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Response of maize to ridge-furrow planting with surface drip irrigation system in semi-arid conditions of upper Indus basin

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Abstract

In Punjab, maize (*Zea mays* L.) is commonly cultivated using ridge-furrow or double ridge-furrow planting patterns, which require evaluation under drip irrigation. This study assessed maize performance under different planting configurations with drip irrigation during the autumn (2018, 2019) and spring (2019, 2020) seasons. Four treatments were evaluated: M_1) 75 cm spaced ridge-furrow, M_2) 90 cm wide beds, M_3) 105 cm wide beds, and M_4) 120 cm wide beds. Drip lines were installed in furrows for M_1 and on bed tops for M_2, M_3, and M_4. Across seasons, M_1 recorded the tallest plants, averaging 8.1% taller than other treatments. In autumn, M_3 produced the highest fresh ear weight (17.81 Mg ha^{-1}) and grain yield (10.95 Mg ha^{-1}), with the highest water use efficiency (WUE) of 2.05 and 1.78 kg m^{-3} in 2019 and 2020, respectively. In spring, M_2 yielded the highest fresh ear weight (20.75 Mg ha^{-1}) and grain yield (14.52 Mg ha^{-1}), with WUE values of 2.67 and 2.03 kg m^{-3} over two years. Grain protein content exhibited a negative correlation with grain yield, reaching a maximum of 12.2% in the M_4 across both seasons. In contrast, the highest grain oil content was recorded in M_3 during the autumn season and in M_1 during the spring season, with an average value of 4.44%. Results indicate that planting pattern significantly influences maize productivity and resource use under drip irrigation. For optimal yield and WUE, a 105 cm bed width is recommended for autumn maize and 90 cm for spring maize under drip irrigation.

Keywords: Fresh ear weight, Germination %, Grain yield, Planting method, WUE

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Introduction

Maize (*Zea mays* L.), also known as corn, is one of the most important cereal crops globally, serving as a staple food, livestock feed, and industrial raw material (Ahmad & Ahmad, 2018; Rubab et al., 2020). Belonging to the family Poaceae, maize originated in Central America and has since become a widely cultivated crop across diverse agroecological zones. Its adaptability, high yield potential, and diverse uses have contributed to its global significance (Mehmood et al., 2022; Azam et al., 2023). Maize is a rich source of carbohydrates and provides essential nutrients, including proteins, vitamins, and minerals, making it vital for food security in many developing countries (Zia et al., 2023; Jamilah et al., 2024). The global demand for maize continues to rise due to population growth, dietary shifts, and increased use in biofuel production. In sub-Saharan Africa and parts of Asia, maize is a dietary mainstay and a key crop for smallholder farmers (Kekere et al., 2024). However, maize production faces multiple challenges, including biotic stresses such as pests and diseases, and abiotic stresses like drought, soil infertility, and climate variability. These constraints can significantly affect crop productivity and threaten food security in vulnerable regions (Zaman & Qureshi, 2018; Iqbal & Qureshi, 2021).

Water is the most critical agricultural inputs for agricultural production system in Pakistan yet its per capita water availability lowers to 1000 cubic meter (Akram & Iqbal, 2019; Akbar et al., 2021; Awe & Adelakun, 2024). Overall irrigation system efficiency of Indus Basin Irrigation System stands at 41.5% with agriculture sharing 95% of country's total water resources. Moreover, Pakistan is facing 32% shortfall of its current net water requirement for crop consumptive use (Shahid et al. 2022). International Monetary Fund (IMF) has ranked Pakistan third among countries with water scarcity (on basis of an index that relates annual national water availability with annual total withdrawals). This alarming situation demands development of technologies that reduces the irrigation water use that not only can sustain or either improve the yields by judicious use of irrigation water.

During 2022-23 maize was cultivated on an area of 1720 thousand hectares that produced 10.183 million tonnes with average yield of 5922 kg per hectare. Maize has become very important cash crop in the Punjab province and its area under cultivation has substantially increased by 25% from 2018 to 2023 (Government of Pakistan, 2024). Climate of the Punjab province is arid to semi-arid where annual crop evapo-transpirational demand greatly exceeds annual rainfall. Crop production relies on irrigation that generally comes from tributaries of Indus River along with its tributaries and underground withdrawal. Apart from dwindling irrigation water availability, poor soils with salinity, plant lodging, heat stress at crucial crop growth stages and insect pests are standout constraints for sustainable and economical maize production in Punjab province. Farmers in irrigated areas of the Punjab have adopted the sowing method of maize sowing on 75 cm wide ridge-furrow or double ridge-furrows (bed sowing) of different widths, as a management tool amid various stresses. Double ridge-furrows or furrow irrigated raised beds not only saves irrigation water from 12-40%, improves drainage but also reduces the emission of greenhouse gases (Zeng & Li, 2020). Reported advantages of these planting patterns are water savings (Rady et al., 2021) better weeds management, improved plant growth in salt affected soils (Ali, 2025) and ensured germination in case of heavy rains as furrows act as drain channels. Though these patterns are relatively water efficient among the other surface irrigation methods but alarming situation of water scarcity in Pakistan warrants new approaches that may use available irrigation water more precisely to increase water productivity. Researchers worldwide have suggested different ways to further improve furrow irrigation systems for different crops like use of mulches (Pahlevani et al. 2021) and alternative furrow irrigation system (Alotaibi et al., 2025) etc.

