Pak. J. Agri. Sci., Vol. 59(1), 125-134;2022
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/22.239
http://www.pakjas.com.pk

Efficacy of subsurface and surface drip irrigation regarding water productivity and yield of maize

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Pakistan faces surface water and groundwater shortage which are the main reason for assessing more appropriate method of irrigation water use. Subsurface drip irrigation plays an important role to conserves irrigation water and enhances crop yields by reducing surface water evaporation in Pakistan. Two years (2019-20) trials were carried out at "Water Management Research Center" (WMRC), Mansoor Malangi road Faisalabad, under randomized complete block design (RCBD). Maize (Zea mays L.) hybrid variety "YH-1898" was selected for this experiment with sandy loam soil. Sub-surface drip laterals were buried manually at different depths of 0.15, 0.25 and 0.35 m. The results of subsurface drip irrigation for crop water productivity and maize grains yield were compared with surface drip and gravity irrigation methods (furrow-bed and furrow-ridge). The outcomes showed that maximum grain yield (8753 and 8860 kg/ha) was achieved in both the seasons in 2019 and 2020, respectively under sub-surface drip irrigation installed at a depth of 0.15 m. Similarly, the results of water productivity also revealed that the highest water productivity (2.074 and 2.085 kg/cm^3) was concluded both the years in 2019-20, respectively under subsurface drip irrigation installed at a depth of 0.15 m. It is concluded that maximum grain yield and water productivity can be accomplished by the installation of sub-surface drip laterals at 0.15 m depth for maize crop in a semi-arid region of Pakistan.
Keywords: Irrigation, drip lateral, subsurface drip, water productivity, yield.

INTRODUCTION

Surface water scarcity and groundwater deterioration are responsible to retrospect the convenient utilization of water. Water scarcity and accessible water resources are global challenges. In Pakistan's irrigated agriculture, Indus basin is the foremost water resources where precipitation is the basic source of surface water. It have a capacity to divert 128 billion cubic meters irrigation water annually but water is flowing in sea is 35 billion cubic meters because of inadequate storage and 30% shortage of water requirement will be faced as projected by 2025 (Qureshi, 2011). Rizwan *et al.* (2019) reported multiple events of floods and droughts as less and intense precipitation had significantly reducing and rising trends respectively. In 1951, the accessibility of surface water per capita was 5260 cubic meters. By 2016, it declined to 1000 cubic meters. In 2025, it lessened to 860 cubic meters. Probably, which will be labelled our country as a "scarce" country rather than a "water stress" country (GoP, 2018). In Pakistan, the population is increasing at a ratio of 2.4% per year (GoP, 2018-19). The increase in population needs more food with limited water resources of Indus Basin Irrigation System. The water application losses in gravity irrigation is due to deep percolation, run off and evaporation from soil surface that could be retrieved using subsurface drip irrigation system to avoid such losses. According to Rizwan *et al.* (2018), the massive amount of irrigation water could be redeemed by the use of water conservation techniques. Therefore, it is increasingly important to contemplate which irrigation technologies are most effective in water usage and will be produced immense yield with finite irrigation. Due to the limited available water resources, the usage of the subsurface drip irrigation (SDI) method to irrigate major crops is increasing and enhanced the crop yield (Grabow et *al*., 2011; Khalilian *et al*., 2000; Lamm and Trooien, 2005; Lamm, 2016; Lamm *et al*., 2011; Mo *et al*., 2017). Subsurface drip irrigation is substantiating to be an effective technique to apply irrigation to crops; for example, maize, cotton and

Muneer, M. A., M. Arshad, M. A. Shahid and M. A.-ul-Haq. 2022. Efficacy of subsurface and surface drip irrigation regarding water productivity and yield of maize. Pakistan Journal of Agricultural Sciences. 59. 125-134: 2022.
[Received 18 Feb 2021; Accepted 31 Jan 2022; Published 18 Mar 2022]

