Research Article

Effect of Deficit Irrigation under Different Furrow Irrigation Techniques on Cauliflower Yield and Water Productivity in Mardan, Pakistan

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Abstract | In the dry region of the world, water scarcity is one of the emerging problems which is a severe constraint on food production. The available limited resources of water should be used economically and efficiently to sustain and improve agriculture productions. Based on actual crop requirements, irrigation techniques need improvement to get maximum yield with reduced irrigation. A field experiment was performed at Mardan region, Khyber Pakhtunkhwa, Pakistan, during 2018-19 with the objectives to evaluate the effect of different furrow irrigation techniques and deficit irrigation on cauliflower yield and water use efficiency (WUE). Three furrow irrigation techniques; alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and conventional furrow irrigation (CFI) techniques with three levels of irrigation; full irrigation, 80% of full irrigation (DI_{20}), and 60% of full irrigation (DI_{40}) were carried out in randomized complete block design (CRBD) with three replications. Crop water requirement was calculated using CropWat software. Total four irrigations were applied during the growing period of cauliflower. Data on plant parameters were collected periodically and analyzed with statistical software (Statistix 10). The study indicated significant differences in yield and WUE. The highest yield 36.12 tons/ha was observed under CFI with 100% water application. Among the three furrow irrigation systems, AFI gave the highest WUE, while minimum WUE was associated with CFI. It can be concluded from this research study that AFI with full irrigation is the best method as compared to other furrow irrigation techniques to enhance WUE and to save water without a significant reduction in the yield of cauliflower.

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Introduction

Cauliflower (*Brassica Oleracea* L.) belongs to the Brassicaceae family, which also includes cabbages, Brussels sprouts, broccoli, mustard, and rape seeds. It was discovered in the Mediterranean region over 2000 years ago, and has been cultivated in the USA since 18th century. The edible part of the plant is a cluster of immature flowers buds referred to as a curd which contains vitamin A, C, K and anti-oxidant (anti-cancer) (AFF, 2011). It is a shallow rooted crop, rooting depth ranging from 40 cm to 60 cm and few roots extend beyond that, depend upon the soil type and condition (Kage *et al.*, 2000). It is usually grown in winter season with temperature requirements ranging from 18 to 20°C during the day to produce a marketable curd, its night temperature requirement is 3 to 12°C and its growing period ranging from 100 to 140 days depend upon the cultivars and climatic condition (AFF, 2011).

It is a world leading vegetable with total production of about 18.54 million tons annually; China and India are the highest vegetables producing countries followed by United States (FAO, 2017). Cauliflower is an important vegetable crop in Pakistan and its cultivable area is about 12,634 hectares with 12 tons per hectare production annually. In Khyber Pakhtunkhwa, it is cultivated on about 1,450 hectares that producing about 16,710 tons, annually (Nasir and Amin, 2016). The yield of this important vegetable crop is very low in comparison to other countries; with the water scarcity is a major constraint.

For the purpose to make the water saving irrigation method acceptable to farming community in Pakistan and to use the available water efficiently, cauliflower can be subjected to certain level of deficit irrigation which may cause water stress in the crop. As cauliflower in Pakistan is generally irrigated with flood irrigation method in which it is grown on ridges and water is applied in all furrows. This method may lead towards huge amount of water loss through the seepage from the furrow beds. Every crop can tolerate a specific level of deficit irrigation beyond which acute losses occur in production (Chai *et al*., 2016). From different researchers, it is stated that using suitable irrigation management techniques at field level; yield obtained under mild deficit irrigation and full irrigation strategy is almost same (Arshad and Ibrahim, 2014). Therefore, in arid and semi-arid regions of Pakistan, where water availability is a constraint on agricultural production, deficit irrigation method may play an essential role in saving limited water resources of the country as well as mitigating drought effect on crops like cauliflower. However, before using this strategy, it is essential to have knowledge about crop yield response to different levels of deficit irrigation (Nagaz *et al*., 2012).