Drip irrigation system is one of the most efficient irrigation systems that give more control on irrigation water (Yang et al., 2023). Drip irrigation allows localized water application to the plants thus reducing evaporation from field, minimizing runoff and deep percolation, and ensures even distribution of water in whole field (Guo and Li, 2024). Advantages of drip irrigations are of great significance especially for arid and semi-arid areas where erratic rainfall and dwindling irrigation water supplies threat successful crop production. Though various studies have been conducted regarding maize production under surface or subsurface drip irrigation system under different climatic regions, however authors could not find a single study where suitability of ridges, beds or other planting patterns were evaluated under surface drip irrigation system for maize production. Integration of surface drip irrigation with ridge-furrow and double ridge-furrow planting patterns might significantly enhance maize water productivity, improve crop growth parameters, and reduce irrigation water use compared to conventional ridge-furrow irrigation under the arid to semi-arid conditions of Punjab. The objectives of this study were to estimate the impact of planting patterns under drip irrigation system on plant and ear characteristics, and to find out the most efficient sowing pattern/method to grow maize if irrigation is to be provided with drip surface irrigation system on the basis of grain yield and water use efficiencies.

Materials and Methods

Study area and climatic conditions

The field experiment was conducted in two distinct seasons i.e., autumn season of the years 2018 & 2019 and spring season of the years 2019 & 2020 at Water Management Research Farm, Renala Khurd, Punjab in collaboration with Maize & Millets Research Institute, Yusafwala Sahiwal. The farm is situated at an altitude of 181 m above mean sea level and is intersected by 30 51′ 19″ latitude 73° 32′ 36″ E longitude. Geographically area is located in irrigated plains of lower Indus basin with arid to semi-arid climate. Mean climatic parameters of the area are depicted in Table-1. The climatic data regarding average daily maximum, minimum and monthly rainfall is presented in Fig. 1. Effective rainfall during was calculated by the formula below as suggested by soil conservation method of USDA:

$$P_{eff}(mm) = \left(P \times \frac{125 - 0.2 \times P}{125}\right); P \leq 250\ mm$$
$$P_{eff}(mm) = 125 + 0.1 \times P;\ P \geq 250\ mm$$

Where P_{eff} is the effective rainfall and P is the total rainfall.

Soil characteristics and planting methods

Soil of the area is loam in texture (haplargids, camborthids and calciorthids with some Natrargids) of old river terraces (USDA, Soil Survey of Pakistan). Other characteristics of soil are; soil pH 8.2 and 8.3 for 0-15 cm and 15-30 cm soil depths. Organic matter in the soil was 0.62 and 0.48%, EC was 1.1 mS cm^{-1} and 1.4 mS cm^{-1}, soil available potassium was 210 ppm and 196 ppm, soil available phosphorus was 12 ppm and 9 ppm, saturation was 41% and 38% for 0-15 cm and 15-30 cm, respectively. Considering the prevailing sowing methods in the core maize growing areas of Punjab, four planting patterns were evaluated, described as M_1) 75 cm spaced ridge-furrow with sowing on one side of ridge, M2) 90 cm wide beds (double ridge furrow) with sowing on both side of bed, M_3) 105 cm wide beds (double ridge furrow) with sowing on both sides of bed, M_4) 120 cm wide beds (double-ridge furrow) with sowing on both sides of bed. Parallel beds and ridges were constructed by tractor mounted rider and bed shaper width of which was adjusted according to the size of the pattern. In M_2, M_3 and M_4 drip line was placed on the center of bed top while in M_1 drip line was placed in the furrow. Further description is provided in Fig. 2.