peanuts (Khalilian *et al*., 2000). Zaccaria et al., (2017) revealed that it can save 20 to 30% irrigation water and improved yield 10 to 30% in California. By this method, irrigation water will be saved up to 23% because the evaporation losses were negligible, so it enhanced the crop yield as compared with surface drip irrigation (Douh and Boujelben, 2010). For maize production, subsurface drip irrigation system can rescue 35% to 55% irrigation water as compared to gravity irrigation system (Lamm and Trooien, 2003). The sub-surface drip buried at 0.15 and 0.30 m depth for maize crop. The lateral 0.15m burial depth gave good yield and crop water productivity (Qiu *et al*., 2017). Afzal *et al.* (2020) stated that sub-surface drip lateral installed at a depth of 0.12 m presented maximum onion (shallow rooted crop) yield in semi-arid zone of Pakistan with dripper discharge of 4 l/hr at 1 bar operating pressure. Umair *et al.* (2019) also stated that the sub-surface drip irrigation method reduced evapotranspiration by 15% in comparison with surface drip irrigation and 26% in comparison with the gravity irrigation system, with a significant grain yield. Besides, the sub-surface drip irrigation method improved crop and irrigation water productivity by 24.95% and 19.59% respectively as equated to gravity irrigation. Valentin *et al*., (2020) reported that irrigation water productivity was enhanced up to 25% under subsurface drip irrigation as compared to sprinkler irrigation. Camp *et al.*, (2000) conducted research trials on subsurface drip irrigation for more than 30 crops at various drip lateral depths ranges from 0.02 to 0.7 m. Similarly, crops like tomato, onion, beans, peas, cabbage, carrot, maize, water melons and potato were sown to evaluate the subsurface drip irrigation system (Lamm and Trooien, 2003; Enciso *et al.*, 2005). These researchers and many others concluded that the lateral geometry of subsurface drip irrigation was varied for various crops and soils (Dukes and Scholberg, 2005; Montemayor Trejo *et al*., 2006; Singh and Rajput, 2012; Douh *et al*., 2013). The lateral depth for maize (deep rooted crop) is not defined by any researcher in semi arid region of Pakistan and need a research to assess the suitable lateral depth of sub-surface drip irrigation for optimization of water productivity and yield of maize. In the light of previous conversation, the current research trial was designed to examine the best geometry of subsurface drip irrigation to enhance water productivity and yield of maize using soil moisture based irrigation scheduling in semi-arid climate of Faisalabad, Pakistan.

MATERIALS AND METHODS

***Site specification*:** The sub-surface drip irrigation research trials for 2019 and 2020 growing seasons on maize crop were carried out at the research trial area of “Water Management Research Centre” (WMRC), Mansoor Malangi road Faisalabad, under a mixed cropping zone containing wheat, maize, cotton, sugarcane and almost all vegetables which are situated in Rachna Doab, at a latitude of “31.25°N” and longitude of “73.09°E” and altitude of “184.4 m” above sea level (ASP, 2006).

***Soil and water parameters*:** The mixed compound soil samples were excavated from four different soil profile depths (0-0.15 m, 0.16-0.30 m, 0.31-0.45 m and 0.46-0.60 m) to find out the field capacity (F.C.), permanent wilting point (P.W.P.), bulk density (B.D.) and soil texture class. The texture class of the soil was calculated using the hydrometer method, expressed by Moodie *et al.* (1959), while F.C. and P.W.P. were estimated by pressure membrane equipment. The core method was used to record B.D. Soil physical properties of research area areas shown in Table 1.

Tube-well water was available for irrigation at the research trial area. The characteristic of the tube-well water was found as moderate for irrigation with an average reading of electrical conductivity (EC), potential of hydrogen (pH), sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) shown in Table 2. The Flame Atomic Spectrophotometer was used to calculate Na^+, Ca^{2+} and Mg^{2+} ratio for SAR and RSC data calculation. The EC and pH meter were used to record EC and pH of irrigation water.

Table 2. Characteristics of tube-well water.

EC (dS/m)	pH	SAR (meq/L)	RSC (meq/L)
2.15	7.66	16.87	4.31

Treatments: The subsurface laterals were buried manually after digging at different depths i.e. 0.15, 0.25 and 0.35 m, respectively. The outcomes of the sub-surface drip treatments were evaluated with surface drip and furrow irrigation methods. The treatments of the research experiment were as under:

T_1 = Subsurface drip irrigation with lateral at 0.15 m depth,
T_2 = Subsurface drip irrigation with lateral at 0.25 m depth,
T_3 = Subsurface drip irrigation with lateral at 0.35 m depth,
T_4 = Surface drip irrigation, T_5 = Gravity irrigation using

Table 1. The soil physical properties of the research area.

Depth(m)	F.C. (% by vol.)	P.W.P. (% by vol.)	B.D. (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Soil Type
0.00-0.15	21.43	8.55	1.55	63.7	22.16	14.14	Sandy loam
0.16-0.30	21.28	8.5	1.56	64.4	21.89	13.71	Sandy loam
0.31-0.45	21.28	8.48	1.58	66.5	20.06	13.44	Sandy loam
0.46-0.60	21.20	8.43	1.59	67.1	19.40	13.50	Sandy loam

furrow-bed planting, T_6 = Gravity irrigation using furrow-ridge planting (control).

The experimental plots (6 m x 22 m) were prepared under randomized complete block design (RCBD) with six treatments and three replication blocks as shown in Figure 1.