Kumar *et al*. (2007) stated that 13 to 33% water may be saved by employing 60 to 80% deficit irrigation which caused 14 to 38% yield reduction of onion crop in comparison with full irrigation requirements. However; crops like maize which is sensitive to water stress throughout the growing season can results higher water use efficiency but lower yield the application of deficit irrigation (Pandey *et al*., 2000). With the interaction of deficit irrigation with alternate furrow and fixed furrow irrigation systems the final yield can be optimized while saving a lot of water. A research study by Hassene and Seid (2017), reported that AFI has the maximum crop water use efficiency (CWUE) for cabbage crop than the other methods of furrow irrigation methods for 100% of evapotranspiration level with the highest benefit cost ratio (CBR). According to Eba and Seyoum (2018) the alternate method of irrigation is more effective in enhancing water use efficiency as compared to other methods of furrow irrigation. According to Hassene and Seid (2017), fixed furrow irrigation with full irrigation requirement, yield reduction was less than 10%, and was 7.5% yield reduction than the conventional furrow irrigation method for cabbage crop. While 25% water stress crop, the yield reduction under FFI was 16.9% less than that for CFI. The traditional method of furrow irrigation results huge water losses in terms of deep percolation which causes low water use efficiency. The objective of the study was to evaluate the effect of deficit irrigation and furrow irrigation techniques on cauliflower yield and its water use efficiency.

Materials and Methods

The field experiment was performed on cauliflower crop which was transplanted on ridges and furrows. The site was located in Mardan region which is situated at a distance of 60 km from Peshawar, capital of Khyber Pakhtunkhwa Province of Pakistan. It was carried out for cauliflower production under different furrow irrigation techniques from 29 September 2018 to 30 January 2019. The altitude of the site is 310 meter, and lies in 34° 13′ 1″ N and 71° 56′ 40″ E longitude and latitude respectively as depicted from Figure 1. The climate of this region is considered to be a local climate, the average temperature is 22.9°C and the yearly rainfall is 559 mm. The temperature may reach up to 45°C in mid-summer and almost touching freezing point in mid-winter. The average temperature in January is 10°C and is considered to be the coldest month of the year while average temperature of June is 33.2°C and is the warmest month of the year. The region receives maximum of its rainfall in July and August while October and November are considered the driest months of the year as shown in Figure 2.

Factorial combination of three irrigation regimes i.e. full irrigation (FI) (100% of ET_c), 80% of ET_c (DI_{20})