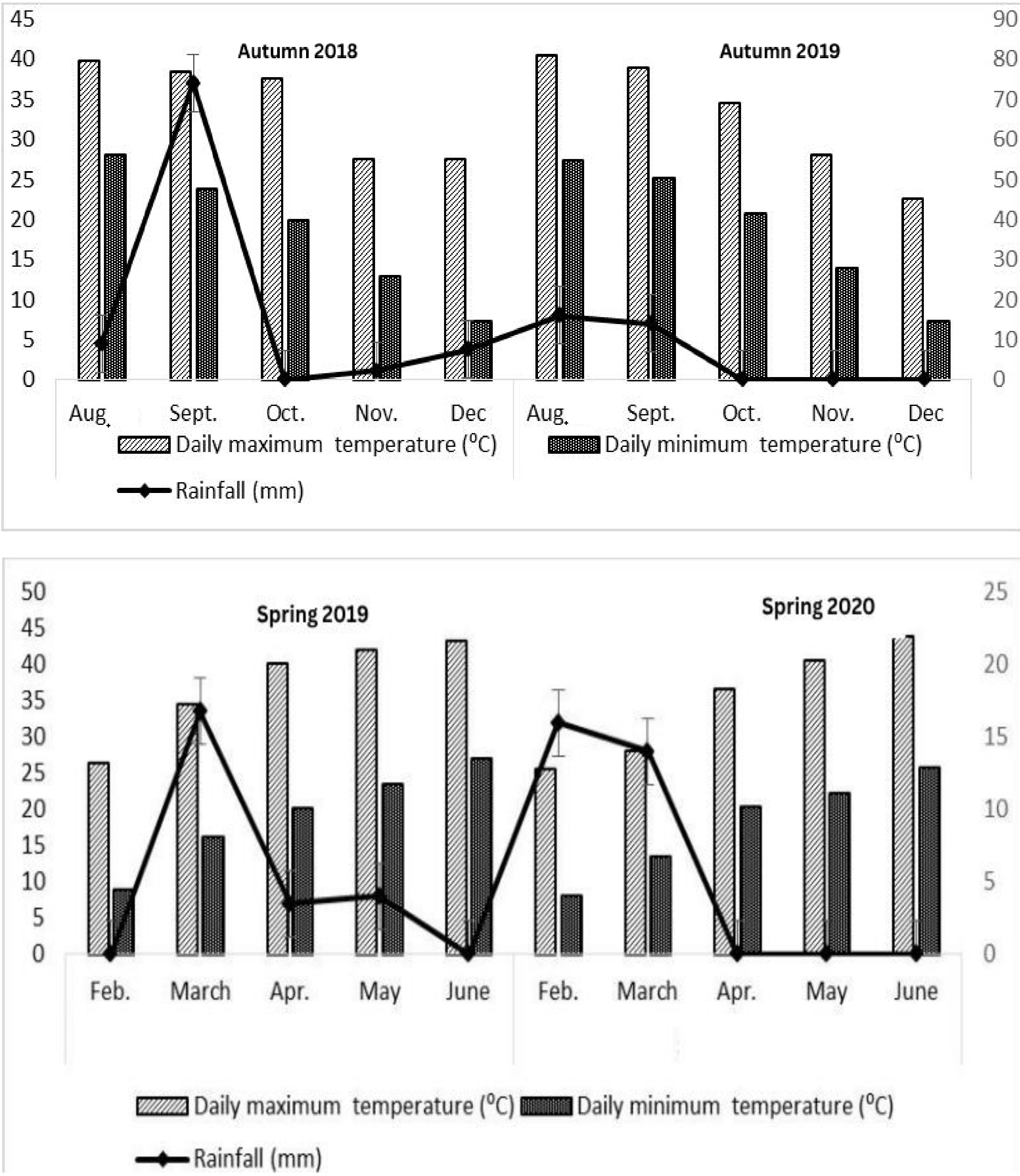

Fig. 1 Daily maximum and daily minimum temperature (C) and rainfall during the crop growth months in four growing seasons

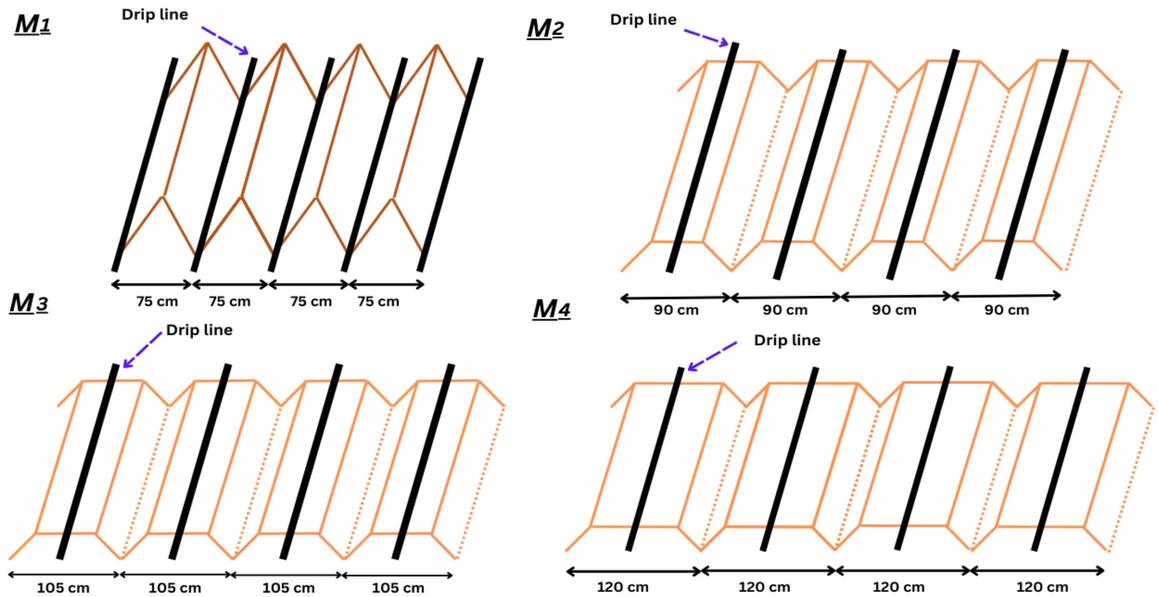

Fig. 2 Schematic view of treatments: M_1) 75 cm spaced ridge-furrow with sowing on one side of ridge and drip line in furrow M_2) 90 cm wide beds (double ridge furrow) with sowing on both side and drip line in center of bed top, M_3) 105 cm wide beds (double ridge furrow) with sowing on both sides and drip line in center of bed top, M_4) 120 cm wide beds (double-ridge furrow) with sowing on both sides and drip line in center of bed top