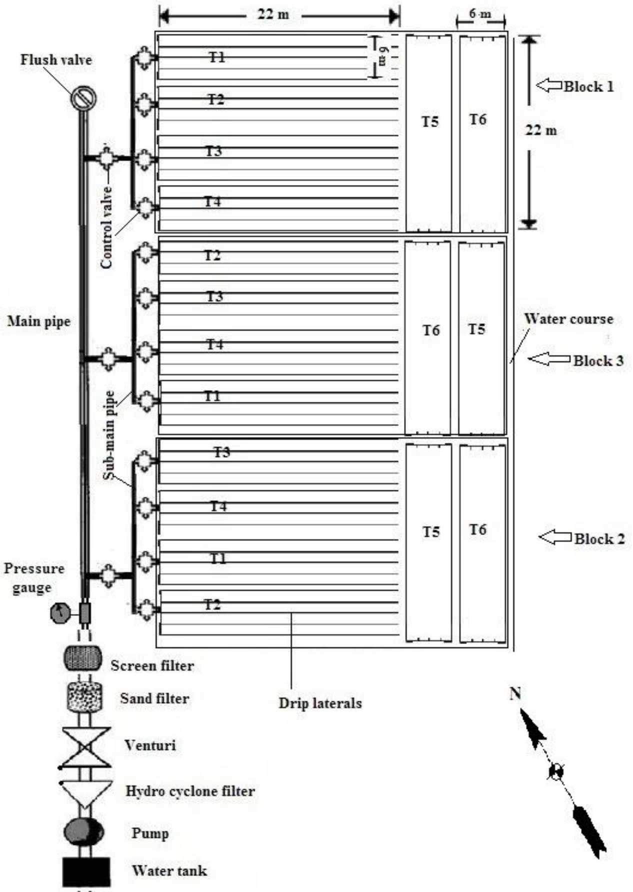

Figure 1. Layout of trial research plot

Maize hybrid variety "YH-1898" was sown during both seasons 2019 and 2020 on both sides of the drip laterals in a zigzag pattern. Plant to plant ($P_x P$) and row to row ($R_x R$) spacing was 0.23 m and 0.76 m respectively. The distance between surface or subsurface drip laterals was 0.92 m and emitter to emitter as 0.3 m shown in Figure 2.

The maize crop was irrigated with gravity irrigation, surface drip irrigation (DI) and subsurface drip irrigation (SDI) with different geometry of lateral depths during the growing season. One bar pressure was maintained to delivered discharge at the rate of 4 L/h in DI and SDI treatments (Afzal *et al.*, 2020). The crop was irrigated based on daily soil moisture irrigation scheduling. The daily soil moisture data was recorded using Time Domain Reflectometry (TDR) shown in Figure 3. To attain maximum grains yield of YH-1898, NPK levels (300-150-100 Kg/ha) were used (Ghani *et al.*, 2017). The collected field data of experimental site was comprised of germination rate, plant height (cm), dry matter weight (kg), maize grain yield (kg/ha), water productivity (kg/m^3) and harvest index.

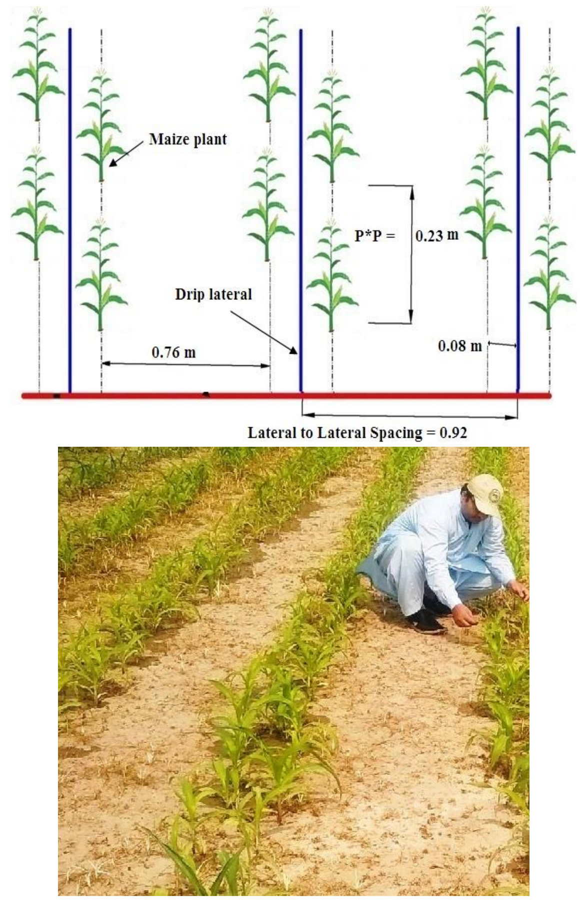

Figure 2. Trial demonstration and data recording of Maize crop

Figure 3. TDR meter for soil moisture measurement

***Statistical analysis*: ** The maize crop data were evaluated using analysis of variance method and assessment of treatment means was formed by least significant difference (LSD) test at five percent probability level (Chauhdary, 2018).

