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Effect of the irrigation frequency and quality on yield, growth and water productivity of maize crops

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RESEARCH ARTICLE

Abstract

A research study was conducted to examine the crop responses of maize under two irrigation systems, i.e. raised bed and high-efficiency irrigation system (HEIS; drip irrigation) systems, with three irrigation frequencies and three levels of irrigation water quality. The trial was carried out in a completely randomised design mode with triple replication of each treatment. The raised bed irrigation system demonstrated better performance in terms of crop parameters: plant height, biological yield and grain yield for the raised bed system were recorded as 1, 5 and 21%, respectively, higher than the drip irrigation system. Field measurements for the HEIS showed that the biological yield, grain yield and harvest index were quadratically correlated with the frequency of irrigation. Better results were obtained for plots irrigated every 2 or 6 days than for those irrigated every 4 days. Good-quality water raised plant biological yield by 12% and grain yield by 14.85%. The irrigation frequency had a clear-cut effect on total dry matter weight and grain yield was dependent on the quality of the irrigated water. The raised bed with furrow irrigation system produced the highest harvest index for all of the levels of water quality and the highest water use efficiencies were observed for good-quality water. The vigorous crop growth in those plots irrigated using the raised bed irrigation system resulted from salts leaching away from the crop's root zone; however, because it uses more irrigation water for crop production than the HEIS, this system is not preferred.

Keywords: HEIS, irrigation frequency, irrigation quality, maize, raised bed irrigation system

1. Introduction

One of the most grown and ranked third crop of the world is maize, which is grown over 118 million hectares (mha) and has an average production is 600 million metric tons per annum. In Pakistan, maize is the fourth major crop which is grown over one mha area with an average production of 3.5 million metric tons (Jabran *et al.*, 2011). Maize is a versatile crop and it provides food for humans, raw material for the industries and feed for poultry and livestock (Khaliq *et al.*, 2004). Demand of water is ever increasing throughout the world, whereas the availability of fresh water is restricted. The shortage of water affects every continent of the world and a large number of people, especially in developing countries that are under water stress conditions (World Bank, 2011). To meet the food requirements of the increasing world population, there is need to put all efforts for enhancing the water productivity of crops in agriculture (Sarwar and Bastiaanssen, 2001).

According to the recent studies, one-third of the population of developing countries is under severe water shortage. They may not have enough water for agricultural, industrial and domestic uses in the year 2025 (Seckler *et al.*, 1998a,b). In most of countries where water and land resources are limited, the big challenge in the near future is to enhance food production by using a minimum amount of water (FAO, 2002). Due to the rising scarcity and costs of water for agriculture in the world, there is need to develop irrigation methods with maximum water use efficiency (Hess, 1996).

The development of shallow plant roots is due to frequent irrigations and a large amount of the water as a result of these frequent irrigations that remains in the upper 39.6 cm of the soil, and as the plant age increases, the depth of water extraction will also increases (Myers *et al.*, 1984). Depending upon the climatic conditions, the optimal growth and yield of maize crop requires 58.42 to 68.58 cm of water (Reddy, 2006). The growth and productivity of crop may be reduced by deficiency of water at any growth stage (Paudyal *et al.*, 2001).

In Pakistan, irrigated agriculture supplies more than 90% of agricultural output, is responsible for about 22% of gross domestic product and employs 45% of the country's workforce (GOP, 2008a,b). The population is increasing at a rate of 3%, while water deficiencies are rapidly reducing agricultural growth rates and need to be addressed (CIA World Factbook, 1995). While the rate of population growth has decreased from more than 3% in the 1980s to 2.09% in 2009-2010, it is still high (Ahmad and Farooq, 2010). Pakistan's current per capita water availability is 1,200 m^3 and will become 855 m^3 in 2020 (Kamal, 2009). Of the total geographical area of Pakistan, i.e. 79.6 mha, 22 mha are under cultivation (Ahmed and Farooq, 2010). About 70% of the cropped area lies in Punjab, 20% in Sindh, less than 10% in the province Khyber Pakhtunkhwa and just 1% in Baluchistan. Pakistan is among the countries that have the highest irrigated crop production areas in the world. Cultivatable wasteland with high potential for crop production comprises 8.9 mha. In light of the above, this study was carried out to examine the effects of different irrigation frequencies and levels of water quality on the yield and growth parameters of maize over two years using raised bed and drip irrigation systems.

