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Demonstration and Evaluation of the Effect of Different Irrigation Levels and Water Use Efficiency on the Growth and Yield of Wheat

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ABSTRACT

A field experiment was conducted to study the response of wheat to different irrigation levels at Adaptive Research Farm, Vehari during 2010-2011 and 2011-2012 in randomized complete block design. Four irrigations @ 4 acre-inch, 3 acre-inch, and 2 acre-inch and farmers practice were applied. Results revealed that application of different irrigation levels to wheat affected number of grain spike^{-1}, 1000 grain weight, and grain yield (kg ha^{-1}) significantly, while non-significant effect was observed on other parameters. From the two years average results, maximum grain yield (4232.5 kg ha^{-1}), no. of grains spike^{-1} (51), 1000 grain weight (46.5 g) were recorded from the plots where 3 acre inch water was applied. Highest water use efficiency of 20, 19.89 kg ha^{-1}/mm was observed from the plots where 2 acre inch water was applied.

Keywords: Irrigation, wheat, WUE, grain yield and thousand grain weight.

INTRODUCTION

Wheat (*Triticum aestivum L.*) is an important cereal crop of the world. Due to its high demand and adaptability, wheat is grown on a large area of the world all round the year. A healthy wheat crop is not a symbol of prosperity but also an important source of strength for the nation. It ranks 1st among the cereal crops and is the staple food in Pakistan. Wheat being a major principle food of about 180 million people and annually grown on approximately 8.61 million hectares with annual production of 25 million tons while per hectare average production is 2,585 kg ha^{-1} (Anonymous, 2008-09). Wheat is among the major cash crops of Pakistan and accounts for 2.8% in gross domestic production (GDP), in the year 2008-09 (GOP, 2008-09). The zoning is mainly based on cropping pattern, disease prevalence and climatologically factors. In Pakistan, wheat is grown in different cropping systems, such as; cotton - wheat, rice - wheat, sugarcane - wheat, maize - wheat, fallow - wheat. Of these, cotton-wheat and rice-wheat systems together account about 60% of the total wheat area whereas rain-fed wheat covers more than 1.50 million hectares. There is around 60% yield gap in wheat, which needs to be narrowed. The major reasons for low productivity and instability are late plating due to delayed harvesting of Kharif crops like cotton, sugarcane and rice and non availability of proper inputs like seed, inefficient fertilizer use, weed infestation, shortage of irrigation water, drought in rainfed and terminal heat stress, soil degradation. Irrigation plays a key role in the development of agriculture sector of a country. Pakistan is severely affected by water scarcity and is already one of the most water-stressed countries in the world and will move to outright water scarcity by 2025 according to the International Water Management Institute (IWMI), due to a high level of population growth. The water availability per capita has reduced to 1200 m^3 and is seemed to reduce 800 m^3 by the year 2025 (Schahbazian *et al*., 2007). The demand for water is likely to grow from 4 to 15% of aggregate water demand in the next twenty years (GOP, 2008-09). Future water needs for agriculture can be attained by using water resources efficiently. Pakistan has been facing water shortages and drought