RESULTS AND DISCUSSION

Individually irrigation methods and sub-surface drip at different lateral depths impact the development of maize crop. The agronomic growth parameters examined in the current research trial comprised germination rate, dry matter weight (Kg), 1000-grains weight (Kg), grains yield (kg/ha) of maize and harvest index. The data records were statistically examined for analyzing the significance of the lateral depth of sub-surface drip and the best irrigation system for maize to save water. These agronomic growth parameters have been debated as under.

Germination data of maize: Germination data was recorded after the emergence of maize seedlings in each research plot with the help of a square meter ring of iron to avoid any miscalculation. The results presented that no significant differences were observed in the germination rate of maize crop using different irrigation systems and different geometry of subsurface drip laterals. The detail is given in Table 3.

Height of maize plant: It was noticed that the outcomes of different geometry of subsurface drip and surface irrigation methods on plant height was a statistically significantly different as shown in Table 4. Maximum plant height observed were 197 and 202 cm using 0.15 m lateral depth and minimum 189 and 196.33 cm under gravity irrigation using furrow-ridge irrigation in 2019 and 2020, respectively. The results displayed that as the subsurface lateral depth increased; the height of the maize plant was decreased due to less water availability on the upper surface of the soil. These outcomes are in agreement with the scientist Qiu et al. (2017). The outcomes of maize plant height using surface irrigation revealed that maximum plant height of 195 and 200 cm was observed under drip irrigation and minimum 189 and 196.33 cm using gravity irrigation of furrow-ridge planting in 2019 and 2020, respectively. These outcomes are in accordance with the conclusions of researcher (Irfan *et al*., 2014). Many researchers like (Stanghellini *et al*., 2003; Anjum *et al*., 2014; Irfan *et al*., 2014; Chauhdary *et al*., 2017) have described based on their experimental studies that the effective use of irrigation water; for example, surface drip irrigation plays a significant role to the greatest use of irrigation water for farming and enhances irrigation efficiency. Particularly, in the dry and hot climate zones, surface drip irrigation has enhanced water use efficiency by decreasing losses of evapotranspiration. Therefore, farming practices under a range of water salinities in drip irrigation system can be maintained under frequent application of water.

Dry matter weight: It was observed that the results of different geometry of subsurface drip and surface irrigation methods on dry matter weight were statistically significantly different as shown in Table 5. Maximum dry matter weight observed was 17400 kg/ha and 18510 kg/ha by subsurface drip irrigation using 0.15 m depth of drip lateral and minimum 15737 kg/ha and 16997 kg/ha under gravity irrigation using

Table 3. Germination data of maize per m^2 in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	**R_2**	**R_3**	**Mean**	**R_1**	**R_2**	**R_3**	**Mean**
T1 = SDI*-0.15m	13	13	13	13.00^a	13	13	12	12.67^a
T2 = SDI-0.25m	12	13	13	12.67^a	13	13	12	12.67^a
T3 = SDI-0.35m	13	13	12	12.67^a	12	13	12	12.33^a
T4 = DI**-0m	13	13	13	13.00^a	13	12	13	12.67^a
T5 = Furrow-bed	13	13	13	13.00^a	12	13	13	12.67^a
T6 =Furrow-Ridge	13	13	13	13.00^a	13	12	13	12.67^a
		$LSD_{0.05}$		0.285		$LSD_{0.05}$		0.51

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

Table 4. Plant height of maize in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	**R_2**	**R_3**	**Mean (cm)**	**R_1**	**R_2**	**R_3**	**Mean (cm)**
T1=SDI*-0.15m	197	198	196	197.0^a	201	202	203	202.0^a
T2 = SDI-0.25m	196	197	196	196.3^a	201	200	202	201.0^a
T3 = SDI-0.35m	185	189	190	188.0^b	195	196	194	195.0^d
T4 = DI**-0m	196	195	194	195.0^a	200	199	201	200.0^{ab}
T5 = Furrow-bed	192	190	189	190.0^b	198	198	199	198.3^{bc}
T6=Furrow-Ridge	189	190	188	189.0^b	198	196	195	196.3^{cd}
		$LSD_{0.05}$		1.217		$LSD_{0.05}$		0.914

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation furrow-ridge irrigation in 2019 and 2020, respectively. The outcomes displayed that as the subsurface lateral depth increased; the dry matter weight was decreased due to less water accessibility on the upper surface of the soil. These consequences are in accord with the scientists (Pablo et al., 2007; Qiu et al., 2017).

The results evaluation of maize dry matter weight using surface/gravity irrigation shown that maximum dry matter weight of 16477 kg/ha and 18033 kg/ha was monitored under surface drip irrigation and minimum 15737 kg/ha and 16997 kg/ha using gravity irrigation of furrow-ridge planting in 2019 and 2020, respectively. These outcomes are in accord with the effort of researchers such as (Irfan *et al*., 2014; Chauhdary *et al*., 2017) because drip irrigation provides suitable subsoil environment to the plant for efficient nutrient uptake resulting in a good crop growth (Ibrahim *et al*.,2011; Yamin *et al*., 2020).