Crop establishment, experimental design and resource management practices

Planting was done on 10th and 19th August (autumn season) in 2018 and 2019, respectively while in spring season planting was done on 13th and 20th February in 2019 and 2020, respectively. For this study, maize hybrid 31R88 of Corteva Agriscience was used in autumn while DK6789 of Bayer Crop Sciences was used in spring season. To maintain the required planting density, dibbler marking of known distance was used and marking was done on the edges in case of beds while on ridges 1/3 down from the ridge top. Same day, one maize seed was planted per hill. A total population of 86450 plants ha^{-1} in spring and 74100 plants ha^{-1} in autumn was maintained. Treatments were laid out in randomized complete block design and were replicated four times. Each plot consisted of 5 m long twenty planting patterns while data was recorded from six central rows from each plot. Irrigation water requirement of maize in area and subsequently irrigation scheduling was determined by CROPWAT 8.0 that is a decision-support computer program developed by Smith (1991) and recommended by FAO. The program uses rainfall, soil, crop and climatic data of an area for developing equations to calculate crop water requirements, irrigation scheduling etc. based on reference evapotranspiration. In both study years, during autumn season, 541 mm water in 20 irrigation events was applied with 1259 operational time while in spring season 720 mm was applied in 30 irrigation events with 1667 minutes operational time. The treatment M_1 was first furrow irrigated to facilitate the germination as drip line in this treatment was in furrow while seeds were placed on bed slant about 7.5 cm from furrow base that could greatly hamper water availability to seed for germination. Afterward irrigation was applied according to plan through drip irrigation system. Fertilizers (Nitrogen, Phosphorus and Potassium) were applied through drip-fertigation. Detail of drip-fertigation schedule is given in Fig. 3 and 4.

Crop management, data collection and post-harvest evaluation methods

Weeds were controlled by pre-emergence application of Primextra Gold (S-metolachlor + atrazine) 720 SC (400 ml acre^{-1}) while Furadan 3G (Carbofuran) was applied at V5-V6 stage against stem borer. Crop was harvested at the appearance of black layer at the kernel tip. Germination rate was calculated as:

$$\text{Germination rate \% (Q)} = (\text{n}/\text{N}) \times 100\%$$

Where n is the germinated plants per unit area and N is number of planted seeds in unit area. At harvesting, central six rows were cut, ear detached and dehusked manually and weighed for fresh ear weight. Ear characteristics like ear length, grain rows ear^{-1} and grains row^{-1} were estimated from sampled ears from each plot. Grain moisture was determined by Agratonic™ MT-16 grain moisture tester; subsequently grain yield was expressed at 15% grain moisture. Grain starch%, oil% and protein% were determined by 'Inframatic 9200', a whole grain near infra-red (NIR) analyzer. Water use efficiency (WUE) was calculated as:

$$\text{Water Use Efficiency (kg m}^{-3}\text{)} = \text{Grain Yield (kg ha}^{-1}\text{)/Water Applied (m}^{3}\text{ha}^{-1}\text{)}$$

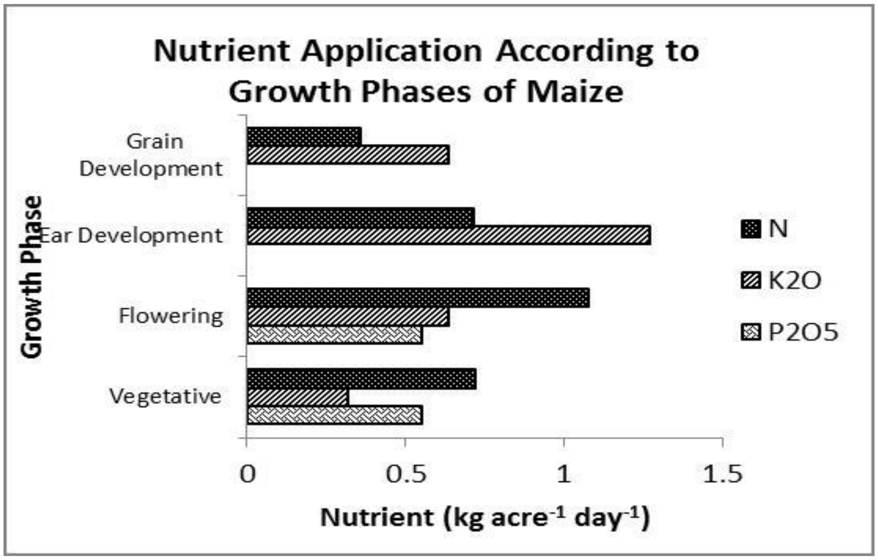

Fig. 3 Nutrients (N, P & K) applied to crop through drip irrigations system in four distinct growth phases