2. Materials and methods

Physical properties of soil

The physical properties of the soil, such as texture, bulk density, field capacity and permanent wilting point, were measured using standard methods.

Soil texture

Soil texture measurements were carried out using the hydrometer method for different layers (0-15, 15-30, 30-45 and 45-60 cm) in the field (Table 1). The soil texture was then determined using the textural triangle developed by Moodie *et al.* (1959) at the United States Department of Agriculture, and was found to be sandy loam.

Soil bulk density

The efficiency of irrigation systems has been studied by Patel and Singh (1981), Agassi and Ben-Hur (1992) and Singh *et al.* (1992), who described increasing bulk density with decreasing infiltration. In the current study, bulk densities were calculated at different locations in the field using ASAE standard S269.4 (ASAE, 1998). It was observed that the bulk density ranged from 1.51 to 1.60 g/cm^3 (Table 2) (Meek *et al.*, 1988, 1992; Rawls *et al.*, 1982).

Field capacity and permanent wilting point

A pressure-plate apparatus was used to determine the field capacity and permanent wilting point through measurement of soil samples taken from various plots at depths of 0-45 cm. The field capacity soil moisture content ranged from 21.6 to 21.9% (Jabro *et al.*, 2009; Rawls *et al.*, 1982), as shown in Table 3. Field capacity is affected by various factors, such as the initial soil water content, the soil texture, the presence or amount of organic matter, the presence of impeding layers and evapotranspiration (Kirkham, 2005). The permanent wilting point obtained after analysis was 8.0% by volume (Hanson *et al.*, 2000; Rawls *et al.*, 1982).

Chemical analysis of soil and water

Groundwater samples were collected after 15 minutes of tube well operation and tested for electrical conductivity (EC), pH, residual sodium carbonate and sodium absorption ratio (SAR). Chemical soil analyses were carried out similarly to estimate the EC, pH and SAR at three points in the field at depths of 0-45 cm. Average values for the soil EC (1.92 dS/m), pH (8.1) and SAR (4.25) were determined via laboratory analysis (Table 4).

Table 1. Soil texture of experimental site.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Soil texture
0-15	62.4	23.4	14.3	sandy loam
16-30	67.2	19.2	13.7	sandy loam
31-45	65.6	18.2	16.3	sandy loam
46-60	68.2	16.4	15.5	sandy loam

Table 2. Infiltration rate and bulk density (g/cm^3) of soil at experimental site.

Sample no.	Infiltration rate(cm/h)	Bulk density (g/cm^3)		
		0-15[a]	16-30	31-45
1	0.80	1.54	1.56	1.55
2	0.78	1.55	1.58	1.51
3	0.75	1.51	1.50	1.53
4	0.74	1.60	1.60	1.51
5	0.78	1.59	1.58	1.58
6	0.74	1.52	1.53	1.51

[a] Soil depth (cm)

Table 3. Field capacity moisture content measurements.

Location	Field capacity % moisture content (vol. basis)	Wilting point % moisture content (vol. basis)
1	21.6	8.42
2	21.7	8.00
3	21.9	8.00

3. Results and discussions

Irrigation water quality and irrigation frequency influence the growth of maize plants. The parameters measured in the study were germination rate, plant height, total dry matter (TDM) weight, grain yield (GY) and harvest index (HI). The data were statistically tested to assess the importance of irrigation water quality and frequency. Germination rates were observed before the application of irrigation water and were therefore independent of the treatment effects. The average germination rate was 12 plants/m^2.

Plant height

The effects of irrigation frequency on plant height were statistically significant. The observed plant heights were 186.3 cm for irrigation every 2 days, 176.6 cm for irrigation every 4 days and 184.8 cm for irrigation every 6 days (Figure 1).

Plant height was observed to reduce with a change in irrigation frequency from every 2 to every 4 days, but to increase with a further change in irrigation frequency from every 4 to every 6 days (Table 5). Researchers have recorded plant heights for maize under different climate, crop type, soil salinity and frequency conditions (Balaswamy *et al.*, 1986; Hussaini *et al.*, 2001, 2002; Inamullah *et al.*, 2011; Jiotode *et al.*, 2002; Riaz *et al.*, 2007; Sachan and Gangawar, 1996). A possible reason for the observed differences is that salts in the soil remain in a diluted state with irrigation every 2 days, hindering growth less than with irrigation every 4 days. With irrigation every 6 days, the amount of water applied is sufficient to flush the salts out of the root zone, creating a favourable soil environment for crop growth. However, irrigation every 6 days is not suitable for the high-efficiency irrigation system (HEIS; drip irrigation system) as it becomes like the traditional flood irrigation applied a small number of times, an exercise that has been discouraged by other researchers (Kara and Biber, 2008). Accordingly, an irrigation frequency of every 2 days might be the most suitable practice under the conditions of the current experiment.