Number of grains per cob: The quantity of grains per cob is a natively controlled factor however the environmental and nutritious level can also influence the quantity of grains per cob. The maize grain yield is completely linked to the number of maize optimum grains per cob. More kernels per cob result in higher maize kernel yield. The outcomes showed statistically significant differences in the results. Maximum numbers of grains per cob were witnessed i.e. 481 and 485 by subsurface drip irrigation using 0.15 m depth of drip lateral and minimum (463 and 450) were under gravity irrigation using furrow-ridge irrigation in both seasons 2019 and 2020, respectively, shown in Table 6. The outcomes showed that higher maize yield was attained with efficient utilization of irrigation water. The outcomes are in agreement with the researcher Hassanli et al. (2009) because subsurface drip irrigation provides most favourable soil moisture content in the root-zone.

Thousand grains weight: Efficient utilization of irrigation water influenced 1000-grains weight at five percent level of probability as shown in Table 7. Statistically significantly more 1000-grains weight of 0.269 kg and 0.281 kg was noted when using 0.15 m lateral depth of subsurface drip irrigation in both seasons, respectively. The smallest 1000-grains weight of 0.237 kg and 0.243 kg was documented in control farmer practice where gravity irrigation using furrow-ridge irrigation in 2019 and 2020, respectively. The results are in accord with the investigators Howell et al. (1997), Camp (1998), Lamm (2016) and Qiu et al. (2017) because subsurface irrigation provides ease to make available maximum irrigation water to plant root zone.

In the comparison of the sub-surface lateral depth; the results as presented in “Table 7” showed that 0.15 m lateral depth of subsurface drip contributed more 1000-grain weight and revealed better water productivity than 0.25m and 0.35 m lateral depth of sub-surface drip. The minimum 1000-grain weight was recorded using 0.35 m lateral depth of sub-surface drip in both seasons 2019 and 2020, respectively.

In an evaluation of the surface or gravity irrigation systems; the outcomes in the Table 7 displayed that surface drip irrigation system contributed more 1000-grain weight (0.253 kg and 0.267 kg) in both season 2019 and 2020, respectively than gravity irrigation (furrow-bed and furrow-ridge). The lowest 1000-grain weight (0.237 kg and 0.243 kg) were noted

Table 5. Dry matter weight of maize in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	**R_2**	**R_3**	**Mean (kg/ha)**	**R_1**	**R_2**	**R_3**	**Mean (kg/ha)**
T1 = SDI*-0.15m	17500	17100	17600	17400^{a}	18600	18480	18450	18510^{a}
T2 = SDI-0.25m	17200	16900	17330	17143^{b}	18500	18400	18300	18400^{a}
T3 = SDI-0.35m	15890	15940	15800	15877^{d}	17100	17200	17150	17150^{c}
T4 = DI**-0m	16500	16380	16550	16477^{c}	18100	18050	17950	18033^{b}
T5 = Furrow-bed	15850	15810	15830	15830^{d}	17200	17250	17300	17250^{c}
T6=Furrow-Ridge	15730	15700	15780	15737^{d}	16990	16950	17050	16997^{d}
		$LSD_{0.05}$		104		$LSD_{0.05}$		59

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

Table 6. The number of grains per cob of maize in both seasons 2019 and 2020.

	2019				2020			
Treatment	**R_1**	**R_2**	**R_3**	**Mean**	**R_1**	**R_2**	**R_3**	**Mean**
T1 = SDI*-0.15m	485	478	480	481.00^{a}	488	482	485	485.00^{a}
T2 = SDI-0.25m	482	478	475	478.33^{ab}	484	482	481	482.33^{a}
T3 = SDI-0.35m	467	462	465	464.67^{cd}	450	458	455	454.33^{c}
T4 = DI**-0m	470	475	468	471.00^{bc}	468	459	461	462.67^{b}
T5 = Furrow-bed	465	467	469	467.00^{cd}	459	450	448	452.33^{c}
T6=Furrow-Ridge	458	462	470	463.33^{d}	446	451	453	450.00^{c}
		$LSD_{0.05}$		3.358		$LSD_{0.05}$		3.437

