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Water Productivity and Economic Profitability of Maize Plantation on Raised Beds Under Drip Irrigation and Conventional Ridge Planting

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Abstract

Water productivity can be enhanced by using drip irrigation on raised beds to minimize water wastage. This was demonstrated in field trials carried out on farmers' fields with Maize (*Zea mays L.*) in semi-arid area during 2020 and 2021. This study compared water productivity, crop yield and economic profitability of raised beds under drip irrigation with bed furrow and conventional ridge planting. Three treatments, T1 (raised bed planting with drip irrigation), T2 (bed planting with furrow irrigation) and T3 (ridge planting with furrow irrigation) were designed. Data on yield parameters, water productivity and quality parameters were recorded. Results revealed that the treatment of raised bed planting with drip irrigation (T1) was found to be superior as it showed significantly higher grain yield (7.67 and 8.2 t ha^{-1}) compared to bed furrow (T2; 5.91 and 6.2 t ha^{-1}) and conventional ridge furrow (T3; 3.99 and 4.6 t ha^{-1}) treatments during 2020 and 2021, respectively. Plant height, 1000-gain weight, grain yield/cob and grain protein contents of T1 treatment were significantly higher than in the other planting methods. Maximum water productivity (3.25 and 4.65 kg ha^{-1} m^3) was also obtained from T1 treatment with 34% and 54% water savings compared to bed furrow and 60% and 63% water saving compared to ridge furrow treatments during 2020 and 2021 seasons, respectively. The results suggest that both crop and water productivity can be enhanced by adopting drip irrigation on raised beds in Punjab, Pakistan, where water wastage is a common issue.

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Introduction

Pakistan is an agricultural country and its overall economy is critically linked with agriculture development, so the Government of Pakistan always gives top priority to modernizing the agriculture sector. In Pakistan, the agricultural sector contributes 21% of the gross domestic product (GDP) and employs 62% population of the country directly or indirectly [1]. In the country, water availability is becoming scarce and per person water accessibility was 5,260 m^3 in 1951, turn down to 1038 m^3 in 2010, and it may decrease to 800 m^3 in 2025 [2]. With a rapidly rising population, water resources are under immense stress due to increasing competition for water among industrial, domestic and agricultural sectors. The agriculture sector of Pakistan utilized 95% of water as compared to others like ecological, domestic and manufacturing, etc. But the water use efficiency of this sector is very low (45%) [2], thus it wastes the maximum amount of water as well. There is a dire need to use advanced technologies like drip irrigation to address the water security situation by minimizing water wastage and improving water productivity [3, 4].

Maize is the 3rd most important cereal crop after wheat and rice in Pakistan, which shares the major amount of water for its growth [2]. Throughout Pakistan, cereal harvest has 0.13 kg/m^3 output of water, whereby in the USA, China and India, it is 1.56 kg/m^3; 0.82 kg/m^3 and 0.39 kg/m^3, respectively. Water productivity for maize crops in the country is very low (0.3 kg/m^3) compared to Argentina (2.7 kg/m^3) [2]. The gap in the water productivity for different crops shows that there is a great scope for improvement in water productivity that can help increase both the horizontal and vertical expansion of agriculture [5]. The current efficiency of the Indus basin in Pakistan is 35.5 percent [6], which reveals enormous water waste in farmers' fields due to the use of traditional wild flooding and farmers' unawareness of improved irrigation practices. The water productivity can be increased by reducing the water applied through (i) precision land leveling, (ii) proper field layout, (iii) higher efficiency irrigation system and (iv) adopting proper irrigation scheduling. The maize crop is very sensitive to drought [7-9] and crop yield is negatively affected by water stress when it occurs during the reproductive stages (tasseling, silking, pollination, or grain filling). In the semiarid environment of division Faisalabad, the reproductive growth stages usually overlap with the period of peak crop evapotranspiration (Etc), thus, making moisture stress during crop critical stages even more critical. Drip irrigation provides water and nutrients directly to each plant on a regular and continuous basis, the most effective way to convey directly water and nutrients to plants as and when required [8]. Several authors have shown that drip irrigation enhanced water productivity and efficacy of NPK through their timely and precise applicability as per the requirement of maize crop growth [10-12]. Drip irrigation technology is likely to be useful elsewhere in Punjab, for vegetable and fruit production and row field crops, where water and fertilizer use needs to be economized. This would also help develop new food systems to provide nutritious food to the masses at an affordable price. Moreover, drip irrigation could also possibly help alleviate salinity-induced land degradation. Thus, due to scarce water resources and brackish groundwater, interest in high-efficiency irrigation systems to irrigate row crops in the division of Faisalabad is growing rapidly. Thus, the use of drip irrigation with maize crop is increasing substantially each year. Drip irrigation is a new emerging and proven technology for maximizing water use efficiency and has been successfully used in China, US, Israel, Australia and Gulf countries [13].

