23 and 1.28 kg/m^3 for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively (Figure 2). FWUE in the 1st season were less than those of the 2nd season. It was noticed that FWUE under both gated pipe and drip irrigation realized the utmost ones compared to the other irrigation practices.

The FWUE of both growing seasons could be arranged in the ascending order of basin < furrow < alternative furrow < gated pipe < drip irrigation. The CWP followed the same trend of FWUE. For both seasons, CWP values varied from 1.17 to 1.54 kg/m^3 at different irrigation practices. On the average basis of both seasons, the CWP were 1.28, 1.31, 1.38, 1.46 and 1.50 kg/m^3 for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. In general, CWP in the 1st season were less than those of the 2nd season. It was noticed that CWP under both gated pipe and drip irrigation realized the utmost ones compared to the other irrigation practices. The CWP of both growing seasons could be arranged in the ascending order of basin < furrow < alternative furrow < gated pipe < drip irrigation practice (Figure 2).

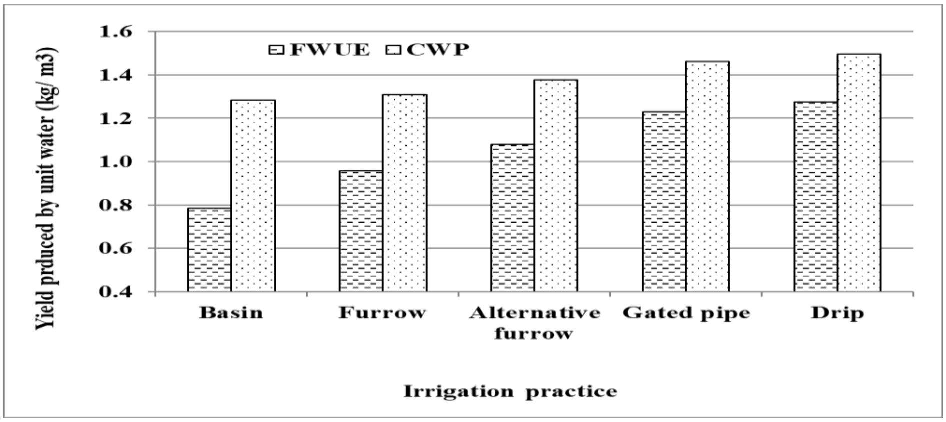

Figure (2): Field water use efficiency and crop water productivity for different irrigation practices as average of both growing seasons.

These results are in agreement with those obtained by Zhang *et al*. (2017) who showed that different irrigation methods combined with different irrigation frequency affected both the grain production and WUE under the same seasonal irrigation amount. Fang et al. (2018) found that increasing irrigation frequency would maintain the top soil layers with higher soil water contents where root length density (RLD) was greater that improved crop water use and yield under limited water supply. The improved yield and WUE under drip irrigation (DI) than that of basin (BI) and sprinkler irrigation (SI) under limited irrigation supply was associated with reduced soil evaporation. The drip lines were placed on crop rows such that inter-row spaces were not wetted during the irrigation, which reduced the soil evaporation. Therefore, more soil water was conserved and used for the crop growth which benefited the grain production under water deficit condition. The WUE improvement under SI was much smaller than that of DI and pillow irrigation (PI), it was related to the larger soil evaporation under SI. Yang *et al*. (2020) stated that the water requirement rules of crops in its different growth stages has demonstrated that the amount of irrigation water affects both water use efficiency and crop yield. Firouzabadi *et al*. (2021) revealed that the mean irrigation water productivity obtained for drip and furrow irrigation treatments were 1.74 and 1.01 kg/m^3, respectively. The drip irrigation caused a 33% reduction in applied irrigation water use and a 72% increase in irrigation water productivity compared to the furrow irrigation method.