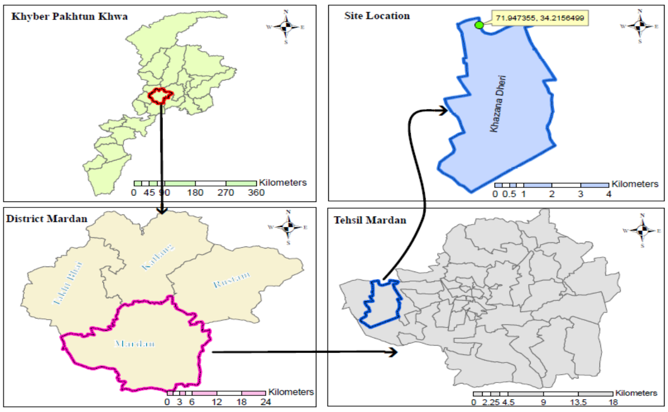

Figure 1: *Map of the study area (District Mardan).*

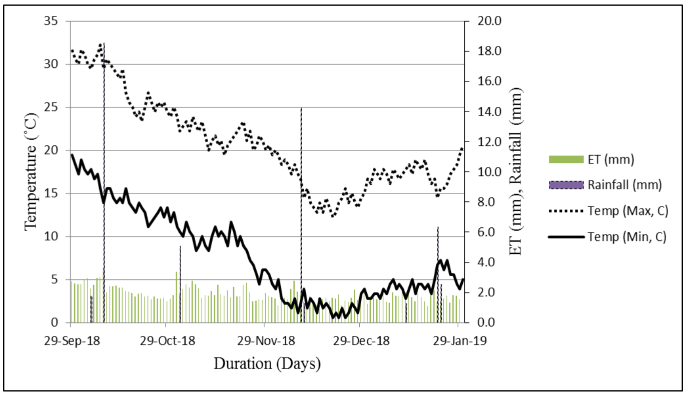

Figure 2: *Climatic data recorded during the study period.*

and 60% of ET_c (DI_{40}), and three forms of furrow irrigation systems i.e. conventional furrow irrigation (CFI), alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI) were assessed in randomized complete block design (RCBD) with three replications, resulting in total twenty-seven experimental plots. In order to have distinguished between replication some distance was provided. Proper ridges were made in between plots in order to avoid water seepage. Dikes of 15 cm height were provided at the end of the tail to avoid water loss through runoff. Each plot was 5 m wide and 10 m long. One plot contained three sub plots for one full and two deficit irrigations. Each sub plot contained six furrows and each furrow is 0.5 meter which made total cultivated area of 300 square meters. Field layout is shown in Figure 3. Before transplanting cauliflower, the field was ploughed with tillage equipment to make a proper seedbed for cauliflower. Furrows were made with the help of cultivator as shown in (Figure 4). A flooded irrigation was provided, as this was necessary for cauliflower transplantation. 18 days old cauliflower sample were transplanted on that side of the furrow which was in front of sun radiations. Precession transplanting was carried for sowing of crop, distance between plants and rows were kept uniform. A distance of 10 cm was provided between plants and row to row distance 45 cm.

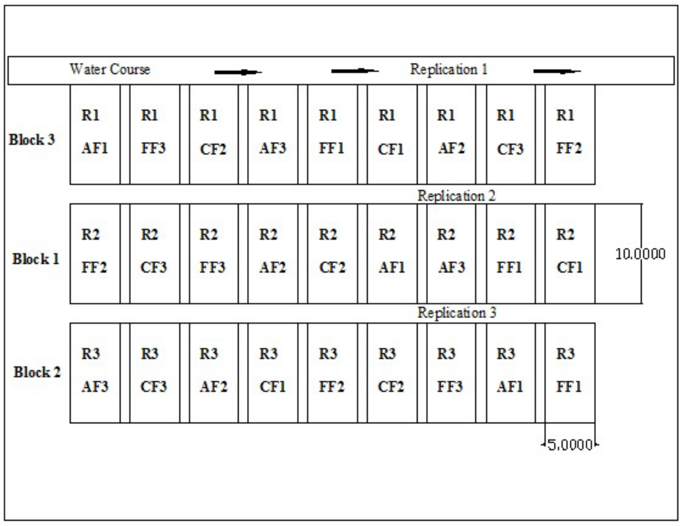

Figure 3: *Layout of the experiment.*

Figure 4: *Bed (Furrow) preparation for cauliflower.*

Crop water requirement and irrigation schedule

Crop water requirement (CWR) is the water requirement to compensate the losses of water from cauliflower through evapotranspiration, was determined from the actual evapotranspiration. The crop coefficient was taken from Allen *et al.* (1998) who reported a value of 0.7 for initial crop stage, value of 0.7-1.05 for developmental stage, for mid-season stage is 1.05 and for late season stage is 0.85 to 1.05. Reference evapotranspiration was measured on daily basis using Modified FAO Penman-Monteith equation which is based on climatic data such temperature, rainfall, humidity, sun radiation and wind speed (Allen *et al.*, 1998). Food and Agriculture Organization (FAO) CropWat software, version 8.0 which is based on Modified Penman-Monteith equation was used for it. The location of the meteorological station or site such altitude and coordinates, daily maximum and minimum temperature, air humidity, sunshine duration and wind speed were used as input values for CropWat version 8.0. From the reference evapotranspiration, actual evapotranspiration was calculated using crop coefficient (K_c).

$$ET_o = \frac{0.408\Delta(R_n - G) + \left[\frac{C_n}{T+273.16}\right] u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Where;
Et_o is the reference evapotranspiration; R_n is the net radiation flux (MJ/m^{2}day); G is sensible heat flux into the soil (MJ/m^{2}day); e_s is the mean saturation vapor pressure (kPa); e_a is the mean ambient vapor pressure (kPa); γ is psychometric constant (kPa/ °C); Δ is the slope (first derivation of the function e (T); T is the air temperature (°C).

From the reference evapotranspiration, actual evapotranspiration was measured by using crop coefficient as follow;

$$ET_c = K_c \times ET_o$$

Where;
ET_c is the actual evapotranspiration (mm/day); K_c is the crop coefficient; ET_c is the reference evapotranspiration (mm/day).

The net irrigation requirement which is the irrigation requirement of the crop for a specific period of time excluding effective rainfall (P_e) in that period was calculated using Crop Wat version 8.0 which is based on Allen *et al*. (1998) as follow;

$$IR_n = ET_c - P_e$$

Where;
IR_n was the net irrigation requirement (mm) for cauliflower; ET_c was the actual evapotranspiration (mm); P_e was the effective rainfall (mm).