To conserve and increase water resources and increase the water use efficiency in the country, we must increase crop water productivity so that farmers may get more yield by applying less quantity of water. This will only happen when we will change the traditional way by applying water using high-efficiency irrigation systems. This study was, therefore, designed to compare the water savings and increase in water productivity among drip irrigation, bed furrow and conventional ridge planting. The results revealed that high-efficiency irrigation systems such as drip irrigation have the potential to achieve high application efficiency and water productivity [5]. This study also focuses on changing the conventional planting geometry of maize cultivation to double row planting on raised beds and shifting to a drip irrigation system in division Faisalabad through efficient utilization of farm resources and effective application of precious inputs, leading to an uplift of the farmers' economic situation.

Materials and Methods

The study was carried out with hybrid maize P1429 by sowing on 15th February 2020 and 2021 to compare the effects of drip irrigation, bed furrow irrigation and ridge furrow irrigation on crop and water productivity in district TT Singh, Faisalabad division, Punjab, Pakistan. The experimental site was a farmer's field (longitude 72°41'E, latitude 30°58'N, altitude 163 m above sea level) having a loam textured soil. The experimental site was located in Northern Irrigation Plain according to the Agro-ecological zones of Pakistan. The mean maximum and mean minimum temperatures in summer (April-October) were 49°C and 27°C, respectively. In winter temperature range between 6°C and 21°C (November-March). The average precipitation was about 350 mm. Three treatments were as follows: T1 (bed planting with drip irrigation), T2 (bed planting with furrow irrigation) and T3 (ridge planting with furrow irrigation). The beds of 80 cm in width, 15 cm in height and 40 cm apart were made on well-pulverized dry soil by furrow bed shaper. Ridge furrows of 15 cm in width, 15 cm in height and 30 cm apart were prepared with a ridger. A measured quantity of water was applied through cut-throat flume in ridge and bed furrow treatments. Whereas for drip irrigation, a ridge 30 cm wide in the center of the bed-furrows was made on well-pulverized soil to support irrigation water applied by drippers. The crop was sown in a paired row and irrigation was applied through a drip irrigation system based on crop evapotranspiration using one lateral for two rows having 2 lph (liters per hour) capacity with 40 cm distances within drippers. The data of water applied through each drip and furrow irrigation was recorded through flow meters. Recommended levels of N (250 kg ha^{-1}), P (200 kg ha^{-1}) and K (150 kg ha^{-1}) were used as urea, triple super phosphate (TSP) and sulfate of potash (SOP), respectively, under drip irrigation. A total of 1.7 kg of urea, 0.5 kg TSP and 0.5 kg SOP $acre^{-1}$ were applied daily through fertilizer venture to each treatment while fertilizer was broadcasted in furrow irrigation at land preparation, vegetative growth and flowering according to local farmer's practice. Data regarding crop growth like plant height, grain yield per cob, number of grains per cob, 1000-grain weight (g) and biological yield (t ha^{-1}) were recorded at crop maturity. The crop was harvested manually on 26 April 2020 and 25 April 2021. Data regarding total water used per hectare, number of irrigations, water used per irrigation, and total yield (t ha^{-1}) were recorded. Water productivity (WP) was calculated as: WP (kg m^3) = output (kg ha^{-1}) / water applied (m^3 ha^{-1}) [14]. The protein contents of maize grain were determined by using the micro-Kjeldahl distillation method [15]. Crude oil contents in grains were determined by the Soxhlet method [16]. The data were analyzed by using standard statistical procedure "Mstate" software [17]. The comparisons among treatment means were made according to Duncan's New Multiple Range Test [19].

Results and Discussion

The data regarding crop and water productivity is shown in Table 1. Water productivity had its highest value (3.25 kg ha^{-1} m^3) from treatment T1 (raised bed with drip irrigation) while T3 (ridge furrow irrigation) resulted in the lowest water productivity (0.81 kg $ha^{-1}m^3$) during 2020. The corresponding values for water productivity in 2021 were 4.65 kg $ha^{-1}m^3$ and 0.97 kg $ha^{-1}m^3$ for T1 and T3, respectively. The higher water productivity in drip irrigation was attributed to high water contents in the root zone keeping the soil at or near field capacity. The results of higher water productivity under drip irrigation are in good agreement with the results of previous report [20]. The higher water productivity with less water achieved in treatment T1 showed that the crop attained a fair part of the potential crop water requirement with balanced nutrition compared to surface treatments. These results revealed that surface irrigation not only endures wasteful use of irrigation water, it also results in lower crop and water productivity. Whereas, drip irrigation ensures uniform delivery of water directly to the plant root zone and thus creates more suitable conditions in the root zone area for plant growth and production which enhanced crop and water productivity with a considerable reduction in the applied water. Similar

Table 1 Effect of different irrigation methods to improve crop and water productivity of maize during 2020.