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conditions for the last several years due to lesser rains and high temperatures with the result wheat production both in irrigated and rainfed areas is being hampered. Primarily the irrigation system of Pakistan was designed for the cropping intensity of about 70% and this figure is increased up to 200%, which is three folds greater than the designed irrigation supply of canal network due to the food requirement of the growing population. In Pakistan the canals are required to deliver a fixed supply of water to each distributary and minor canal. The design of each system is based on an equitable supply to be delivered to each water course that means a uniform cropping intensity with a fixed water duty rate. It is very common on all farms in the country. Thus, the situation has increased the irrigation demand three folds of the canal supplies. To meet this irrigation shortage, most of the farmers have installed tube wells and are using groundwater. The share of groundwater has increased changing canal based agriculture to groundwater based agriculture. Area irrigated by canals and tube wells for agricultural practices by the year 2008 and 2009 was 19.27 Mha (GOP, 2008-09). Many forward-minded farmers have turned toward new water saving techniques as an important management tool. Improved cropping patterns and conversion to crops with higher economic returns can escort us to sustainable agriculture and are very much supportive in assessing the performance and efficient utilization of irrigation system. There are a number of well known and emerging irrigation management objectives and needs in Pakistan. In the Punjab, large quantities of irrigation flow are derived from unaccounted groundwater, and there are fears of long term over abstraction and also of degradation due to salt mobilization from existing saline areas. Surface and groundwater interactions and their quantification at basin scale are not well understood, but underpin the long term sustainability of irrigated agriculture in the region (Ahmad *et al.*, 2005). So, there is a need to study water distribution and consumption patterns and the impacts of this on productivity. Better estimates of crop area and actual water consumption are required, since surface water supplies are not only used directly in the field, but also provide a substantial, but unquantified portion of groundwater recharge (Ahmad *et al.*, 2009). In many areas, irrigation provides the means to optimize plant water use and to increase crop production. Implementing sound irrigation water management practices is necessary to overcome excessive irrigation and eliminate many associated problems. The relationship between yield and crop water use has been investigated by many researchers. (Johnson and Schmidt, 1968; Lee and Kaltsikes, 1973) recorded the effect of various irrigation regimes to maximize wheat crop yield. Information on the optimum time to apply limited amounts of water to obtain the maximum yield of high quality crops is essential for efficient use of irrigation water (Matsunaka *et al.,* 1992). Sharma *et al.* (1990) found that when the same amount of water was applied at different growth stages, there was a significant difference in productive tillers. Chaudhary and Kumar (1980) reported that maximum reduction of productive tillers was obtained when moisture stress occurred at the tillering stage. Grain yield of wheat was significantly increased with increasing irrigation frequency. Soil moisture conditions affect nutrient availability to the crops. Optimum irrigation increases N absorption by the crop, leading to a greater number of wheat tillers and a greater yield (Matsunaka *et al.,* 1992). The optimum use of irrigation water should be an important strategy for increasing agricultural production in Pakistan. Seasonally about 250 – 350 mm water is required for wheat production with 1.5 – 4.0 mm as daily evapo-transpiration (Sattar, 2004). Water is the most important factor and critical input for successful crop production. Water should be utilized for optimum and economic yield. Modern high yielding crop practice methods can be sustained only with good water control and management at the farm level. The optimum population of the planet earth depends to a large extent on the availability of water for both raised and irrigated agriculture to grow crops and produce food in the most efficient way (Ali, 2009).The objectives of this study were to determine the effect of four irrigation rates on wheat grain yields and water use efficiency.

MATERIALS AND METHOD

Physical Environment of the Study Area

The study was conducted during the Rabi seasons of 2010-11 and 2011-12 at the Adaptive Research farm, Vehari. The site was situated at 30o 01' 56" N latitude and 72 o 21' 22" E longitude, while the elevation is 455 ft. The weather of the study area is sub-tropical. The climate of the district is hot and dry in summer and cold in winter. The maximum and minimum temperature ranges between 42°C and 28°C in summer. During winter, the temperature fluctuates between 21°C and 5°C. The average rainfall is about 127 mm. The topography of the study area is plain land and moderately well drained. The soil on the site is clayey loam.

Figure1. *Experimental site at Adaptive Research Farm, Vehari*

Management of Water Regimes

The experiment consisted of four irrigation rates which were replicated three times in a randomized complete block design (RCBD) under different irrigation levels. Irrigation schedule was done in conformation with recommended irrigation practices in the experimental plots (Khair, 1995). Treatment combination comprised 4 levels of irrigation during wheat growth stages. The treatments were 4 acre- inch irrigation (T_1), 3 acre- inch irrigation (T_2), entire field would be irrigated however, actual area irrigated with 2 acre- inch irrigation (T_3) and farmer's practice, without any practice (T_4).

Cultural Practices

Each treatment's plot had dimensions of 60 ft x 35 ft for the year 2010-11 and 62 ft x 20 ft for the year 2011-12. Plots in each replication were separated by a buffer zone 3.5 ft wide and diked to contain the irrigation water and eliminate runoff. Replications were separated by a buffer zone 2 ft wide. Irrigation water was applied to the watercourse and within the plots, through diked water channels. Depth of water and time for each irrigation was estimated. A pre-sowing irrigation was applied for proper seed germination. A high yielding variety of wheat (*Triticum aestiuum L.*), Sahar-2006 was sown in the experimental plots on 14 December, 2010 and 17 November, 2011 for the growing year 2010-11 and 2011-12 respectively. Planting was done with a seed drill at a row spacing of 9 inches and at a rate of 50 kg acre^{-1} for both seasons. Recommended NPK fertilizer @ 128-114-62 kg ha^{-1} was applied. Full dose of PK was applied at sowing and N was added in two splits i.e. half at first irrigation and remaining half at second irrigation.

