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Original Article

EFFECT OF SUPPLEMENTAL IRRIGATION ON WHEAT WATER PRODUCTIVITY UNDER RAINFED ECOLOGY OF POTHOHAR, PAKISTAN

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ABSTRACT

For rainfed ecology, water is the most limiting natural resource and its effective utilization is indispensable in order to optimize crop water productivity. A field study on wheat crop was carried out to asses the impact of different irrigation depths through sprinkler irrigation system at three phonological stages viz. tilleing, anthesis and grain filling. Randomized Complete Block Design (RCBD) was used in the trail and had three repeats. The area under study received 195 mm seasonal rainfall. Supplemental irrigation depths at three phonological stages, using small quantities of water through sprinkler irrigation system, significantly promoted the crop growth. The irrigation depth 25 mm gave the maximum output for biological yield (6504), grain yield (2030), thousand grain weight (28), plant height (87) and spike length (10). The highest water productivity of 0.97 kg/m^3 was achieved with 25 mm supplemental irrigation depth when applied at tillering and anthesis stages.

Keywords: Wheat Water productivity, Grain Yield, Phenological stages, Irrigation depths

INTRODUCTION

Sporadic and scanty pattern of rainwater limits the economical crop production in rainfed region of Pakistan. The yield of the major crops are 30 to 50% lower than the national average yields mainly because of the shortage of available soil moisture at the critical crop phenological stages. The sowing of wheat crop is often delayed due to uncertain rains. The date of the first significant rain determines the sowing date in rainfed agriculture (Anderson and Smith, 1990). In rainfed environment, where small quantity of water is available, sowing of the crop can be managed by supplemental irrigation applying small quantities of water through sprinkler irrigation to moist the required depth for seed emergence. In Pakistan, wheat is main staple food and it contributes 2.2 % to GDP. The normal Pakistani wheat yield is 2787 kg ha^{-1} (Anon., 2012-13). The normal yield under rainfed ecology even can be improved by managing the available small quantities of irrigation water in a judicious way considering the insufficient rainfalls. Most of the land area of Pakistan is classified as arid to semi-arid because rainfall is not sufficient to grow agricultural crops, forest and fruit plants and pastures. About 68 per cent of the geographical area of Pakistan lies under annual rainfall of 300 mm, 80 per cent of which is concentrated in July-Sept; whereas about 24 per cent lies under annual rainfall of 301-500 mm. Only 8 per cent of geographical area receives annual rainfall more than 500 mm. Supplemental irrigation may, therefore, be supportive for successful wheat production. This objective of efficient use of water under rainfed situations is achievable by adoption of pressurized irrigation (sprinkler, trickle and hosefed) in the water scarcity areas of Pakistan. Sprinkler irrigation system can improve the water use efficiency and minimize the labour and capital requirements and, at the same time, maintain a favourable growing environment for the crop. Despite these water shortages, wastage of irrigation water is common because of inefficient methods and poor scheduling, resulting decrease in water use efficiency (WUE) and profits. The relationships between crop yields and water use are complicated. Yield may depend on when water is applied or on the amount. Information on optimal scheduling of limited amounts of water to maximize the yields of high quality crops is essential (Al-Kaisi *et al*., 1997). The various crop development stages possess different sensitivities to moisture stress (FAO, 1979; English and Nakamura, 1989). Improving water productivity can contribute to water savings, which can be used to irrigate additional lands with higher total production to improve the sustainability of the existing water resources (Oweis *et al*., 2000).Timing, duration and the degree of water stress can affect yield. Wheat can be categorized as winter or spring types according to chilling requirements, winter hardiness and day length sensitivity. Winter wheat requires a cold period or chilling (vernalization) during early growth for normal heading under long days. Winter wheat in its early stages of development exhibits a strong resistance to frost, down to - 20°C, whereas Spring wheat does not require chilling for heading. However, it is also sensitive to frost. For winter and spring wheat minimum daily temperature for measurable growth is about 5°C. Mean daily temperature for optimum growth and tillering is between 15 and 20°C. Occurrence of (spring) frost is an important factor in selection of sowing date. A dry, warm ripening period of 18°C or more is preferred. Studying the response of wheat to environment at different phenological stages may prove useful for optimizations of growth, development and yield formation. Grain yield and straw ratio are correlated to the duration and intensity of water deficit. Rains especially early in the growth periods, plant and head number per m^2 are considered higher compared to no rain. In the later situation, the time to heading is also usually shortened. Slight water deficits in the vegetative period may affect crop tillering or may even somewhat hasten maturation. The flowering period is most sensitive to water deficit. Pollen formation and fertilization can be seriously affected under heavy water stress that can reduce the number of heads per plant, head length and number of grains per head. At the time of flowering, root growth may be very much reduced and may even cause a considerable damage. The loss in yield due to water deficits during the flowering period may not be recovered by providing adequate water supply during the later growth periods. Water deficit during the yield formation period results in reduced grain weight and hot, dry and strong wind in combination with a water deficit during this period causes shriveling of grain. During the ripening period a drying-off period is often induced by discontinuing irrigations and water deficit during this period only has a slight effect on yield (FAO, 2009).