3.4 Wheat yield and its traits

Wheat yield and its traits as affected by different irrigation practices are shown in Table (5). During both seasons, the wheat plant heights varied from 95.17 to 102.68 cm. On the average basis of both seasons, the plant height values were 101.84, 97.79, 98.57, 100.89 and 95.66 cm for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. It was noticed that the plant heights in the 1st season was less than those of the 2nd one. The plant heights at basin and gated pipe irrigation practices were superior to the other irrigation practices through both growing seasons. The harvest index values were 46.21, 47.30, 46.19, 46.29 and 49.35 g; the grain yields were 2836.50, 2941.50, 2876.50, 3164.00 and 3113.00 kg/ fed.; the straw yields were 3671.67, 3675.50, 3652.00, 3691.50 and 3646.00 kg/ fed. for the corresponding irrigation practices. The nitrogen contents were 2.13, 2.41, 2.21, 2.52 and 2.22 % and the phosphorus contents were 0.37, 0.38, 0.37, 0.53 and 0.52 for basin, furrow, alternative furrow, gated pipe and drip irrigation practices, respectively. It was noticed that the wheat harvest index at drip irrigation practices was superior to the other irrigation practices through both growing seasons. The wheat grain yield could be arranged in a descending order of gated pip > drip > furrow > alternative furrow > basin irrigation practice. The wheat straw yields were slightly differed during both growing seasons.

Table (5): Wheat yield and its traits as affected by different irrigation practices through 2019/2020 and 2020/2021.

Wheat yield and its traits in the first growing season (2019/2020)						
Irrigation practice	Plant height (cm)	Harvest index	Grain yield (kg/feddan)	Straw yield (kg/feddan)	Nitrogen content (%)	
					Grain	Straw
Basin	101.00 a	43.10 ab	2812.00 d	3671.00ab	2.12 b	0.39 a
Furrow	97.33 ab	43.93 a	2789.00 e	3679.00 ab	2.39 a	0.37a
Alternative furrow	98.00 ab	45.10 a	2937.00 c	3653.00 b	2.18 b	0.37a
Gated pipe	100.67 ab	42.47 ab	3128.00 a	3694.33 a	2.51 a	0.53 a
Drip	95.17 b	44.83 a	3097.00 b	3646.67 b	2.18 b	0.53 a
LSD	5.18	4.27	21.59	30.76	0.18	0.20
	Wheat yield and its traits in the second growing season (2020/2021)					
Basin	102.68 a	49.31 b	2861.00 d	3672.33 a	2.14 cd	0.35 c
Furrow	98.24 bc	50.67 b	3094.00 c	3672.00 a	2.43 ad	0.38 bc
Alternative furrow	99.14 abc	47.27 c	2816.00 e	3651.00 ab	2.24 bcd	0.36 c
Gated pipe	101.11 ab	50.10 b	3200.00 a	3688.67 a	2.53 a	0.52 a
Drip	96.14 c	53.86 a	3129.00 b	3645.33 ab	2.26 bc	0.50 ab
LSD	3.55	1.90	31.07	50.52	0.21	0.11

The nitrogen content of wheat grain and straw were the utmost at gated pipe compared to the other irrigation practices. The wheat yield and its component quantity and quality were compatible with those obtained by Fang *et al*. (2018) who found that seed weight and harvest index were all increased under drip irrigation (DI) compared to basin irrigation for all seasons. The average increase in seed weight was 12.9% and 7.4% for harvest index (HI) during the three seasons. The higher HI was usually related to a higher WUE. Also, they proved that the improved soil water condition during the grain-fill significantly increased seed weight and HI. Firouzabadi *et al*. (2021) found that the maximum and minimum values of two-year average weight of 1000 kernels were also obtained from 75 cm spacing among tapes (T1) and 60 cm furrow spacing (F) treatments at 44.3 and 42.1 g, respectively.

4. Conclusion

It might be concluded that applying more irrigation water than can be stored in the top 60 cm of the soil profile will result in inefficient utilization of this water by winter wheat. Gated pipe and drip irrigation practices produce the highest of wheat grain and straw yield, irrigation water use efficiency, crop water productivity and the highest irrigation performance of water application, water storage efficiency, non-beneficial water consumption and distribution uniformity. Selection of a suitable irrigation method would depend on the specific conditions of water resources, crop types and management requirements.

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