The effects of water quality were also found to be statistically significant. It was observed that plant height decreased linearly with deteriorating quality of the irrigation water. When averaged across all of the treatments, plant height decreased from 186.9 to 179.0 cm (Table 5) as the water quality changed from good (EC=0.25 dS/m) to poor (EC=3.4

Table 4. Chemical properties of irrigation water and soil.

Source	EC (dS/m)	pH	Sodium absorption ratio	Residual sodium carbonate
Good quality water	0.25-0.65	7.6	3.3	1.67
Marginal quality water	2.00-2.15	7.7	14	3.23
Poor quality water	3.2-3.40	7.8	18	5.25

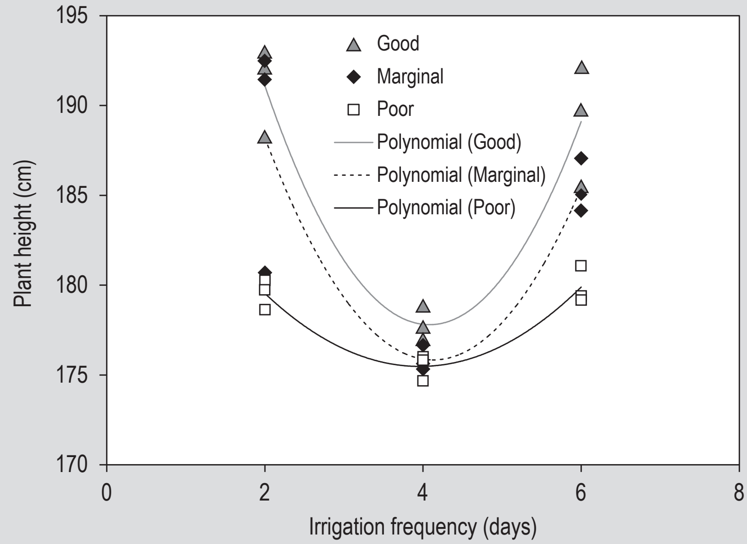

Figure 1. Plant heights (cm) with respect to irrigation frequency (2, 4 or 6 days), for different levels of water quality (good, marginal, poor).

Table 5. Mean plant height (cm) for different irrigation frequencies and levels of water quality.[1]

Water quality	Drip irrigation frequency (days)			Average	Raised bed system
	2	4	6		
Good	191.1	179.2	189.1	186.9[a]	188.3
Marginal	188.2	175.9	185.4	183.6[b]	184.8
Poor	179.5	174.6	179.9	179.0[c]	182.1
Average	186.3[a]	176.6[b]	184.8[a]	–	185.1

[1] Averages followed by different letters are significantly different at α=0.05.

dS/m), amounting to a 4.5% decrease in plant growth. The method of irrigation chosen should be able to provide a quantity of water to the root zone that is just sufficient to meet evaporative demand and minimise salt build-up (Bresler *et al.*, 1982; Munns, 2002).

Consequently, this and earlier studies clearly show that crop growth is adversely affected by increasing levels of salinity of the irrigation water. Average plant heights in the raised bed plots, usually irrigated via furrows, were normally higher than those averaged across all of the irrigation frequencies and levels of water quality for drip irrigation (Table 5).

The quadratic equations (Table 6) for irrigation frequency and plant height were additionally analysed to investigate mathematical correlations between them with different levels of irrigation water quality. The relationship is shown graphically in Figure 1. Plant height is highest for good-quality water and smallest for poor-quality water. Moreover, the curve for poor-quality water is flatter, suggesting that there is no obvious effect of frequency on plant height; this indicates that poor-quality water is less sensitive to irrigation frequency.

Table 6. Mathematical models for irrigation frequency and plant height.