Hence, keeping in view the germination and growth constraints in relation to soil moisture deficit with special reference to certain phenological stages under rainfed environment, the present study was undertaken to test the effects of supplemental irrigation through sprinkler system at appropriate growth stages in affecting wheat growth and productivity.

METHODOLOGY

The research was executed at National Agricultural Research Centre (NARC), Islamabad, Pakistan (33° 42' N, 73º 10' E) during 2009-10 in the field station of Water Resources Research Institute (WRRI). The experiment was laid out under RCBD having three replications on an area of 47 m x 40 m with subplot size of 15 m x 4.5 m. The crop was sown on December 4, 2009 using variety Pirsabak-04. Two irrigation depths (10 and 25 mm) were applied as supplemental irrigation at three stages viz. tillering, anthesis and grain filling . The following treatments were allocated to plots.

Table 1. Table of Treatments

Codes	Decodes of Treatments
T1	no irrigation at tillering
T2	no irrigation at tillering and anthesis stages
T3	no irrigation at tillering, anthesis and grain filling
T4	10 mm irrigation at tillering
T5	10 mm irrigation at tillering and anthesis stages
T6	10 irrigation at tillering, anthesis and grain filling
T7	25 mm irrigation at tillering
T8	25 mm irrigation at tillering and anthesis stages
T9	25 irrigation at tillering, anthesis and grain filling

Soil samples were collected for different depths with the help of soil tube before sowing and at each irrigation interval at the target stage and after the harvesting of the crop to asses the soil moisture regime and nutrient status (Table 2). Climatic data was recorded during the cropping period. Different phenological stages were monitored in the field. All the other agronomic measures were practiced evenly for all the treatments.

Table: 2. Soil Nutrient Status

pH	Ec(ms/cm)	N (ppm)	P (ppm)	K (ppm)
8.13	0.33	22.2	1.13	107.6

The observations were recorded for different growth and development parameters, and grain yield. Half of the plot was kept for growth and development study and the remaining half plot was used for final grain yield. The relation of irrigation to crop yield is called the irrigation-production function. Many researchers (Zhang *et al*., 1993) have reported that this function can be described with a quadratic relationship:

$$Y = b_0 + b_1W + b_2W^2 \quad ....[1]$$

Where Y = crop yield (kg/ha), W = Total irrigation during the whole crop-growth period (mm), b_0, b_1 and b_2 are coefficients (kg/ha, kg/ha / mm, kg / ha /mm²), respectively).

Statistix Software was used to analyze the data and the means were compared on least significance difference basis as described by Steel *et al*., (1997).

RESULTS AND DISCUSSION

Rainfall, Temperature and Relative Humidity during 2009-10

The weather conditions for the period under research are summarized in Fig. 1 a, b and c. Seasonal rainfall was 195 mm (Fig. 1a). The maximum rainfall was recorded in the month of February (89 mm). The air temperature during the season was normal. Mean air temperature of December, January, February, March and April were 20, 21, 19, 29 and 34° C (Fig. 1b). The maximum average temperature was recorded in the month of April (34° C). The minimum average temperature was observed in the month of January (2.5° C). The average humidity increased from December to February (maximum 71 %). But after February, it decreased to 45 % in April (Fig. 1c).