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

Table 7. Thousand grains weight of maize in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	**R_2**	**R_3**	**Mean (kg)**	**R_1**	**R_2**	**R_3**	**Mean (kg)**
T1 = SDI-0.15m	0.275	0.268	0.265	0.269^{a}	0.285	0.280	0.279	0.281^{a}
T2 = SDI-0.25m	0.255	0.251	0.253	0.253^{b}	0.276	0.278	0.275	0.276^{b}
T3 = SDI-0.35m	0.243	0.248	0.245	0.245^{c}	0.258	0.255	0.254	0.256^{d}
T4 = DI-0m	0.255	0.251	0.254	0.253^{b}	0.268	0.265	0.267	0.267^{c}
T5 = Furrow-bed	0.233	0.240	0.242	0.238^{cd}	0.255	0.252	0.249	0.252^{e}
T6 =Furrow-Ridge	0.232	0.237	0.243	0.237^{d}	0.243	0.245	0.241	0.243^{f}
		$LSD_{0.05}$		0.0035		$LSD_{0.05}$		0.00145

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

Table 8. Grain yield of maize in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	**R_2**	**R_3**	**Mean (kg/ha)**	**R_1**	**R_2**	**R_3**	**Mean (kg/ha)**
T1 = SDI-0.15m	8850	8730	8680	8753^{a}	8910	8870	8800	8860^{a}
T2 = SDI-0.25m	8300	8340	8480	8377^{b}	8670	8560	8610	8613^{b}
T3 = SDI-0.35m	7590	7630	7550	7590^{d}	7800	7650	7750	7733^{d}
T4 = DI-0m	7980	8100	7950	8010^{c}	8440	8390	8510	8447^{c}
T5 = Furrow-bed	7340	7450	7480	7423^{e}	7440	7520	7490	7483^{e}
T6 =Furrow-Ridge	7270	7380	7490	7380^{e}	7220	7310	7100	7210^{f}
		$LSD_{0.05}$		70		$LSD_{0.05}$		60

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

under farmer practice (furrow-ridge) in both seasons 2019 and 2020. The outcomes are in accord with the investigators Anjum *et al*. (2014), Amin *et al*. (2015) and Ibrahim *et al*. (2016).

Grain yield: Effective consumption of irrigation water affected grain yield at 5% level of probability as shown in Table 8. These outcomes presented statistically significant results of different irrigation systems and obtained maximum maize grain yield i.e. 8753 kg/ha and 8860 kg/ha by subsurface drip irrigation using 0.15 m depth of lateral in both seasons 2019 and 2020, respectively. The minimum grain yield of 7380 kg/ha and 7210 kg/ha were recorded in control farmer practice where gravity irrigation using furrow-ridge method in both years 2019 and 2020, respectively. The outcomes are in consensus with the researchers Lamm and Trooien (2005), Payero et al. (2008), Mo et al. (2017), Qiu et al. (2017) and Farag (2018) for the reason that subsurface drip irrigation efficiently utilized irrigation water and fertilizer and enhanced maize crop yield.

In an assessment of the subsurface drip lateral depth geometry; the outcomes shown in “Table 8” presented that 0.15 m lateral depth of subsurface drip irrigation impacted maximum grains yield and discovered improved water use efficiency than 0.25 m and 0.35 m lateral depth of subsurface drip irrigation in both seasons 2019 and 2020, respectively. The minimum grains yield (7590 kg/ha and 7733 kg/ha) were documented using 0.35 m lateral depth of subsurface drip in both years 2019 and 2020, respectively.

In the evaluation of the surface or gravity irrigation systems; the results shown in the Table 8 displayed that surface drip irrigation system contributed highest grain yield (8010 kg/ha and 8447 kg/ha) in both years 2019 and 2020, respectively than gravity irrigation (furrow-bed and furrow-ridge). The minimum grain yield i.e. 7380 kg/ha and 7210 kg/ha was observed by farmer control practice (furrow-ridge) in both seasons 2019 and 2020. The results are similar to the researchers Mateos *et al*. (1991), Hassanli *et al*. (2009), Kuscu *et al*. (2013), Ibrahim *et al.* (2016) and Chauhdary *et al.* (2017) because drip irrigation effectively utilized its resources like irrigation water, fertilizer and avoid any plant stress.

Harvest index: It is the ratio of grain yield (kg/ha) and dry matter weight (kg/ha). The influences of different irrigation systems and geometry of subsurface drip irrigation on harvest index (HI) of maize crop were statistically inspected in Table 9. Maize crop under 0.15 m lateral depth of subsurface drip irrigation displayed a statistically greater harvest index (0.503 and 0.479) in both the seasons 2019 and 2020, respectively than that of other irrigation methods. The minimum harvest index was inspected in control treatment furrow-ridge planting which is 0.469 and 0.424 in both the years 2019 and 2020, respectively. The outcomes are in similar with the scientists Arbat et al. (2010), Ayars et al. (2015) and Farag (2018).

In an evaluation of the subsurface drip lateral depth geometry; the consequences in the Table 9 revealed that there is no significant difference found in 0.15 m and 0.25 m lateral depth of subsurface drip irrigation in season 2019. During 2020, 0.15 m lateral depth of subsurface drip impacted maximum harvest index (0.479) than 0.25m (0.468) and 0.35 m (0.451) lateral depth of subsurface drip irrigation. The minimum

Table 9. Harvest index in both seasons 2019 and 2020.