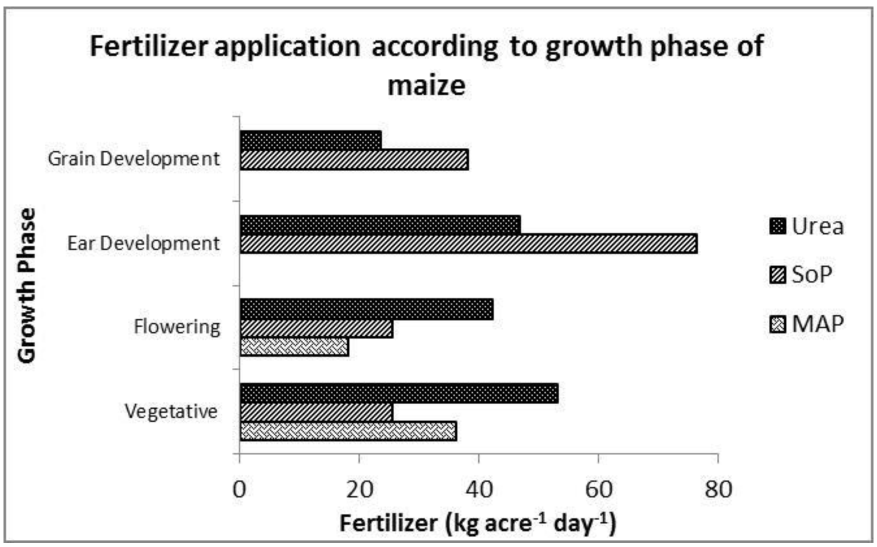

Fig. 4 Detail of the fertilizers applied in various growth phases of the crop through drip irrigations system

Statistical analysis

Data collected was subjected to analysis of variance technique using SAS software (version 9.1; SAS Institute, Cary NC). The significant difference between treatment means was identified by using least significant difference test at 5% probability (P<0.05).

Results and Discussion

Effect of planting methods and seasonal variability on germination, plant growth, and microclimatic interactions under drip irrigation

The four growing season i.e., Autumn 2018, Autumn 2019, Spring 2019 and Spring-2020 represented the typical growing season in terms of weather attributes. Low sunshine in the beginning of the spring improves as the crop grows while plants get plenty of sunshine and heat starting from later vegetative stages to maturity. Contrastingly, in autumn season sunshine intensity lowers just prior to flowering till maturity.

Effect of planting methods on germination percentage was significant (P<0.05). Over the years, germination in autumn ranged from 89.5% to 95.5% compared to 91.8% to 95.7% in autumn and spring, respectively (Fig. 5). Within treatments, germination was greatest in M_2 in both the seasons that was statistically not different from M_3 while lowest was recorded by M_4 in both the seasons. Width of the bed top was different in M_2, M_3 and M_4 being 38 cm, 55 cm and 71 cm. As the drip line was placed at the midst of bed top and seeds were planted on the edges of the beds, water had to travel horizontal distance of 19 cm, 27.5 cm and 35.5 cm to reach the seed in M_2, M_3 and M_4, respectively. Decrease in germination % from M_2 to M_4 might be attributed to the fact that water could not reach to the seed effectively with increased bed size as under tilled conditions, inadequate soil moisture is the primary germination limiting factor. According to Ali et al. (2024) extent of horizontal movement of the water in drip irrigation system depends on soil type, initial soil moisture contents and amount of water applied ha^{-1}. Vishwakarma et al. (2023) studied the soil wetting pattern of loam soil under drip irrigation system for variable discharge rate i.e., 2, 4 and 8 L h^{-1} and found that maximum horizontal soil wetting from the emitter was up to 20.64 cm, 23.94 cm and 28.81 cm, respectively, after 120 minutes of irrigation. While Kilic (2023) in a laboratory experiment reported that the radius of horizontal wetting front was 7.9 cm after 05 minutes of irrigation and reached to the maximum to 28.9cm after 125 minutes of irrigation. In this study, prior to study land was tilled and prepared dryer with water contents well below field capacity at sowing which might have further limited the horizontal water movement. In M_1, lower germination % might be attributed to the fact that seeds were planted manually, that might have created the unevenness of seeding depth/placement hence shallow seeded plants could not get the proper moisture for germination. According to Ma et al. (2022), in ridge furrow maize planting method, the changes in micro-topography leads to uneven distribution of soil moisture between ridge and furrow.