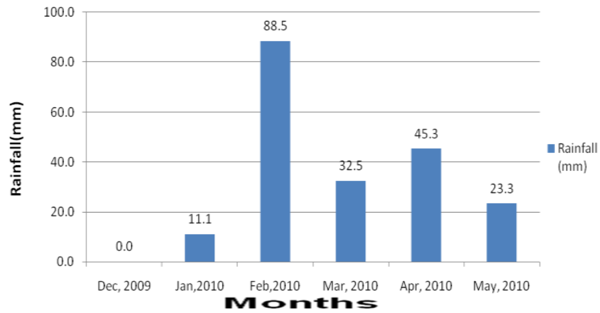

Fig. 1(a) Rainfall Pattern during the crop period (2009-10)

Fig. 1(b) Maximum and Minimum Temperature during 2009-10

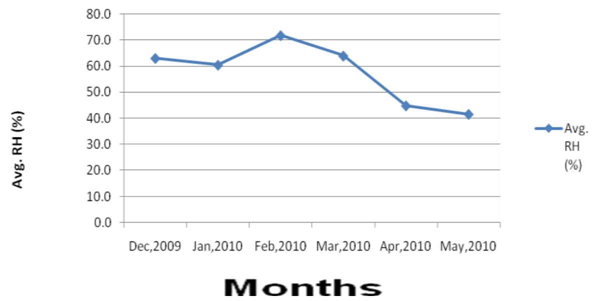

Fig. 1(c) Average Relative Humidity during 2009-10

From the Figure 2(a), it was observed that soil moisture %age varied from 6.2, 5.6, 9.2, 10.5 and 12.5 at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths respectively before sowing of the wheat crop. Maximum %age of soil moisture was recorded in 90-120cm depth i.e 12.5%.

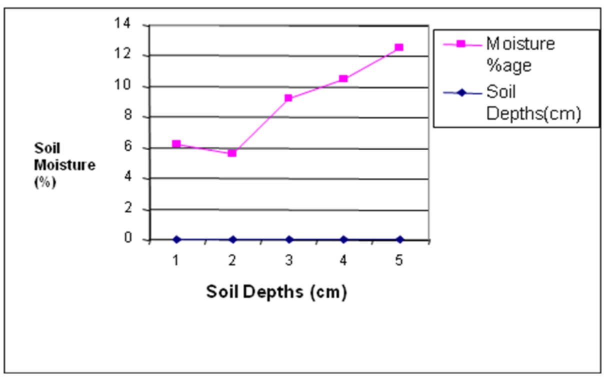

Fig. 2 (a) Soil Moisture before Sowing

Soil moisture significantly varied with different irrigation depths. Soil moisture recorded at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths at tillering stage were 13.5, 12.9, 10.8, 11.4 and 12.9 at rainfed, and 17.2, 15.6, 11.1, 11.9 and 12.5 at 10mm and 13.8, 12.7, 9.2, 10.7 and 10.8 % at 25mm plots, respectively. Maximum moisture percentage at tillering stage was recorded in 10mm plots i.e 17.2% (Fig. 2 b). At anthesis, soil moisture taken at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths were 4, 4.4, 8.6, 10.4 and 12.4 at rainfed, 3.5, 5.1, 7.3, 9.7 and 12 % at 10mm and 4.3, 5.2, 8.6, 11.1 and 13.8 % at 25mm plots respectively. Maximum moisture percentage at anthesis stage was recorded in 25mm plots i.e 13.8% (Fig. 2 c). At grain filling stage, soil moisture recorded at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths were 3.3, 3.2, 5, 7.9 and 10 at rainfed, 2.9, 3.7, 4.8, 7.5 and 10.5 at 10mm and 2.9, 3.1, 7.4, 88 and 11.4 % at 25mm plots, respectively. Maximum moisture percentage at grain filling stage was recorded at 25mm supplemental irrigation depth i.e 11.4% (Fig. 2 d). At harvest, soil moisture at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths at harvest were 8.6, 5.3, 7.2, 9.3 and 12.6 at rainfed, 9.5, 6.2, 6.1, 5.9 and 7.4 at 10mm and 8.9, 6.3, 6.7, 7 and 7.9 % at 25mm plots, respectively. Maximum moisture percentage at harvest stage was recorded in rainfed plots i.e 12.6% (Fig. 2 e).