Irrigation frequency	Regression model	Coefficient of determination
2-day	$y = 3.1x^2 – 25.1x + 228.9$	R^2=0.89
4-day	$y = 2.7x^2 – 22.6x + 222.4$	R^2=0.73
6-day	$y = 1.1x^2 – 8.4x + 192.1$	R^2=0.89

Plant total dry matter weight

Plant TDM weight determinations were carried out three times during the cropping period and analysed statistically at harvest time. The main effect of irrigation frequency was statistically significant, suggesting that the frequency of irrigation had a clear-cut effect on TDM weight. The effect of irrigation frequency, as for plant height, was quadratic with a TDM weight for irrigation every 2 days being 11.4% higher than irrigation every 4 days (Table 7).

The TDM weights were the same for irrigation every 2 days and every 6 days. This interesting result sheds light on two main irrigation management practices, i.e. frequent irrigation every 2 days and the leaching of salts with irrigation every 6 days. On average, the recorded TDM weights were 19.7, 16.7 and 15.7 t/ha, respectively, for irrigation water of good, marginal and poor quality. The TDM weight rose by 25.5% as water quality changed from poor (EC=3.4 dS/m) to good (EC=0.25 dS/m). Adverse effects of irrigation water salinity on TDM weight have been reported by Oster (1994), Shalhevet (1994), Shani and Dudley (2001), Gideon *et al.* (2002), and Katerji *et al.* (2003, 2004). The quadratic relationships between irrigation frequency and TDM weight are shown in Figure 2 for the three levels of water quality (Table 8).

The influence of the raised bed system on TDM weight is relatively positive compared with drip irrigated plots. This may be because raised bed systems have some flood irrigation characteristics and thus salt leaching may occur in the root zone.

Maize grain yield

Maize GY data were statistically analysed using the CRD mode. The main effect of irrigation water quality was highly significant, suggesting that different levels of water quality delivered different GY values. The reductions in yield were 1.16 t/ha for marginal-quality water (EC=2.15

Table 7. Mean total dry matter weight (t/ha) for different irrigation frequencies and levels of water quality.[1]

Water quality	Drip irrigation frequency (days)			Average	Raised bed system
	2	4	6		
Good	20.41	18.84	20.11	19.7[a]	19.40
Marginal	17.16	15.04	16.60	16.7[b]	18.01
Poor	15.61	13.88	15.07	15.5[c]	17.44
Average	17.73[a]	15.92[b]	17.26[a]	17.3	18.28

[1] Averages followed by different letters are significantly different at α=0.05.

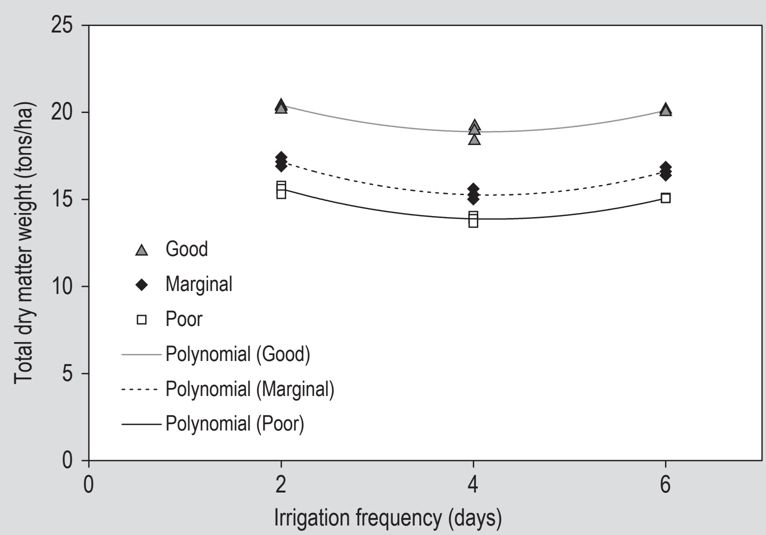

Figure 2. Plant dry matter weight (t/ha) with respect to irrigation frequency (2, 4 or 6 days), for different levels of water quality (good, marginal, poor).

Table 8. Mathematical models for irrigation frequency and total dry matter weight.