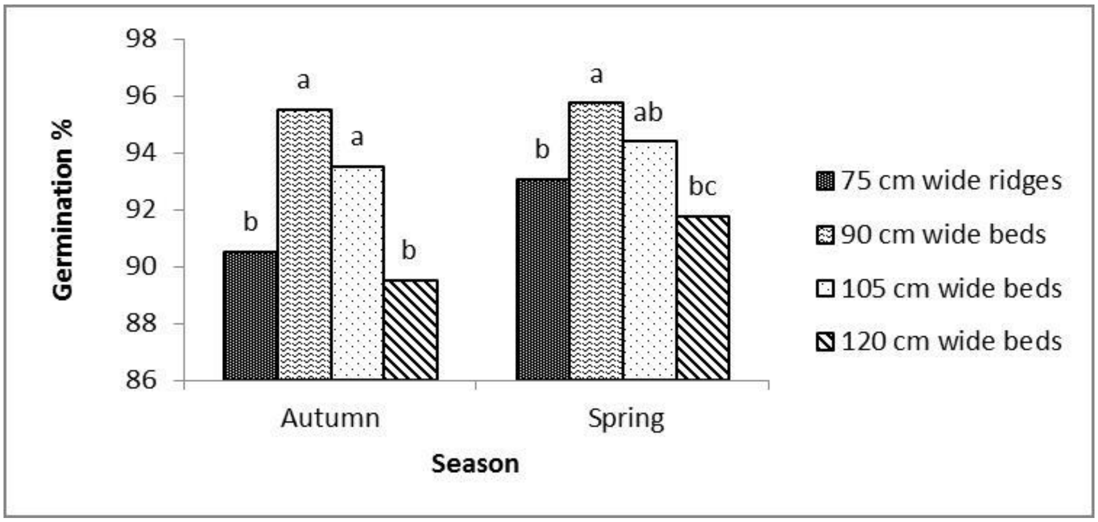

Fig. 5 Germination % as affected by different planting pattern coupled with drip irrigation system

Effect of planting methods and seasonal variation on morphological and yield-related traits under drip irrigation

Plant height and ear insertion height varied ($P<0.05$) with planting method and result is depicted in Table 1. The tallest plants and highest ear insertion point was recorded in ridge sowing in both the seasons. Khan et al. (2012) have also reported taller plants in ridge-furrow compared to double-ridge furrow method in autumn season in District Multan. Similarly, results are in agreement to Ali et al. (2022) who recorded taller maize plants in 60 cm wider ridge furrow compared to 60 cm and 75 cm wide bed sowing. Among the bed sowing treatments, plants were tallest at 105 cm wider beds in autumn while in spring season, 90 cm wider beds produced tallest plants. This variation can primarily be attributed to differences in moisture regimes arising from variable bed size. Mo et al. (2020) have also obtained improved plant height and yield contributed parameters with changing planting method with drip irrigation methods. In all study instances, highest ear insertion point was observed in M_1 and generally it was not different from M_3. In autumn season, 10% longer ears were obtained than spring season as revealed by the results in Table 2. Similar results have also been reported by Pukhrajsingh (2018) while studying effect of planting methods on maize hybrid in autumn and spring season in India. Impact of treatments on ear length was not clear as response was significant only in one growing instances out of four. Similarly, no clear pattern of variation was observed for ear length.

The effect of the planting patterns was non-significant ($P>0.05$) on number of rows ear^{-1} in both the seasons Table 2. However, non-significantly, rows ear^{-1} was highest in M_3 in autumn. While in spring season grain rows ear^{-1} were maximum at the narrowest bed size (90 cm) that decreased as the bed size increased to 105 cm and 120 cm. Grains row^{-1} also remained unaffected of the treatments (Table 3). However, grains row^{-1} was the greatest, though non-significantly, in M_3 in autumn season while in spring season non-significantly greatest grains row^{-1} was obtained from M_2 and it decreased as the bed size increased.

Number of ears per unit area is one of the primary maize yield attribute and is a function of planting density, germination, emergence and seedling survival. Number of ears also reflects the effectiveness of climate and management practices for plant growth within at a temporal and spatial level. In autumn, number of ears ha^{-1} was significantly altered by the treatments though treatments M_1, M_2 and M_3 produced statistically similar number of ears ha^{-1} while M_4 produced the lowest number of ears in both the years (Table 3). In spring, treatments affected the number of ears^{-1} only in 2019 while 2020 it remained unaffected however M_2 produced the greatest number of ears in both the years. Greater number of ears ha^{-1} in M_2 in all growing instances was apparently due to better moisture conditions in this planting method that supported the better germination and plant growth to bear ears later. Lowest ears number in M_1 might have been the result of lower germination % and subsequent less favorable micro climate for plant growth compared to other treatments.

Fresh ear weight was affected ($P<0.05$) by the treatments in all growing instances however response pattern was variable between seasons (Table 4). In autumn season, M_3 yielded the highest fresh ear weight of 16.90 Mg ha^{-1} in 2019 and 18.73 Mg ha^{-1} in 2020. The M_1 (75 cm ridge) produced 11.7% and 15.2% lower fresh ear weight compared to M_3. The widest bed size (120 cm) i.e. M_4 produced the lowest fresh ear weight that was 19.4% and 18.2% lower compared to M_3 in 2019 and 2020, respectively. While in spring season, planting pattern with 90 cm wide beds (M_2) produced the highest fresh ear weight in both the years with two year average of 20750 kg fresh ears ha^{-1} that was 2.5% greater than ridge sowing (M_1) and 21 % greater than M_4 that produced the lowest fresh ear yield. Treatments effect on grain yield ha^{-1} was significant but response pattern was not the same for autumn and spring season. Average over years, grain yield varied between 9.59 Mg ha^{-1} to 12.84 Mg ha^{-1} in autumn and between 11.01 Mg ha^{-1} to 14.59 Mg ha^{-1} in spring season. Average over treatments and year, grain yield in spring season was 19% greater than autumn. In autumn season, grain yield was the greatest at M_3 in both years with an average of 10.95 Mg ha^{-1}. While in spring season the highest grain yield in both years was recorded at M_2 with average of 11.29 Mg ha^{-1}. Ridge sowing (M_1) produced the lowest grain yield than all bed sizes that may be attributed to lower plant stand. Average grain yield from ridge sowing was 9.65 Mg ha^{-1} that was 12.4% lower than average of three bed sizes that reflects the suitability of bed pattern in providing the better moisture conditions and growing circumstances for maize under drip irrigations system compared to ridge sowing. This suitability comes from the fact that drip line was placed on the bed top where applied water along with fertilizers reached the equidistant maize rows on both sides more efficiently compared to ridges.