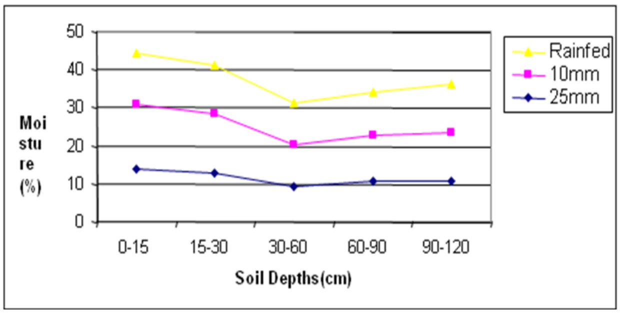

Fig. 2 (b) Soil Moisture (%) at Tillering Stage

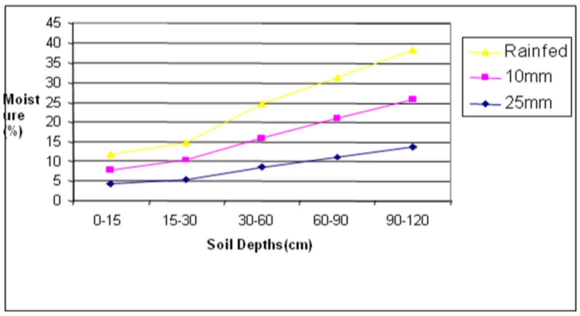

Fig. 2 (c) Soil Moisture (%) at Anthesis Stage

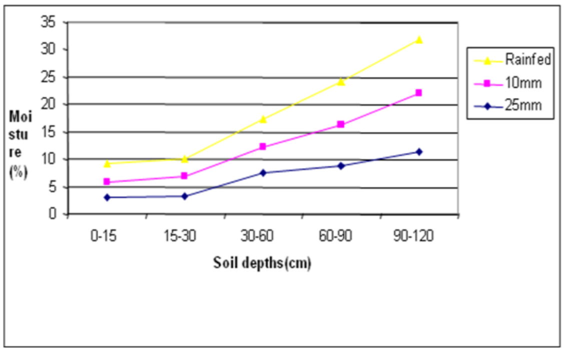

Fig. 2 (d) Soil Moisture (%) at Grain Filling Stage

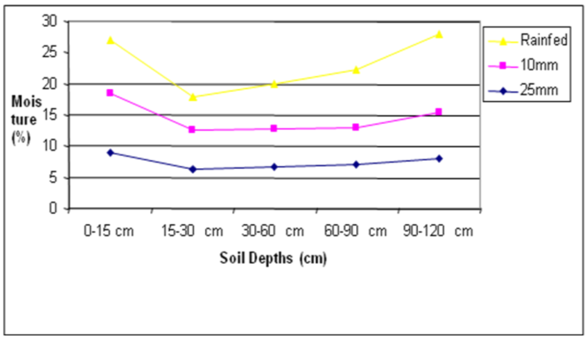

Fig. 2 (e) Soil Moisture (%) at Harvesting Stage

Significant difference among the irrigation plans was recorded for number of tillers / m² (Table 3). Maximum number of tillers / m² were recorded at 25 mm depth at tillering and anthesis stages (269) followed by 25mm depth at tillering stage (261). Whereas minimum was noted in rainfed plots (107).These results are in agreement with the conclusion of Singh *et al.*, 1979 who reported that number of tillers significantly increased with increase in the amount of profile stored water.

Significant effect on spike length was experienced for different irrigation plans (Table 3) . Maximum spike length was recorded at 25 mm depth at tillering stage (10.3) followed by 25mm depth at tillering and anthesis stages (10). Minimum spike length was recorded in rainfed at tillering , anthesis and grain filling stages (6.4).

Table (3) Impact of different irrigation strategies on Wheat traits

Treatments	Bio yield kg/ha	Grain yield Kg/ha	Harvest index (%)	Thousand Grain weight (g)	Plant height (cm)	Spike length (cm)	No of tillers/m²	Water productivity kg/m³
T1	3093C	1025CD	34ABC	23.1 B	59.3CD	7.2CDE	113 C	0.52
T2	2254C	792 D	35AB	24.1AB	59CD	7DE	107 C	0.407
T3	2297C	842 D	37A	27AB	54D	6.4 E	113 C	0.43
T4	5682AB	1695AB	30BC	25AB	69.3BC	8.4BCD	219AB	0.858
T5	3910BC	1252BCD	32ABC	24.2AB	73B	9ABCD	166BC	0.633
T6	4088BC	1395ABCD	35AB	27.2AB	69.3BC	9ABCD	162BC	0.672
T7	5800AB	1645ABC	28C	25AB	88A	10.3A	261 A	0.798
T8	6504A	2030A	31ABC	26.4AB	82AB	10AB	269 A	0.93
T9	5089AB	1837 AB	36AB	28.2 A	76AB	9ABC	212AB	0.774
C.V	15.59	16.14	6..97	6.71	6.37	7.61	14.08	
LSD		652.39	6.7069	4.9864	12.945	1.8444	73.744	

The significance of the role of plant height is an important character especially under rainfed conditions considering the wheat straw and grain yield (Table 3). Data presented exposed that there was considerable difference with the irrigation depths in plant height. Maximum plant height recorded was at 25 mm depth at tillering stage (88) followed by 25mm depth at tillering and anthesis stages (82). Whereas, the lowest plant height was observed in rainfed tratment (54). These answers are in consistence with the conclusion of Singh *et al.*, 1979 who described that plant height significantly increased with increase in the amount of profile stored water.