Treatments	Plant height (cm)	No. of grains cob^{-1}	1000-grain weight (g)	Grain yield cob^{-1} (g)	Grain yield (t ha^{-1})	Grain oil (%)	Grain protein (%)	Irrigation applied (m^3ha^{-1})	WP (Kg ha^{-1} m^3)
T1	142.1a	478.28	205.0a	281.02a	7.67a	3.27	7.01a	1937c	3.25a
T2	132.0b	476.18	147.5b	187.85b	5.91b	3.27	6.40b	2971b	1.98b
T3	131.2b	457.08	104.9c	163.05c	3.99c	2.29	5.39c	4918a	0.81c
LSD	1.146	NS	0.4419	0.8181	0.025	NS	0.0914	14.76	0.1521
CV (%)	1.06		0.36	0.19	0.66		1.81	1.89	2.93

T1= raised bed planting with drip irrigation; T2 = raised bed planting with furrow irrigation; T3 = ridge planting with furrow irrigation
WP = water productivity; NS = non-significant

results have been reported by Ertek and Kanber [14] that the water productivity of cereals in Pakistan is far below its achievable levels, due to inefficient water use, which is much lower (0.3 kg/m^3) for the maize crop than that the international benchmark (1.0 kg/m^3). The results presented in Table 2 revealed that drip irrigation used 40% and 60% less water compared to furrow bed and ridge irrigation, respectively in 2020. Drip irrigation used 53% less water compared to bed furrow irrigation and 63% less water compared to ridge irrigation in 2021. The results revealed that the large-scale introduction of the drip irrigation system among farmers by On-Farm-Water-Management has led to a large expansion of agriculture in Punjab, and in many places drip irrigation is now the preferred irrigation technique. Studies have consistently shown a large water use reduction with drip irrigation. For example, one study showed an 80% decrease in water use with a 100% increase in crop yields. This study also showed an improvement in the standard of living in the village by 80% [20].

The average grain yield of bed sowing with drip irrigation treatment (T1) was significantly higher (7.67 and 8.2 t ha^{-1}) compared with bed planting with furrow irrigation (T2; 5.91 and 6.2 t ha^{-1}) and conventional ridge plating (T3; 3.99 and 4.6 t ha^{-1}) during 2020 and 2021, respectively. During both seasons, yields peaked with treatment T1 with less water usage (1937 and 1764 m^3/ha) compared to T2, (2971, 3843 m^3/ha) and T3 (4918, 4804 m^3/ha), respectively. Overall, water saving recorded from treatment T1 was 34% and 54%, significantly higher compared to T2 and T3 during both seasons. Both yield and yield components (Tables 1 and 2) of maize were significantly affected by the different irrigation methods. The low yield obtained during both growing seasons in conventional ridge planting is attributed to the reason that maize crop is generally under-fertilized, either due to poor availability of fertilizers. In both years, maximum numbers of grains per cob (478.2 and 4091.8) were recorded in bed planting with drip irrigation but it remained statistically at par with all other treatment combinations. However, during both years, ridge furrow irrigation treatment gave the minimum number of grains per cob (457 and 463, respectively). The highest grain yield under drip irrigation may be attributed to a higher 1000-grain weight and more grain numbers per cob due to a balanced and sustained supply of soil moisture and plant nutrition. Drip irrigation ensures balanced nutrition to plant roots, as per the need of plants at different growth stages [21]. Thus, the crop water productivity of maize was enhanced under limited moisture conditions through improved water and fertilizer management under drip irrigation treatment. These results are also quite in line with previous work [22], which established that a balanced supply of soil moisture and nutrition in well-pulverized soil on the raised bed under drip irrigation nourished maize crop well and resulted in higher number grain yield due to better yield contributing factors such as number of cobs per plant, number of grains per cob and 1000-grain weight. Balanced plant nutrition and optimum soil moisture under drip irrigation promote greater photosynthetic activities resulting in adequate assimilates for translocation to various sinks and hence the production of higher total dry matter [23]. The increased water productivity and crop yield achieved under drip irrigation may be due to excellent soil–water–relationship with higher oxygen concentration in the root zone and well-organized utilization of water and nutrients as already reported earlier [24, 25], who concluded that the higher nutrients uptake and moisture contents under drip irrigation enhanced water productivity. The maize yield and water productivity may vary due to irrigation methods, crop variety and soil type under different climate conditions [26]. Grain oil contents were significantly affected during both study years. Table 1 revealed maximum grain oil contents (3.27% and 5.41%) were obtained under drip irrigation treatment and minimum oil contents (2.29% and 5.07%) were obtained from conventional ridge

Table 2 Effect of different irrigation methods to improve crop and water productivity of maize during 2021.