Effective rainfall is that part of the rainfall that is used beneficially by crops. It can be calculated using a method given by Allen *et al*. (1998) as;

$$P_e = 0.6 \times P - \frac{10}{3} \text{for P month} <= 70 \text{ mm}$$

$$P_e = 0.8 \times P - \frac{24}{3} \text{for P month} > 70 \text{ mm}$$

Where;
P_e represented effective rainfall which is a fraction of rainfall (mm); P represented the total rainfall in growing season (mm).

Gross irrigation water is total water requirement of crop which include for losses during conveyance and application to the field. It was calculated dividing net irrigation requirement by irrigation efficiency (E_a) as follow;

$$IR_g = \frac{IR_n}{E_a}$$

Where;
IR_g is gross irrigation water requirement (mm); E_a is the irrigation efficiency (%).

Irrigation water in the experiment was applied at constant interval of two to three weeks. Total four irrigation events were carried out in entire cropping season. First irrigation was performed on 14th October 2018, second was applied on 4th November 2018, third was on 16th November 2018 and last one was on 5th December 2018.

Data collected

Climatic data: Climatic data was collected from Sugar Crops Research Institute (SCRI) weather station located in Mardan District of Khyber Pakhtunkhwa on daily basis for the entire growing season i.e. September 29, 2018 to January 31, 2019. Relative humidity (RH), sunshine hours, maximum and minimum temperature, wind speed and rainfall were recorded which was used for reference evapotranspiration estimation.

Soil and water data: Two samples at a depth of 20 and 40 cm per point were collected to assess the soil profile and other related parameter. The samples were analyzed for soil texture, bulk density, pH, wilting point, field capacity and electrical conductivity in the laboratory of Agricultural Engineering Department, UET Peshawar. Irrigation water samples were analyzed for its pH and electrical conductivity.

Curd diameter (cm): The curd diameter was measured after its production at two weeks interval. A measuring tape was used to measure the diameter of the curd.

Average curd weight (gm): After harvesting final curd weight was recorded. To find the mean value three random plants were selected from each treatment. A digital balance was used to measure the weight of the curd in gm.

Marketable yield (tons/ha): The final yield was then converted to tons per ha in order to distinguish among the yield from different treatments.

Water use efficiency: Water use efficiency (WUE) is expressed in kg per ha and is the yield produced per unit of water applied (FAO, 2017). It was calculated using the following equation;

$$IWUE = \frac{Y}{IR_g}$$

Where;
IWUE is the irrigation water use efficiency (kgha^{-1}mm^{-1}); Y is the yield (tons/ha); IR_g is the gross irrigation requirement (mm).

Crop water use efficiency is the yield production in term of actual evapotranspiration. It was calculated using the following equation;

$$CWUE = \frac{Y}{ET_c}$$

Where
CWUE is the crop water use efficiency (kgha^{-1}mm^{-1}); Y is the yield (tons/ha); ET_c is the actual crop evapotranspiration (mm).

Yield assessment: To assess the effect of different irrigation treatment on crop production, the yield of cauliflower produced per plot (5x10 m) was converted into kg per hectare, therefore final yield was converted into suitable scale so that the differences can easily be identified.

$$Y = y \times 10$$

Whereas;
Y is the yield in tons; y is the yield in kg normalize to per square meter.

Statistical analysis
After the harvesting of crop, the collected data was put for analysis. To analyze the data a statistical software STATISTIX version 10 was used. Least significance difference (LSD) test at rate of 5% was performed for means separation of various data.

Results and Discussion

Depth of irrigation water applied
A total 195.1 mm of irrigation water was applied in four irrigation events to cauliflower for its entire growing period under full irrigation with 100% evapotranspiration requirement for conventional furrow irrigation (CFI). For 20% deficit irrigation (80% of full irrigation) 156.08 mm was applied, while for 40% DI (60% of full irrigation) an amount of 117.09 mm was applied in CFI.

In alternate furrow irrigation (AFI) and fixed furrow irrigations (FFI), total amount of 97.5 mm was applied under full irrigation treatment as this amount was 50% of conventional furrow irrigation system because water was applied in alternate or specific furrows. For 20% and 40% deficit irrigation an amount of 78.05 mm and 58.5 mm of water was applied respectively.