Data obtained in the table 3 shown that there were significant differences among the irrigation plans regarding biological yield. The highest biological yield was recorded at 25 mm depth at tillering and anthesis stages (6504) followed by 25mm depth at tillering stage (5800). Minimum biological yield was observed in rainfed at tillering and anthesis stages (2254). These fresults are in line with the study of Ahmad *et al*., 1999 who shown that the wheat straw and grain yields were increased by applying supplemental irrigation at all the three strategies.

Irrigation plans significantly affected grain yield (Table 3). The highest grain yield was recorded at 25 mm depth at tillering and anthesis stages (2031) which was followed by 25mm depth at tillering, anthesis and grain filling stages (1838). The lowest grain yield was experienced in rainfed at tillering and anthesis stages (792).These findings are in partial agreement with the work of Tadayon and Emam (2008) who reported that highest grain yield was obtained from supplemental irrigation at stem elongation stage, and the lowest yield was harvested at dryland conditions The results are in line with the work of Sarwar (1994) who concluded that soil moisture stress at all the critical growth stages to wheat crop reduced the yield significantly. These results are in dissimilarity to the work of Kazemeini *et al*.,(2009) who reported that there was non significant difference in the grain yield of sunflower in comparison to defecit irrigation and full irrigation depths. These findings are in fractional contradiction to the work of Yaseen and Rao (2002) who found higher grain yield of wheat by Irrigation at crown root initiation, tillering, flowering and milky stages. The higher yields in the plots which received supplemental irrigation 25 mm at tillering and anthesis stages are credited to increases in thousand grain weight, plant height, spike length and number of tillers m^{-2}. The supplemental irrigation promoted growth and development attributes, and water productivity that consequently enhanced the crop productivity.

Harvest index (HI) was significantly affected by different irrigation plans (Table 3). The highest harvest index was recorded with rainfed treatment at tillering, anthesis and grain filling stages (37) followed by 25mm depth at tillering, anthesis and grain filling stages (36). Whereas the lowest HI was determined in rainfed plots at tillering stage (28). These outcomes are in part conformity with the findings of Wang *et al.* (2005) who affirmed that water deficit at tillering tended to increase grain harvest index but decreased biomass.

Table 3 revealed that there were significant differences among the irrigation plans for thousand grain weight . Supplemental irrigation 25 mm depth at tillering, anthesis and grain filling stages resulted in maximum thousand grain weight (28.2) followed by 10mm depth at tillering, anthesis and grain filling stages (27.2). The lowest thousand grain weight was observed in rainfed at tillering stage (23.1). These results are in formation with those of Wajid *et al*., 2002 who told that there was a significant effect on grain weight for different irrigation treatments.

The highest water productivity (kg m^{-3}) was recorded at 25 mm depth (Table 3) at tillering and anthesis stages (0.93) followed by 10mm depth at tillering stage (0.858). Whereas the lowest water productivity was recorded in rainfed at tillering and anthesis stages (0.407). WUE was highest up to two irrigations at two stages. These findings are in line with the results of Kar and Verma (2005) that water use efficiency (WUE) was increased linearly with increased number of irrigations up to three irrigation schedules. However, with four irrigations, the yield was higher, but WUE was lower than that of three irrigations. The increase in water productivity up to two irrigation stages might be due to the effect of increased water application in increasing crop water use without a corresponding increase of yield for the crop with the increase in number of irrigations.

CONCLUSION

Under rainfed environment when the seasonal rainfall was 195 mm, the supplemental irrigations, applying small quantities of irrigation water through sprinkler irrigation system, played a vital role in increasing water productivity and wheat grain yield in accordance with the apposite phenological growth stages. Maximum grain yield and water productivity were achieved under 25mm irrigation regime when applied at tillering and anthesis stages and beyond these stages, water productivity did not increase. If small amount of irrigation water is available under rainfed conditions of Pothohar, Pakistan supplemental irrigation 25 mm at tillering and anthesis can increase growth and development attributes, and water productivity that accordingly can enhance grain productivity. Hence from the results it can be concluded that if water can be managed to supplement wheat crop at tillering and anthesis stages, higher grain yield, straw yield and water productivity can be achieved depending upon soil, varietal and climatic conditions in the particular region.

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