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Impact of supplemental irrigation through sprinkler raingun at alternate phenological stages of wheat crop

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Abstract

In Pakistan, wheat yield in the rainfed area is being affected due to erratic, unexpected pattern of rainfall. Heat stress is also a limiting factor that decreases the grain weight as well as yield badly. Water is a precious finite natural resource in rainfed areas, and its proper utilization is critical for optimizing crop water yield. During wheat growing season 2010-11, research was planned to evaluate various watering treatments at National Agricultural Research Centre (NARC) on wheat crop variety (Chakwal-50). Treatments are applied at three phenological Feeks growth stages viz. Feeks Scale = 2.00 (Tillering), Feeks Scale = 10.50 (Anthesis) and Feeks Scale = 10.5.1 (Grain Filling). The experiment was designed using a randomized complete block design and replicated thrice. The research site perceived 257.7 mm rainfall water during growing season of wheat crop. The 25 mm level of irrigation water produced maximum biological yield (10392 kg/ha), economic yield (3534.3 kg/ha), 1000 grain weight (40.9 g), plant height (90.8 cm) and length of spike (9.3 cm). There were 64% and 55% increments in biological and grain yield kg/ha when level of irrigation water was applied at the rate of 25 mm at Feeks Scale = 2.00, and Feeks Scale = 10.5.1 of wheat as compared to barani at Feeks Scale viz. Feeks = 2.00, Feeks = 10.50 and Feeks = 10.5.1.

Keywords: Grain yield, Irrigation, Phenological stages, Raingun, Sprinkler, Wheat

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Introduction

Pakistan is predominately an agrarian country with diverse type of agro ecological zoning having ancient and vast irrigation supplies (Zhang & Zhou, 2015). Wheat is an international cereal crop as well as our staple crop and as a nation its demand is increasing year by year due to rapid increase in population (Khan et al., 2016; Anser et al., 2018; Shafqat et al., 2019; Shaheen et al., 2023). Since last decades Pakistan is badly affected due to uncertain climatic changes in rabi and kharif seasons and uneven, high/low intensity of rainfall occurrence is limiting and damaging the crop yields (Abubakar, 2020; Mehmood et al., 2020). Wheat in rainfed and irrigated areas of Pakistan is also going under transitional shifts (Ullah et al., 2022). Timeliness and amount of incident rainfall at proper phenological stage of wheat is of major importance and a changing trend has been observed that in October-November rainfall amount is almost zero and it occurs in late January/early February till harvesting (Naheed and Cheema, 2015). So whatever water is available for supplementing wheat crop with moisture, it must be provided with agro-engineering feasible methods (Chami et al., 2015). The irregular and sparse pattern of rains affects the crop output in rainfed areas (Liu et al., 2021). Wheat is grown on 28 MA and its share in value addition in agriculture is 7.8% while in GDP is 1.8. Wheat production dropped to 26.394 MT (3.9%) from 27.464 MT the previous one (Government of Pakistan, 2022).

Crop production will be impacted by global climate change, which includes high temperatures and unpredictable rainfall events (Ishaque et al., 2023). Over the past two decades, enhancement in agricultural efficiency in Pakistan have been brought about largely by the diffusion of high yielding varieties, balanced fertilizer uses and ample availability of irrigation water (Aslam, 2016). The valuable organization of water for crop productivity is becoming ever more important and fundamental during water shortage (Islam et al., 2023). Crop water use efficiency is low under the current irrigation tools (Gautam et al., 2020). Therefore, suitable irrigation scheduling is indispensable that can save water and advances irrigation efficiency. Enhancement in wheat productivity depends upon shift in management techniques including high yielding cultivars, better fine seed bed, in time planting, improved crop population, efficient control of herbs and pests, more effective use of fertilizers and irrigation water (Aslam, 2016). Scarcity of irrigation water particularly during critical phenological stages of crop growth (milky and grain formation stages) considerably affect the crop productivity. There is limited rainfall to sow crops on Pakistan's vast land area (Ashraf et al., 2023). Auxiliary H_2O supply may thus be beneficial for increasing wheat yields. This goal of competent water usage under rainfed conditions is achievable with the implementation of pressurized irrigation (sprinkler) in water-stressed areas of Pakistan, which is subsidized (Aziz et al., 2021).