Observed Data

1) Irrigation time (min)

Four irrigations were applied to each plot. The source of water was tube well. On each irrigation, time required to irrigate each plot according to different irrigation levels is computed through the below mentioned formula.

$T = (A*d)/ Q$

Where,

T= time required to irrigate each plot (min)

A= area of the plot (ac)

d= depth of water applied according to the treatments (inches)

Q= discharge of water (cusec)

Discharge of the tube well was measured through trajectory method using the following formula.

$Q = 0.0174*D^2* X/ \sqrt{Y}$

Where,

Q= discharge (lps)

D= inside pipe diameter (cm) (Note: length of pipe> 6D)

X= horizontal distance of the discharge curve (cm)

Y= vertical distance of the discharge curve up to where it touches the Flowing water surface (cm)]

The plot sizes were 0.048 and 0.0284 acre for the growing season 2010-11 and 2011-12 respectively. Measured discharge value was1 ft^3/ sec for both the seasons. The data regarding germination count, number of tillers (m^{-2}), plant height (cm), 1000 grain weight (g), number of grains $spike^{-1}$, grain yield and water productivity (kg ha^{-1} mm^{-1}) were recorded during the course of experimentation. Agricultural production performance indicators include cropping intensity, ratio of area planted and area harvested, annual yield, productivity of land and water (Rao, 1993). In the present study, an attempt has been made to estimate the productivity of water. Productivity of water or water use efficiency (WUE) is expressed in the below mentioned equation.

$$\mathrm{WUE} = \frac{\mathrm{CY}}{\mathrm{WS}}$$

Where, CY is the crop yield and WS total water supplied.

Statistical Analysis

Data on plant characteristics such as germination count m^{-2}, number of fertile tillers, plant height, no. of grains/spike, 1000grain wt (TGW), and grain yield were recorded from each of the experimental plot and were subjected to analysis of variance, regression and correlation to sort out significant difference among treatments. MSTAT-C was used to find least significant difference (LSD) at 5% for the treatment means.

RESULTS AND DISCUSSION

Irrigation Time (min)

Table 1 and table 2 shows the values of irrigation time of each plot. Farmers are practicing flood irrigation that's why more time was required in T_4 to irrigate. Each treatment was replicated thrice therefore, total time required for T_1 (4 ac-inch), T_2 (3 ac-inch), T_3 (2 ac-inch), T_4 (farmers practice) for Rabi 2010-11 was 34.5, 25.5, 16.5 and 49.5 min respectively. Similarly, for Rabi 2011-12, total time required for T_1, T_2, T_3 and T_4 was 21, 15, 10.5 and 36 min, respectively.

Number of Germination (m^{-2})

Data concerning number of germination counts is shown in Table-1 and 2. Statistical analysis of the data revealed that the different irrigation levels had no significant results on germination counts for the growing seasons because the data for germination counts was recorded before first irrigation. Average maximum germination counts were recorded as 202 in T2 (3 ac-inch) for the Rabi 2010-11 and 213 in T2 (3 ac-inch) for Rabi 2011-12. On the other hand, lowest value for Rabi 2010-11 was recorded as 191 in T4 (farmers practice) and 205 in T3 (2 ac-inch) for the Rabi 2011-12. This variation may be the effect of cultural practice.

Number of fertile tiller (m^{-2})

Tillering is also very sensitive to water stress, being almost halved if conditions are dry enough (Peterson *et al*., 1984; Rickman *et al*., 1983). Different irrigation levels had non-significant effect on tillering counts. Data regarding number of tillers m^{-2} are presented in table 1 and table 2. Average maximum tillering counts were recorded as 299 in T_2 (3 ac-inch) for the Rabi 2010-11 and 287 in T_3 (2 ac-inch) for Rabi 2011-12. On the other hand, lowest value for Rabi 2010-11 was recorded as 276 in T4 (farmers practice) and 244 in T_1 (4 ac-inch) for the Rabi 2011-12.