Effect of planting methods and seasonal variation on grain protein and oil contents under drip irrigation

Protein % in the grain remained unaffected of treatments in two study instances one in each season (Table 5). In autumn 2019 grain protein % was maximum in M_1 while in spring 2020 greatest protein % was obtained in M_2. Grain protein % was negatively related with grain yield (Table 4 and 5). In both the seasons higher protein contents were recorded in M_4 with widest bed top. Apparently, with the increase of bed size, moisture availability to the roots became increasingly difficult resulting in affected plant growth and grain yield i.e., lower starch accumulation. Low starch accumulation in developing grains leads to high protein % in maize kernels Qiao et al. (2022). Contrarily, oil % in grain was significantly affected by the treatments in both the seasons (Table 5). In autumn season oil % was greatest in M_3 while M_2 produced the lowest. In spring season M_1 and M_3 produced the maximum oil% in grain while it remained lowest in M_4 in both the seasons.

Table 1 Plant height and ear insertion point of maize as affected by different planting pattern coupled with drip irrigation in two distinct growing seasons

Planting methods	Plant height (cm)				Ear insertion point (cm)			
	Autumn		Spring		Autumn		Spring	
	2018	2019	2019	2020	2018	2019	2019	2020
M_1	265 ab	262	281 a	262 a	137 a	130 a	129 a	126 a
M_2	239 b	240	250 b	255 a	125 b	116 b	111 b	111 b
M_3	263 ab	258	248 b	240 b	128 a	123 ab	118 b	122 a
M_4	249 a	244	247 b	234 b	127 a	120 b	118 b	108 b
$LSD_{0.05}$	23.12	Ns	23.7	13.5	11.7	8.7	9.4	10.5

Means not followed by the same letter within a column are significantly different

Table 2 Ear length and rows ear^{-1} as affected by different planting pattern coupled with drip irrigation in two distinct growing seasons

Planting Methods	Ear length (cm)				Rows ear^{-1}			
	Autumn		Spring		Autumn		Spring	
	2018	2019	2019	2020	2018	2019	2019	2020
M_1	17.8	17.7a	16.6	15.8	16.7	16.5	17.4	19.0
M_2	17.8	18.1a	15.8	15.6	16.6	16.5	17.5	19.2
M_3	16.7	16.7b	16.3	15.7	16.9	16.7	17.1	18.8
M_4	17.5	16.3b	16.3	14.7	16.8	16.2	16.7	18.4
$LSD_{0.05}$	Ns	1.38	NS	NS	NS	NS	NS	NS

Means not followed by the same letter within a column are significantly different

Table 3 Grains row^{-1} and ears ha^{-1} as affected by different planting pattern coupled with drip irrigation in two distinct growing seasons

Planting Methods	Grains row^{-1}				Ear ha^{-1} (in 1000)			
	Autumn		Spring		Autumn		Spring	
	2018	2019	2019	2020	2018	2019	2019	2020
M_1	34.2	37.2	30.4	31.4	60.28 a	61.14 a	79.44 b	86.53
M_2	35.0	36.6	30.5	31.6	64.38 a	68.24 a	93.75 a	93.06
M_3	35.4	37.5	29.5	30.4	64.17 a	65.40 a	84.52 b	91.87
M_4	33.5	35.1	26.7	28.6	53.33 b	57.75 b	85.76 b	89.27
LSD0.05	NS	NS	NS	NS	6.77	6.14	7.86	NS

Means not followed by the same letter within a column are significantly different

Table 4 Fresh ear weight and grain yield as affected by different planting pattern coupled with drip irrigation in two distinct growing seasons

Planting Methods	Fresh ear weight (kg ha^{-1}) (in 1000)				Grain yield (Mg ha^{-1}) (in 1000)			
	Autumn		Spring		Autumn		Spring	
	2018	2019	2019	2020	2018	2019	2019	2020
M_1	14.90 b	15.88 b	19.88 b	20.16 a	9.59 c	9.70 c	12.78 b	14.46 a
M_2	15.90 b	18.43 a	21.34 a	20.61 a	10.80 ab	11.77 b	14.44 a	14.59 a
M_3	16.88 a	18.73 a	17.81 c	15.12 b	11.08 a	12.84 a	12.19 b	11.43 b
M_4	13.60 c	15.33 b	17.77 c	14.93 b	10.32 b	9.96 c	11.99 b	11.01 b
$LSD_{0.05}$	2.89	1.06	.919	1.18	532	794	848	1039

Means not followed by the same letter within a column are significantly different

Table 5 Protein % and oil % in maize grains as affected by different planting pattern coupled with surface drip irrigation in autumn and spring