Treatments	Plant height (cm)	No. of grains cob^{-1}	1000-grain weight (g)	Grain yield cob^{-1} (g)	Grain yield (t ha^{-1})	Grain oil (%)	Grain protein (%)	Irrigation applied (m^{3}ha^{-1})	WP (Kg ha^{-1} m^3)
T1	176.2a	491.8a	306.13a	284.6a	8.2a	5.41a	7.76a	1764b	4.65a
T2	173.7b	484.0b	298.4a	200.9b	6.2b	5.23b	7.14b	3843a	1.61b
T3	165.8c	463.5	223.4b	183.6c	4.6c	5.07c	6.89c	4804a	0.97c
LSD	1.147	NS	18.64	3.907	0.361	0.028	0.124	14.76	0.1521
CV (%)	0.83	4.03	8.43	2.35	7.09	8.38	7.45	1.89	2.93

T1= raised bed planting with drip irrigation; T2 = raised bed planting with furrow irrigation; T3 = ridge planting with furrow irrigation
WP=Water productivity; NS=Non significant

Table 3 Economic analysis of maize grown under drip, furrow and ridge furrow irrigation system.

Growing seasons	Treatments	Production (Kg ha^{-1})	Yield increase in drip over furrow (%)	Gross income ($ ha^{-1})	Total seasonal cost ($ ha^{-1})	Net profit ($ ha^{-1})	Income increase in drip over furrow (%)	BCR
2020	T1	7669		1089	388	701		1.80
	T2	5910	22%	839	445	394	43%	0.88
	T3	3989	47%	591	417	174	75%	0.41
2021	T1	8200		1287	507	780		1.54
	T2	6199	24%	973	563	410	47%	0.73
	T3	4599	43%	772	541	231	70%	0.43
Two-year average	T1	7934		1288	447	841		1.88
	T2	6054	23%	906	476	402	45%	0.84
	T3	4294	45%	682	479	203	72%	0.42

T1= raised bed planting with drip irrigation; T2 = raised bed planting with furrow irrigation; T3 = ridge planting with furrow irrigation
BCR = benefit-cost ratio (net profit/seasonal total cost)

planting during 2020 and 2021, respectively. Significantly higher grain protein contents (7.01% and 7.76%) under drip irrigation while minimum grain protein contents (5.39% and 6.69%) were recorded in ridge furrow irrigation during 2020 and 2021, respectively.

Economic analysis

The effectiveness of the field study was assessed by economic analysis of drip, furrow and ridge planting (Table 3), which shows 45% and 75% increase in net income with drip irrigation over furrow bed and conventional ridge planting, respectively. An increase in net benefit observed in treatment T1 (raised bed planting under drip irrigation) was due to a considerable reduction in the cost of production and higher yield obtained due to a balanced nutrition supply through fertigation on a sustainable basis throughout the growth period [27]. An average of two years depicts a 23% higher grain yield under T1 compared to T2 (bed furrow) and a 45% higher grain yield compared to T3 (ridge furrow irrigation). The higher BCR (1.80-1.88) was recorded under drip irrigation sites with 34-54% less water used compared with bed furrow and 60-63% less water used compared to ridge planting (T3). The increased yield and water productivity achieved under drip irrigation may be due to excellent soil moisture contents in the root zone that help improve nutrient availability [28].

Conclusions

This two-year field study in a semi-arid region under different irrigation methods showed that maize is well suited to raised bed planting with drip irrigation compared with bed furrow and ridge furrow irrigation for saving water and also it improves grain yield and yield components, grain quality and water productivity. Therefore, farmers may consider using these methods for maize production to increase their irrigation efficiency and yields rather than using bed furrow and ridge planting. The raised bed planting with drip irrigation method is simple and suitable for use in maize production by local farmers in semi-arid regions with limited available water. It was demonstrated that raised bed planting with drip irrigation gave 34% and 54% water savings compared with T2 and T3 during 2020 and 2021, respectively. T1 also resulted in higher grain and water productivity compared with T2 and T3. T1 was the most efficient method for use in areas with partially limited water resources. The research also found that in areas with moderate-severe water restrictions, treatment T2 (raised bed planting with furrow irrigation) with a water saving of almost 42% (3407 m^3/ha) might be feasible. By using those described irrigation methods and strategies, conventional low-water efficiency irrigation methods can be renewed and more irrigation water can be saved. This could also lead to an increase in the amount of land under maize cultivation, greater job creation and an increase in local farm revenue. The results emphasized that by using drip irrigation on raised beds, the maize seasonal irrigation water requirement can be reduced by 34-54% to raised bed furrow irrigation and 60-63% to conventional ridge planting. It is recommended that drip irrigation could be adopted where water wastage is more common to get high crop production and water productivity with scarce water resources.

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Conflict of interest

The authors claim no conflicts of interest

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