Plant Height (Cm)

Data concerning plant height is shown in Table 1 and 2. Statistical analysis of the data showed that plant height has non-significantly ($P \leq 0.05$) affected by the different level of irrigations. Average value of the data (2010-11) indicated that taller plants were produced from those plots on which minimum water (T_4) is applied (101.7 cm), while shorter plants (98.9 cm) were noted in the plots where 4 acre-inch water (T_1) is applied. Similarly, average value of the data (2011-12) indicated that taller plants were produced from those plots on which maximum water (T_4) is applied (103.23 cm), while shorter plants (99.47 cm) were noted in the plots where 4 acre-inch water (T_1) is applied. The possible reason for this variation could be the availability of more space, light and nutrients to wheat plants and more water applied.

1000 Grain Weight (g)

Data recorded on thousand-grain weight is shown in Table 1 and 2 for the two growing seasons. Analysis of the data revealed that thousand-grain weight was significantly ($P \leq 0.05$) affected by the different level of irrigation. The data also indicated that maximum thousand grain weights (48 and 46) was recorded from the plots on which 3 acre-inch water (T_2) was applied, while minimum thousand grain weight (42 and 44) was recorded from plots where farmer practice was adopted (T_4) for both Rabi 2010-11 and 2011-12.

Number of Grains Spike^{-1}

Data regarding number of grains spike^{-1} is shown in Table-1 and 2. The data showed that application of different irrigation levels had significantly ($P \leq 0.05$) affected grains spike^{-1}. Mean value of the data for the year 2010-11 indicated that maximum grains spike^{-1} (51) was produced from the plots treated with T_2, while minimum grains spike^{-1} (46) were produced from plot with farmers practice. Mean value of the data for the year 2011-12 indicated that maximum grains spike^{-1} (51) was produced from the plots treated with T_2, while minimum grains spike^{-1} (45) were produced from plot with farmers practice.

Grain Yield (Kg Ha^{-1})

The effect of irrigation level was found significant on grain yield (Table 1 and 2). It was observed that grain yield was increased with the more efficiently used water. Maximum grain yield was obtained from T_2 (3 acre-inch of water applied) for the Rabi 2010-11 and 2011-12 in comparison of farmers practice. On average, 2.37, 4.81, and 10.45 % yields were increased than that of farmer's practice under T_1, T_2, and T_3 irrigation levels, respectively for 2010-11. Similarly, for 2011-12, on average, 3.26, 4.58, and 8.23 % yields were increased than that of farmer's practice under T_1, T_2, and T_3 irrigation levels, respectively. These results indicated that wheat was quite responsive to increase yield in optimal or near optimal irrigation. The results are in line with Matsunaka et al., 1992 and Sattar, 2004.

Water Productivity (Kg/Ha/Mm)

The agricultural productivity or the efficiency of water to produce crop growth has been computed in table 1 and table 2 for the growing season 2010-11 and 2011-12 respectively. The efficiency ranged from 6.94 to 20 kg/ha/mm in wheat (2010-11) while it ranges from 6.92 to 19.89 kg/ha/mm in wheat (2011-12). The results indicated that water use efficiency was varied and found more due to less seasonal water use and less with increased irrigation. The results are also in accordance with Sharma et al., 1990.

Correlation value is -0.9667 that means that it has a reverse impact. As the total amount of water increases, the value of WUE decreases. The highest value of Water use efficiency is computed from T3, where less water was applied. It implies that it has negative effect. Similarly, for the growing season 2011-12, the correlation value is -0.9648 that also implies the same effect as mentioned above and is highly significant.