Irrigation frequency	Model	Coefficient of determination
2-day	$y = 0.34x^2 – 2.82x + 24.69$	R^2=0.90
4-day	$y = 0.41x^2 – 3.37x + 22.29$	R^2=0.94
6-day	$y = 0.36x^2 – 3.05x + 20.25$	R^2=0.97

dS/m) and 2.21 t/ha for poor-quality water (EC=3.40 dS/m) compared with good-quality water (EC=0.25 dS/m) (Table 9). In addition to a reduced GY, the apparent build-up in salinity occurring with poor-quality irrigation water aggravates the severity of the problem when such water is used over a long period.

The results suggest that saline irrigation water can give relatively acceptable maize yields under a drip irrigation system, which was a main focus of the study. Bernstein and Francois (1973a,b) found that sprinkling with medium-salt irrigation water decreased yields noticeably only at the highest frequency of irrigation, i.e. every 2.3 days, while sprinkling with high-salt water decreased yields more than 50% at all sprinkling frequencies, compared with a yield loss of only 14% with drip irrigation using this water.

The quadratic equations developed for GY suggest that GY is better with irrigation every 2 and every 6 days rather than every 4 days. However, irrigating every 2 days may be better, as irrigating every 6 days becomes similar to flood irrigation. Phene and Beale (1976) reported a 12-14% greater maize yield in drip plots than in plots irrigated via furrows or sprinklers. Increased frequency of irrigation produces better results in terms of crop growth (Al-Tahir *et al.*, 1997; Cetin, 1996; Howell *et al.*, 1995; Istanbulluoglu *et al.*, 2002; Karlberg *et al.*, 2007; Payero *et al.*, 2006). The results of

Table 9. Grain yield (t/ha) for different irrigation frequencies and levels of water quality.[1]

Water quality	Drip irrigation frequency (days)			Average	Raised bed system
	2	4	6		
Good	8.01	6.58	8.09	7.54[a]	8.78
Marginal	6.85	5.61	6.75	6.38[b]	8.03
Poor	5.75	4.73	5.58	5.33[c]	6.64
Average	6.87[a]	5.64[b]	6.81[a]	6.42	7.82

[1] Averages followed by different letters are significantly different at α=0.05.

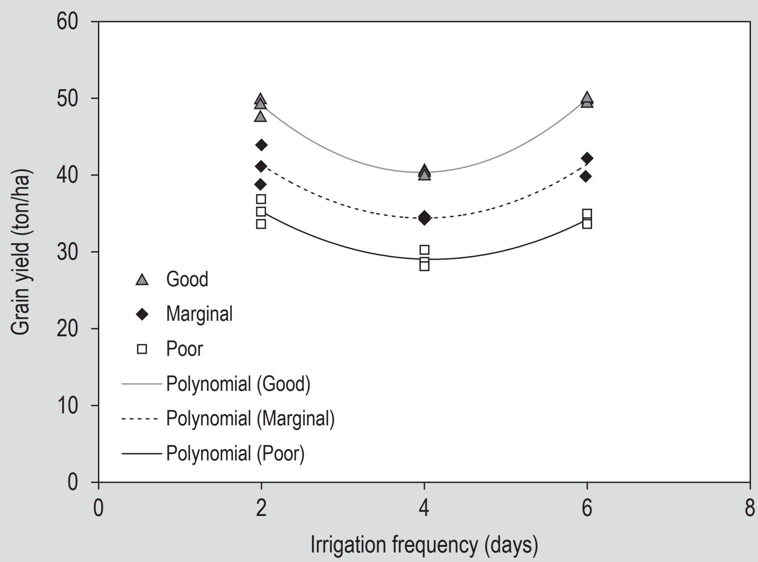

Figure 3. Grain yield (t/ha) with respect to irrigation frequency (2, 4 or 6 days), for different levels of water quality (good, marginal, poor).

another study showed that yield variables and water use efficiencies (WUEs) increased with increasing irrigation frequency and rate (El-Hendawy and Schmidhalter, 2010).

The quadratic equations for GY and irrigation frequency are shown in Figure 3 and Table 10. It is suggested that a higher frequency of drip irrigation is helpful in respect of water savings, nutrient and water uptake, TDM weight, GY and, above all, WUE.

In the present study, the quadratic relationship found for irrigation frequency and maize yield is similar to the findings of Kara and Biber (2008), who reported maize yields of 21.59, 19.15 and 29.16 t/ha for 4, 6 and 13 irrigations, respectively, with a drip system; the water applied was the same for each treatment. It is apparent that in their study the maximum yield was achieved with the shortest interval between drip irrigations, revealing that the shortest interval between drip irrigations produces the best plant development and, therefore, crop yield.