Yield performance
Yield of cauliflower showed significant difference among three irrigation system CFI, AFI and FFI at $p < 0.05$. Mean yield obtained from CFI (34.10 tons/ha) was significantly high from AFI (30.60 tons/ha) and FFI (29.89 tons/ha), but the difference between AFI and FFI was non-significant (Table 1). This was consistent with (Sarkar *et al*., 2010) who reported 9.4% higher yield of cauliflower in CFI than AFI because in CFI system each furrow was irrigated in all events of irrigation, but in alternate and fixed furrow irrigation system, labor, time, water and fuel were saved. The relative decrease in yield of AFI and FFI were 10.25% and 12.32% of CFI. Although yield resulted from CFI was high as compared to AFI but in terms of water use efficiency AFI is well performing; may be due to better application efficiency and less evapotranspiration related to AFI (Eba and Seyoum, 2018; Hassene and Seid, 2017; Zhang *et al*, 2000; Kang and Zhang, 2004; Kashiani *et al*., 2011).

Yield of cauliflower was highly affected in terms of deficit irrigation at $p<0.05$. Mean yield obtained under full irrigation (36.12 tons/ha) was significantly high from yield obtained under DI_{20} (32.64 tons/ha) and DI_{40} (25.84 tons/ha) (Table 1). The lowest yield obtained under DI_{40} was (25.84 tons/ha) because of 40% less water applied than full requirement of the crop. Sohail *et al*. (2018), reported no significant difference in cauliflower's yield with 25% deficit irrigation however showed significant reduction in yield at 50% decrease of irrigation water. According to Woldesenbet (2005), who reported the continuous water stress under deficit irrigation during developmental stage of fruits and vegetable caused yield reduction. Irrespective of furrow irrigation system, the relative decrease in yield of DI_{20} and DI_{40} were 9.6% and 28.45% of full irrigation respectively (Figure 5).

Table 1: *Effect of irrigation system and level on yield (tons/ha).*

	Irrigation level			
Irrigation system	FI	DI_{20}	DI_{40}	Mean
CFI	37.70	33.96	30.64	34.10[a]
AFI	35.85	32.14	23.81	30.60[b]
FFI	34.80	31.82	23.06	29.89[b]
Mean	36.12[a]	32.64[b]	25.84[c]	

LSD value (at $p<0.05$) for irrigation system and irrigation level = 1.92 and 1.62.

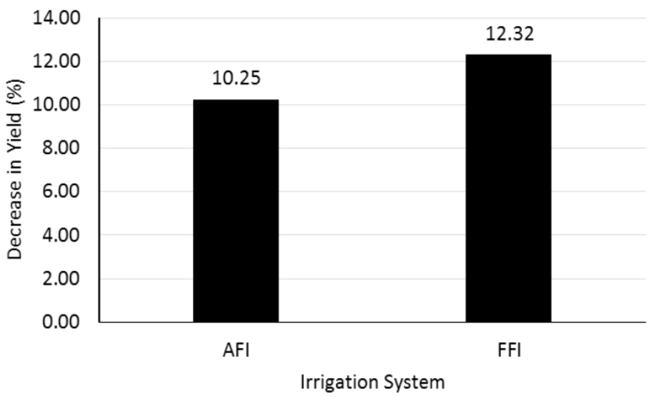

Figure 5: *Relative decreases in yield of cauliflower due to furrow irrigation system.*

Cauliflower yield is highly affected by the interactive effect of irrigation system (CFI, AFI and FFI) and irrigation levels (full irrigation, 20% DI and 40% DI) at $p<0.05$ (Figure 6). Cauliflower yield was higher in conventional furrow irrigation method as compared to AFI and FFI with full irrigation level. The relative decrease in yield was 4.8% and 7.68% in AFI and FFI as compared to conventional system. In DI_{20}, the yield of AFI and FFI was significantly less than CFI with full irrigation, but it was higher than CFI with 40% deficit irrigation. The yield of AFI and FFI in DI_{40} was significantly less than CFI with full irrigation, but the difference between AFI and FFI in terms of yield under DI_{40} treatment was not significant. The relative decrease in yield was 18.71%, 36.82% and 38.8% for CFI, AFI and FFI under DI_{40} treatment with respect to full irrigation method (Figure 7), the reduction is due to the high water stress occurred when irrigation level reduced from full requirement of crop (Sarkar *et al*., 2010).