Table1. *The effect of irrigation levels on grain yield and yield components for the year 2010-11*

Treatments	Time required to irrigate each treatment (min)	Average water applied per treatment (mm)	Average germination counts (m-2)	Average Tiller counts (m-2)	Average plant height (cm)	Average 1000 grain weight (g)	Average no. of grain per spike	Average grain yield (kg/ ha)
T_1	11.5	406.4	201	277	98.9	44 BC	48 AB	3970 BC
T_2	8.5	304.8	202	299	100.73	46 A	51 A	4283.33 A
T_3	5.5	203.2	202	293	102.43	45 AB	49 AB	4064.67 B
T_4	16.5	558.8	191	276	101.70	42 C	46 B	3878 C
CV (%)			5.38	19.48	2.78	2.40	3.21	1.45
LSD			Ns	Ns	Ns	2.132	3.13	117.4
R			-0.8748	-0.8169	-0.0727	-0.8304	-0.6593	-0.6707

Table2. *The effect of irrigation levels on grain yield and yield components for the year 2011-12*

Treatments	Time required to irrigate each treatment (min)	Average water applied per treatment (mm)	Average germination counts (m-2)	Avg. Tiller counts (m-2)	Average plant height (cm)	Average 1000 grain weight (g)	Average no. of grain per spike	Average grain yield (kg/ ha)
T_1	7	406.4	206	244	99.47	44 BC	46 B	3990.67 C
T_2	5	304.8	213	249	101.63	47 A	51 A	4182.67 A
T_3	3.5	203.2	205	287	102.37	46 AB	49 A	4042.00 B
T_4	12	558.8	211	252	103.23	43C	45 B	3864.67 D
CV (%)			3.22	12.62	3.40	4.27	3.14	0.29
LSD			Ns	Ns	Ns	0.656	2.997	23.67
R			0.4119	-0.6662	0.0493	-0.7499	-0.8006	-0.74605

Table3. *Percentage increase in wheat yield (kg/ha) and WUE (kg/ha/mm) in comparison of farmer practice (T4) for the year 2010-11 and 2011-12*

Treatment	Avg. yield (2010-11) (kg/ha)	% increase in wheat yield	Avg. yield (2011-12) (kg/ha)	% increase in wheat yield	WUE (2010-11)	% increase in WUE	WUE (2011-12)	% increase in WUE
T_4	3878	-	3865	-	6.94	-	6.92	-
T_1	3970	2.37	3991	3.26	9.77	40.76	9.82	41.98
T_3	4064.67	4.81	4042	4.58	20.00	188.23	19.89	187.61
T_2	4283.33	10.45	4183	8.22	14.05	102.49	13.72	98.41

Table 3 shows that the highets yield was produced in T_2 (3 acre inch)with 10.45% and 8.22 % yield increase in comparison of farmers practice which has produced the least yield/ ha for Rabi 2010-11 and 2011-12 respectively. Similarly regarding water use efficiency, the highest percentage increase 188.23% and 187.6% is observed in T_2 (2 acre-inches) in comparison of farmers practice.

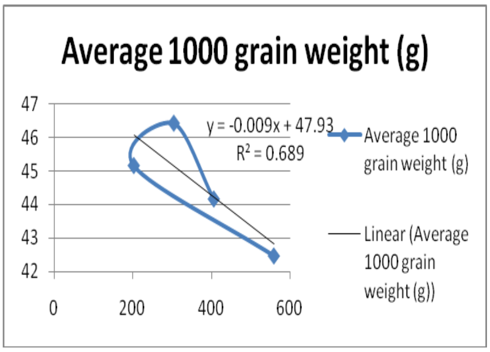

Figure2. *Linear effect of different irrigation levels on Avg. 1000 grain weight (g) (2010-11)*

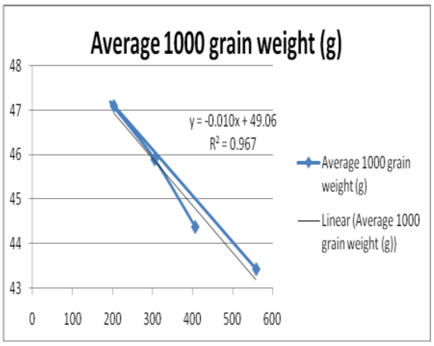

Figure3. *Linear effect of different irrigation levels on Avg. 1000 grain weight (g) (2011-12)*