Harvest index

The HI is an accumulative descriptor of the overall system (irrigation water quality and irrigation frequency, uptake of nutrients by plants, local climate, soil properties, etc.). The effects of irrigation water quality and frequency on HI in maize were determined (Table 11).

A raised bed with furrow irrigation gave the highest HI for all of the water quality levels. For drip irrigation, the maximum HI values (0.40/0.41) were observed for water of good/marginal quality, especially with irrigation every 2 or every 6 days. Plants irrigated with poor-quality water every 4 days gave the lowest HI value (0.34).

Table 10. Mathematical models for irrigation frequency and grain yield.

Irrigation frequency	Model	Coefficient of determination
2-day	$y = 2.29x^2 – 18.16x + 76.25$	R^2=0.98
4-day	$y = 1.75x^2 – 13.95x + 62.23$	R^2=0.86
6-day	$y = 1.42x^2 – 11.647x + 52.85$	R^2=0.89

Water use efficiency

Water use efficiency was determined from the water applied throughout the full cropping season and the yield obtained under each treatment. The highest WUEs (1.239, 1.227 and 1.151 kg/m^3) were observed for good-quality water with irrigation every 6, 2 and 4 days, respectively, followed by water of marginal and poor quality, as shown in Table 12.

4. Conclusions

The effects of different irrigation frequencies and levels of water quality on maize yield and growth parameters under raised bed and drip irrigation systems were examined. Three irrigation frequencies (every 2, 4 or 6 days) and three levels of irrigation water quality (good, marginal and poor) were applied using the HEIS and raised bed systems. The parameters measured were germination rate, plant height, TDM, GY, and HI. The data were statistically investigated to assess the importance of irrigation frequency and water quality. The research trial was carried out in a CRD mode with triple replication of each treatment.

The effects of irrigation frequency on plant height were observed to be statistically significant. Plant height reduced with a change in irrigation frequency from every 2 to every 4 days, but increased with a further change in irrigation frequency from every 4 to every 6 days. The raised bed irrigation system demonstrated better performance than the drip irrigation system; plant height, biological yield and maize yield in the former system were 1, 5 and 21% higher, respectively, than in the latter. The biological yield, GY, and HI values were quadratically correlated with the frequency of irrigation in the HEIS system and better results were obtained for plots irrigated every 2 or every 6 days compared with every 4 days. The effects of water quality were also found to be statistically significant; it was observed that plant height decreased linearly with deteriorating quality of the irrigation water. Good-quality

Table 11. Harvest index for different irrigation frequencies and levels of water quality.

Water quality	Irrigation frequency (days)			Average	Raised bed system
	2	4	6		
Good	0.39	0.35	0.40	0.38	0.45
Marginal	0.40	0.37	0.41	0.39	0.44
Poor	0.37	0.34	0.37	0.36	0.38
Average	0.39	0.35	0.39	-	0.42

Table 12. Observed and simulated TDM, yield and water productivity.

Treatment	Days	Yield observed (t/ha)	Irrigation + rainfall (mm)	Water use efficiency
Good quality	2	8.01	652.90	1.227
Marginal quality	2	6.85	652.90	1.049
Poor quality	2	5.75	652.90	0.881
Good quality	4	7.51	652.90	1.151
Marginal quality	4	5.61	652.90	0.859
Poor quality	4	4.73	652.90	0.724
Good quality	6	8.09	652.90	1.239
Marginal quality	6	6.75	652.90	1.034
Poor quality	6	5.58	652.90	0.855

water was shown to increase the plant biological yield and the GY by 12% and 14.85%, respectively. The main effect of irrigation frequency on the TDM weight was statistically significant, suggesting that the irrigation frequency had a clear-cut effect on TDM weight. Maize GY data were statistically analysed in the CRD mode, with different GY values being observed depending on the quality of the irrigation water. The raised bed with furrow irrigation method produced the highest HI values for all of the levels of water quality, and the highest WUE values were observed for good-quality water with irrigation every 6, 2 and 4 days, respectively, followed by irrigation water of marginal and poor quality. The vigorous crop growth in those plots irrigated using the raised bed irrigation system is likely to be due to salts being removed from the crop root zone through leaching. Despite this, the raised bed irrigation system is not preferred over drip irrigation as it uses more irrigation water in crop production.

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