Planting methods	Protein %				Oil %			
	Autumn		Spring		Autumn		Spring	
	2018	2019	2019	2020	2018	2019	2019	2020
M_1	11.9 a	11.9	12.0	11.6 ab	3.98 b	4.55 ab	4.60 a	4.28 a
M_2	11.8 ab	11.9	11.90	11.2 b	4.02 b	4.38 b	4.20 b	4.15 a
M_3	11.5 ab	11.8	12.1	12.0 a	4.18 a	4.70 a	4.50 a	4.28 a
M_4	12.3 b	12.1	12.2	12.2 a	4.03 b	4.50 b	4.00 b	4.00 b
$LSD_{0.05}$	0.54	Ns	NS	0.77	0.15	0.18	0.20	0.14

Means not followed by the same letter within a column are significantly different

Water use efficiency

Water Use Efficiency of different treatments is depicted in figure-6. In spring season, average WUE was 2.08 kg m^{-3} that was 19.5% greater than autumn season with average of 1.74 kg m^{-3}. This result is largely attributed to shorter growth period and lower grain yield in autumn. In autumn season, greatest WUE of 2.05 kg m^{-3} (2018) and 1.78 kg m^{-3} (2019) were recorded by M_3 that was not statistically different from M_2 in both study years. Greater WUE for M_3 planting method can be attributed to the combined effect of 1) In autumn, temperature decreased as the growth season progressed from seedling stage in August to VT stage in mid-September that further decreased during reproductive phases. This lowered the evapo-transpiration demands and allowed the water to better infiltrate laterally to reach crop rows, even in M_3. In autumn season, wider crop rows are desired owing to the fact that sun rays become more tilted as the season progresses. Whereas lowest WUE was recorded by M_1 with the values of 1.77 kg m^{-3} and 1.34 kg m^{-3} in 2018 and 2019, respectively. Greatest WUE, in spring season, was achieved by M_2 in both the season (2.67 kg m^{-3} in 2019 and 2.03 kg m^{-3} in 2020) and was followed by M_1 that has a WUE of 2.36 kg m^{-3} and 2.0 kg m^{-3} in 2019 and 2020, respectively. Higher WUE by 90 cm wide beds might has been due to the increasing temperature as the season progressed that limited the horizontal water movement in M_3 and M_4 and secondly light penetration even at narrow row spacing as sun became more vertical as season progressed. While M_4 produced the lowest WUE in both study years (2.21 kg m^{-3} and 1.53 kg m^{-3}).

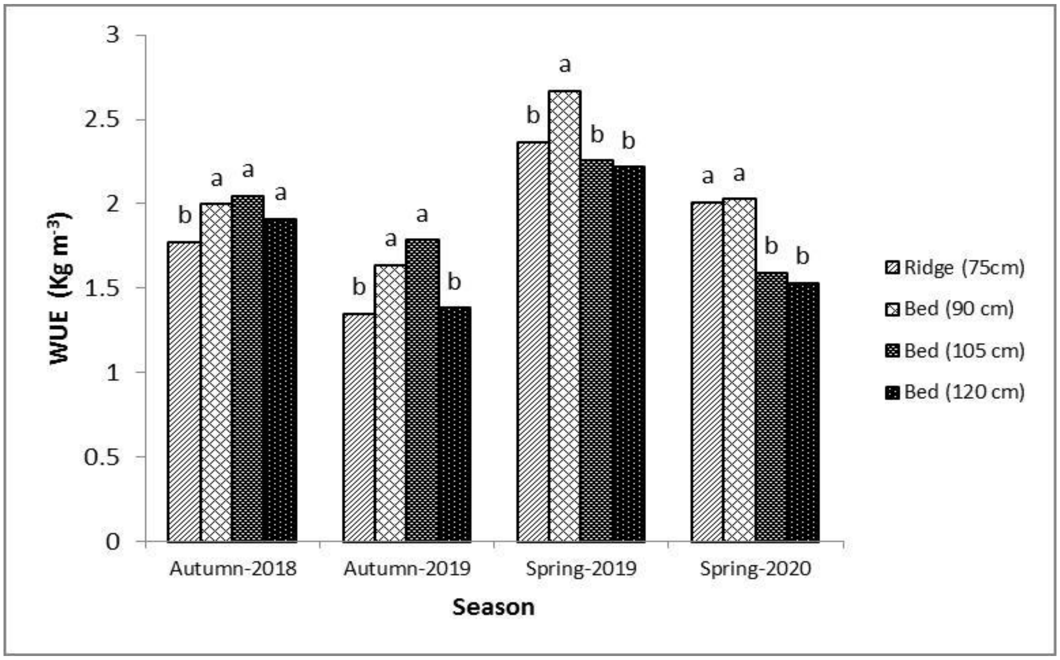

Fig. 6 Water use efficiency of maize grown on different planting patterns coupled with surface drip irrigation system in semi-arid climate of lower Indus basin

Conclusion

In this study, we investigated the impact of different planting patterns (ridge and beds of 90 cm, 105 cm and 120 cm) joined with drip irrigation system on hybrid maize in autumn season of 2018 & 2019 and in spring season of 2019 & 2020. The results revealed that yield response of maize was not similar in autumn and spring. In both the seasons bed pattern produced higher grain yield and WUE compared to ridge sowing. Therefore, it is recommended that, if maize is to be grown on planting patterns coupled with drip irrigation, bed size should be 105 cm in autumn and 90 cm in spring season.

Conflict of Interests: The authors declare no conflict of interest.

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