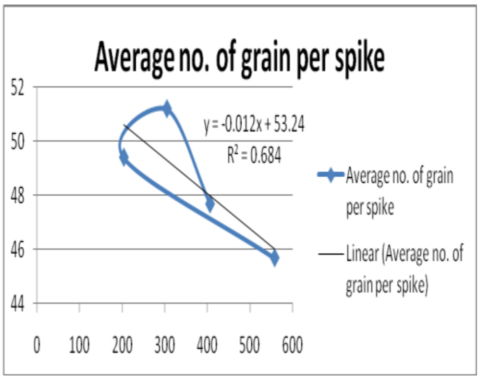

Figure4. *Linear effect of different irrigation levels on Avg. no. of grain spike^{-1} (2010-11)*

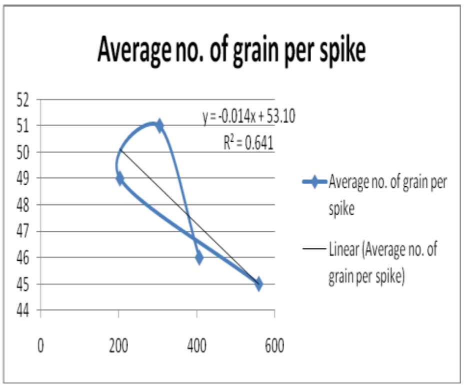

Figure5. *Linear effect of different irrigation levels on Avg. no. of grain spike^{-1} (2011-12)*

Figure 2 showed that there is significant relationship (R^2= 0.689) between different irrigation levels and avg. 1000 grain weight (g) while figure 3 indicated that there is highly significant relationship (R^2= 0.967) between different irrigation levels and avg. 1000 grain weight (g).

Figure 4 showed that there is significant relationship (R^2= 0.684) between different irrigation levels and avg. no. of grain spike^{-1} while figure 5 indicated that there is significant relationship (R^2= 0.641) between different irrigation levels and avg. no. of grain spike^{-1}.

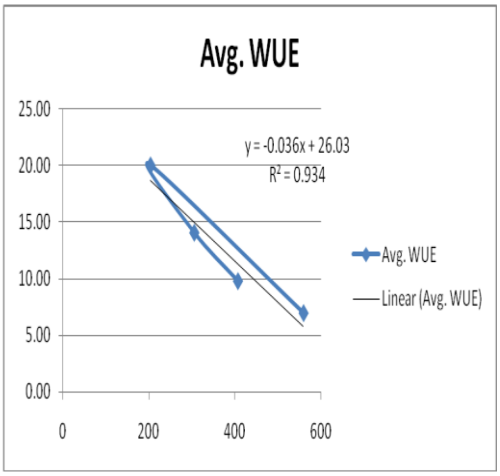

Figure6. *Linear effect of different irrigation levels on Avg. water productivity (kg/ha) (2010-11)*

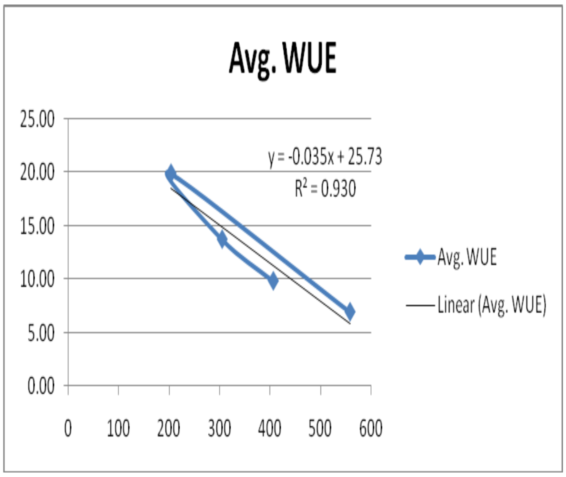

Figure7. *Linear effect of different irrigation levels on Avg. water productivity (kg/ha) (2010-12)*

Figure 6 , 7 shows that there is highly significant relationship (R^2= 0.934, 0.930) between different irrigation levels and water productivity (kg/ha/mm) during 2010-11 and 2011-12, respectively.

CONCLUSIONS

The results concluded that four irrigation levels varied yield and yield components significantly ($p<0.05$) during the both years. Application of water in (3 acre inch) i.e. 304.8 mm offered improved grain yield over 2, 4 acre inches (203.2, 406.4 and 558.8 mm and farmer practice). Therefore water application in 3 acre inch to wheat crop can be recommended in this region.

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