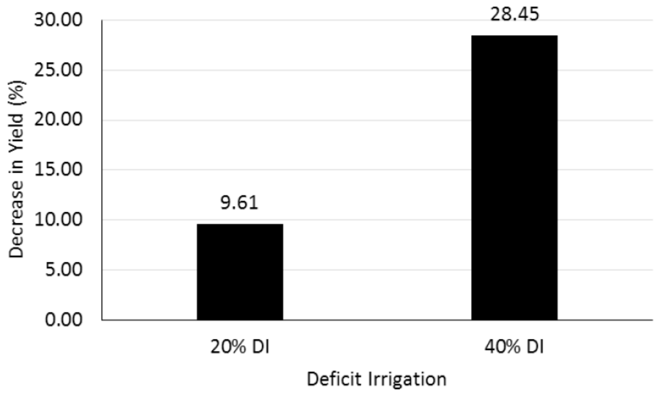

Figure 6: *Relative decreases in yield of cauliflower due DI_{20} and DI_{40}*

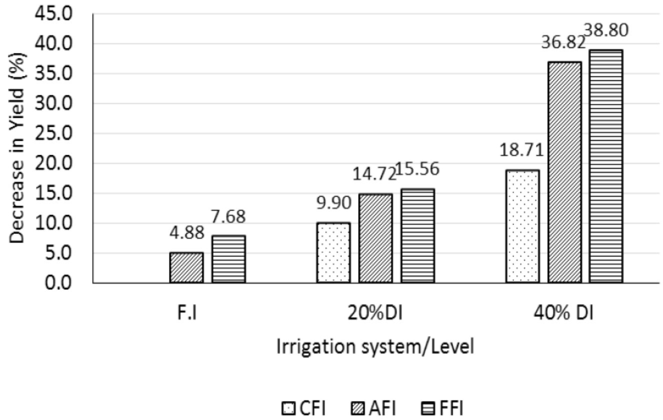

Figure 7: *Relative decreases in cauliflower yield due to the interactive effect of irrigation system and irrigation level.*

Irrigation water use efficiency

Irrigation water use efficiency (IWUE) was highly affected by furrow irrigation systems at $p<0.05$. IWUE of CFI (224.15 $kgha^{-1}mm^{-1}$) was significantly less than AFI (395.64 $kgha^{-1}mm^{-1}$) and FFI (386.42 $kgha^{-1}mm^{-1}$), however the difference between AFI and FFI was not significant as can be observed from (Table 2). The higher efficiencies of AFI and FFI than CFI is due to the 50% less irrigation water applied to AFI and FFI system. Sarkar *et al*. (2010) showed 9.4% increase in water use efficiency of cauliflower in alternate furrow system than conventional system. An increase of 83% showed in water use efficiency of potato by witching the irrigation system from every furrow to alternate furrow (Eba and Seyoum, 2018). This is consistent with Zhang *et al*. (2000), who reported significant improvement in water use efficiency in alternate furrow method. A relative increase of 76.5% and 72.3% in IWUE was observed for AFI and FFI respectively as compared to conventional furrow irrigation system (Figure 8).

Table 2: *Effect of irrigation system and irrigation level on IWUE (kg ha^{-1}mm^{-1}).*

	Irrigation level			
Irrigation system	**FI**	**DI_{20}**	**DI_{40}**	**Mean**
CFI	193.20	217.58	261.68	224.15^b
AFI	367.73	412.14	407.07	395.64^a
FFI	356.92	408.03	394.30	386.42^a
Mean	305.95^b	345.9^a	354.35^a	

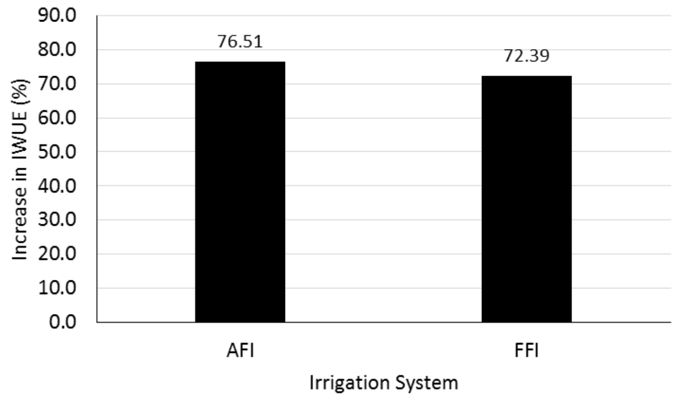

Figure 8: *Relative Increases in IWUE of cauliflower due to furrow irrigation system.*