Treatment	2019				2020			
	R_1	R_2	R_3	Mean	R_1	R_2	R_3	Mean
T1 = SDI*-0.15m	0.506	0.511	0.493	0.503[a]	0.479	0.480	0.477	0.479[a]
T2 = SDI-0.25m	0.483	0.493	0.489	0.488[b]	0.469	0.465	0.470	0.468[ab]
T3 = SDI-0.35m	0.478	0.479	0.478	0.478[bc]	0.456	0.445	0.452	0.451[c]
T4 = DI**-0m	0.484	0.495	0.480	0.486[b]	0.466	0.465	0.474	0.468[b]
T5 = Furrow-bed	0.463	0.471	0.473	0.469[c]	0.433	0.436	0.433	0.434[d]
T6=Furrow-Ridge	0.462	0.470	0.475	0.469[c]	0.425	0.431	0.416	0.424[e]
		$LSD_{0.05}$		0.005		$LSD_{0.05}$		0.004

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

harvest index (0.478 and 0.451) was recorded using 0.35 m lateral depth of subsurface drip in both seasons 2019 and 2020, respectively. The outcomes are in consensus with the work of Qiu *et al.* (2017).

In an evaluation of the surface or gravity irrigation methods; the outcomes presented in the Table 9 showed that the surface drip irrigation system contributed the highest harvest index i.e. 0.486 and 0.468 in both seasons 2019 and 2020, respectively than gravity irrigation (furrow-bed and furrow-ridge). The minimum harvest index (0.469 and 0.424) was noticed under control practice (furrow-ridge planting) in both seasons 2019 and 2020. The outcomes are in consensus with the scientists Mateos *et al.* (1991), Hansona *et al.* (1997) and Irfan *et al.* (2014).

***Water-saving and applied irrigation depth*: ** The irrigation water was applied after a 20% depletion of soil moisture from its field capacity in subsurface and surface drip irrigation Afzal et al. (2020). In gravity irrigation (furrow-bed, furrow-ridge) irrigation water was applied after 50% soil moisture depletion. The graph shows that the depths of the irrigation water applied were 422, 464 and 547 mm for the subsurface lateral depths of 0.15, 0.25 and 0.35 m, respectively in 2019. Similarly, in 2020, the applied depth of irrigation water was 425, 507 and 543 mm for the subsurface lateral depths of 0.15 m, 0.25 m and 0.35 m, respectively. The applied irrigation depth for surface drip irrigation was 487 mm and 468 mm in both seasons 2019 and 2010, respectively. The applied irrigation depth was 752 mm and 738 mm for furrow-bed planting and 782 mm and 788 mm for furrow-ridge planting in both seasons 2019 and 2020, respectively shown in Fig. 4. Subsurface drip irrigation was saved 46%, 40.6% and 30% irrigation water for lateral depth 0.15, 0.25 and 0.35 m, respectively in 2019and similarly, it saved 46%, 35.7% and 31.1% irrigation water for lateral depth 0.15, 0.25 and 0.35 m, respectively in 2020 as compared with gravity irrigation (furrow-ridge planting). The results are in accordance with the researchers Ruskin (2000), Lamm and Trooien (2003), Zaccaria *et al.* (2017) and Umair *et al.* (2019). Drip irrigation saved 37.7% and 40.6% irrigation water in both seasons 2019 and 2020, respectively as related with gravity irrigation (furrow-ridge planting) and similar outcomes reported by Chauhdary (2018).

Subsurface drip irrigation saved 13.3%, 4.7% irrigation water for lateral depth of 0.15 m, 0.25 m and for 0.35 m lateral depth 12% more water was applied in 2019 as related to drip irrigation system. Similarly, 0.15 m lateral depth saved 9.2% irrigation water but for 0.25 m and 0.35 m lateral depth 8.3% and 16% more irrigation water was applied, respectively in 2020 as compared with drip irrigation.