IWUE was highly affected by deficit irrigation at p<0.05. The IWUE under full irrigation (305.95 kgha^{-1}mm^{-1}) was significantly lower than DI_{20} (345.92 kgha^{-1}mm^{-1}) and DI_{40} (354.35 kgha^{-1}mm^{-1}) (Table 2). IWUE at DI_{40} was higher than full and DI_{20} water application; this was due to the limited water application in deficit irrigation. This is consistent with (Sohail *et al*., 2018), who reported highest water use efficiency for cauliflower at 75% DI and lowest at full irrigation. Irrespective of furrow irrigation system, a relative increase of 13.1% and 15.8% was observed in IUWE for DI_{20} and DI_{40} respectively as compared to full irrigation (Figure 9).

The interactive effect of irrigation system (CFI, AFI and FFI) and irrigation levels (full irrigation, 20% DI and 40% DI) was not significant in terms of IUWE. The highest IWUE was observed in AFI system with DI_{20} (412.14 kgha^{-1}mm^{-1}) which was significantly high than CFI system with different irrigation treatments, but non-significant as compared to AFI with DI_{40} and FFI with DI_{20}. The high IWUE of AFI under DI_{20} might be due to the reduced water stress in root zone due to 20% deficit irrigation.

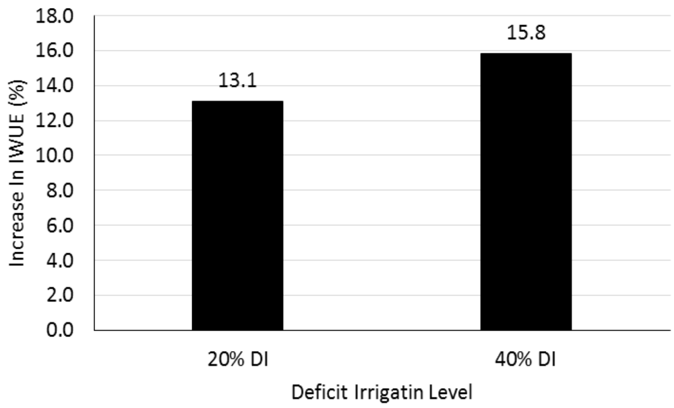

Figure 9: *Relative increases in IWUE of cauliflower due DI_{20} and DI_{40}*

Conclusions and Recommendations

Based on the results of this research study it can be concluded that that the highest yield (34.10 tons/ha) was observed under conventional furrow irrigation system and lowest yield (29.89 tons/ha) under fixed furrow irrigation system. However, the highest yield (36.12 tons/ha) were observed under full irrigation and the lowest yield (25.84 tons/ha) were observed under 40% deficit irrigation. The highest irrigation water use efficiency (354.35 kgha^{-1}mm^{-1}) was observed under 40% deficit irrigation while the lowest IWUE (305.95 kgha^{-1}mm^{-1}) was observed under full irrigation. Alternate furrow irrigation (AFI) showed highest IWUE (395.64 kgha-^{1}mm^{-1}) and lowest IWUE (224.15 kgha^{-1}mm^{-1}) was observed in conventional furrow irrigation system.

AFI method can save substantial amount of water without high losses in yield. It can increase crop water use efficiency and improve farm irrigation management condition. The AFI showed highest IWUE (395.64 kgha^{-1}mm$^{-1)}$ with the 97.5 mm of irrigation water applied as compared to other furrow irrigation methods. In light of this study the AFI practice is recommended for farmer communities with limited water resources due to its high IWUE, CWUE and a profitable yield as it may save up to 50% of irrigation water. As this research study is based on single season of cauliflower, repeating of the experiment in space and time is recommended to improve the validity of the findings. Further study is suggested on furrow irrigation methods with the interaction of fertilizers on yield of cauliflower for the current study region.

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Novelty Statement

This research is work based on furrow irrigation techniques for cauliflower crop which will help farming community to save water in water scarred areas. Water use efficiency can be enhanced in water limiting areas by switching full irrigation into controlled deficit irrigation practice. The study has positive impact on environment and will reduce carbon footprint.

Author's Contribution

Fazal Subhan: Conducted experiment, data collection and data analysis.
Abdul Malik: Supervised the field work and designed experiment.
Zia Ul Haq: Field coordination and provided inputs in designing of experiment.
Tariq Mahmood Khalil: Review the results, provided inputs in methodology and conclusion.

Conflict of interest
The authors have declared no conflict of interest.

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