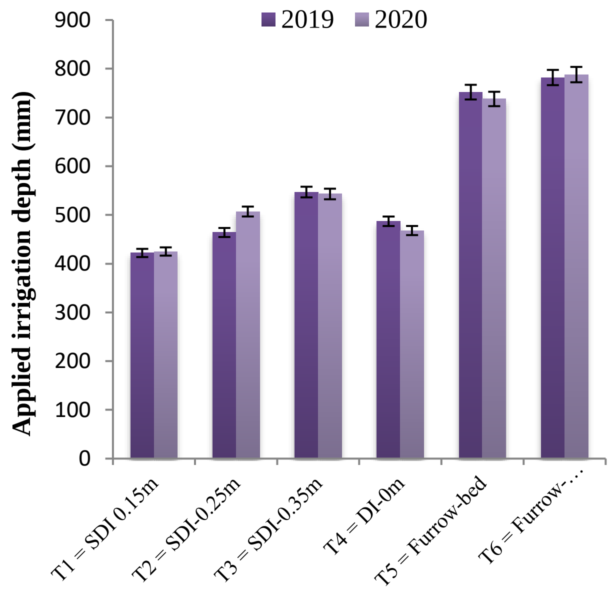

Figure 4. Applied irrigation depth (mm) both seasons 2019 and 2020

Water productivity: The results displayed in “Table 10” show that maize crop under 0.15 m lateral depth of subsurface drip irrigation showed statistically maximum water productivity (2.074 kg/m^3 and 2.085 kg/m^3) in both the seasons 2019 and 2020, respectively than that of the other irrigation systems. The minimum water productivity was examined in control treatment gravity irrigation using furrow-ridge planting which is 0.944 kg/m^3 and 0.915 kg/m^3 in both the years 2019 and 2020, respectively. The outcomes are in sequence with the researchers Hassanli et al. (2009) and Farag (2018) for the reason that subsurface drip irrigation saved evaporation and

Table 10. Water productivity of maize in both seasons 2019 and 2020.

Treatment	Water productivity, 2019				Water productivity, 2020			
	R_1	**R_2**	**R_3**	**Mean (kg/m^3)**	**R_1**	**R_2**	**R_3**	**Mean (kg/m^3)**
T1 = SDI*-0.15m	2.097	2.069	2.057	2.074^a	2.096	2.087	2.071	2.085^a
T2 = SDI-0.25m	1.789	1.797	1.828	1.804^b	1.710	1.688	1.698	1.698^c
T3 = SDI-0.35m	1.388	1.395	1.380	1.388^d	1.436	1.409	1.427	1.424^d
T4 = DI**-0m	1.639	1.663	1.632	1.645^c	1.803	1.793	1.818	1.806^b
T5 = Furrow-bed	0.976	0.991	0.995	0.987^e	1.008	1.019	1.015	1.014^e
T6=Furrow-Ridge	0.930	0.944	0.958	0.944^f	0.916	0.928	0.901	0.915^f
		$LSD_{0.05}$		0.014		$LSD_{0.05}$		0.01

*SDI = Subsurface drip irrigation, **DI = Surface drip irrigation

conveyance losses. Water productivity of maize crop clearly explained the crop water function which is the relationship between yield and irrigation water applied. The outcomes showed that the use of less irrigation increases the yield of maize crop with a suitable lateral depth of subsurface drip irrigation system. For profitable crop function, crop must be supplied with adequate quantity of water at required frequency. Kumar and Palanisami (2010) revealed that drip irrigation has a significant impact on resource saving, cost of cultivation, yield of crop, farm profitability and therefore farmer's profits.

***Conclusions*:** The conclusions derived from different outcomes of the research experiment are given below.

- The maximum maize grain yield (8753 and 8860 kg/ha) was achieved in both the seasons (2019-20), respectively under subsurface drip lateral placed at a depth of 0.15 m.
- The minimum maize grains yield (7380 and 7210 kg/ha) were found using furrow-ridge irrigation system.
- Maize crop under 0.15m lateral depth of subsurface drip irrigation displayed statistically maximum harvest index (0.503 and 0.479) in both the years 2019-20, respectively.
- The outcomes of the trial showed that sub-surface drip irrigation installed at a lateral depth of 0.15 m has saved 46% as compared with furrow-ridge planting.
- The outcomes of water productivity also revealed that the highest water productivity (2.074 and 2.085 kg/cm^3) was recorded during both the years (2019-20), respectively under subsurface drip lateral installed at a depth of 0.15 m.
- The minimum (0.944 and 0.915 kg/cm^3) were recorded using furrow-ridge irrigation.
- It is concluded that maximum grain yield and water productivity can be achieved by installing subsurface drip laterals at a depth of 0.15 m for maize crop in a semi-arid region of Pakistan.

Recommendations

- Subsurface drip installed at lateral depth of 0.15 m in sandy loam soil to achieve higher maize crop yield and water productivity.
- Subsurface drip irrigation system can be used efficiently in water scarcity areas of Pakistan to achieve maximum crop yield per drop of irrigation water.

***Conflict of Interest*:** The Authors declare that there is no conflict of interest.

***Author's Contribution Statements*:** MAM, is a Ph.D. scholar and this piece of writing is a portion of his Ph.D. thesis, MA, supervised the overall research study, MAS, helped to install the layout plan, MAH, help out to analyze the physical parameters of soil and water.

***Acknowledgments*:** The authors aspire to be grateful to the staff of "WMRC", the University of Agriculture, Faisalabad, for their assistance in respect of data compilation.

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