Rain drop like irrigation system (SIS) can develop the WUE and diminish the effort and money necessities and, simultaneously, maintain a good emergent atmosphere for the crop. One potential benefit of sprinkler systems is the capability to improve adjust soil moisture during the harvest period (Winston, 2013). Flood systems relate large quantum of water and must be timed accurately to avoid wet soils which can make harvest operations hard and decrease stands due to compaction damages. Sprinkler irrigation systems have various advantages, including easier water monitoring than flood irrigation systems, less tampering with farming and less land loss, higher application efficiency, high and frequent application may be effectively gifted, and easy computerization and automation (Shankar et al., 2015). The relationship b/w crop production and use of water is intricate. When water is beneficial, yield may be affected. It is critical to have information on the best way to schedule scare water in order to maximize crop yields of good quality crops (Al-Kaisi et al., 1997). The minimal daily temperature for detectable growth in winter and spring wheat is around 5°C. The study of wheat's reaction to distinct time scale phases may be helpful for optimizing growth, development, and yields. Grain and biological yields are related to time and speed of irrigation water/rainfall ratio (Gracia et al., 2016).

Rain, especially in the start of growth cycle, promotes bigger and stronger plants, as well as a larger head number per m^2 than no rain. In subsequent situations, the time to heading in wheat is frequently cut as well. Minor flooding shortages during the vegetative period can have an impact on crop tillering. The reproductive period is the most vulnerable to a lack of moisture (Loka & Oosterhuis, 2012). Pollination and crossing can be hampered by severe water scarcity, which reduces the growth, yield and quality attributes of wheat crop. The yield loss caused by water deficiencies during the flowering stage is irreversible unless adequate water delivery is given during the subsequent growth periods (Masoumi et al., 2010). A drying-off period is frequently created during the maturity phase by halting artificial application of water and water scarcity during this time has simply a little influence on production (FAO, 2009). Irrigation is used to maximize wheat output at important phenological stages of wheat phasic development. However, the advised watering plans differ depending on the experimental environment.

Xue et al. (2003) discovered that optimizing wheat production and water use efficiency necessitates three irrigation applications, one during jointing, booting, and anthesis, totaling 300 mm. Zhang et al. (2004) suggested that with 180 mm of total irrigation, three applications were advised during jointing, booting to heading, and anthesis to the early grain formation phases. Possession in mind the germination, growth, and yield restrictions associated with soil moisture shortages, with a particular emphasis on developmental phases under barani conditions, the current trial was commenced to assess the usefulness of extra water of irrigation via efficient system (sprinkler system) at various growth phases. In short, it was carried out in order to determine the best level of limiting moisture in connection to the optimum phenological stage of the wheat crop.

Materials and Methods

Irrigation at proper phenological stage must be given prime priority in order to get maximum wheat water productivity in limiting aqua resources. The research was organized and carried out at the Water Resources Research Institute (CWRRI), field station NARC, Islamabad, Pakistan (33° 42' N latitude, 73° 10' E longitude) during 2010-11. The experiment was designed using RCBD with three replications. The wheat crop variety Chakwal-50 was sown by using 50 kg/ha healthy and disease free seed. All sowing operations was carried out with the help of highly precise wheat planter having adjustment 1.5 × 5 m in the calibrated planter seed rate adjusted automatically. Additional irrigations of 10 mm and 25 mm were applied through portable sprinkler irrigation (Fig. 2) system at three stages of wheat mentioned above in this research study. The various irrigation levels were allocated to plots.

Irrigation depths at various phenological stages of wheat (Feeks Scales)

I_1= Rainfed at Feeks Scale = 2.00
I_2= Rainfed at Feeks Scale = 10.50 and Feeks Scale = 10.5.1
I_3= Rainfed at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1
I_4= Rainfed at Feeks Scale = 2.00 and Feeks Scale = 10.5.1
I_5= 10 mm at Feeks Scale = 2.00
I_6= 10 mm at Feeks Scale = 10.50 and Feeks Scale = 10.5.1
I_7= 10 mm at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1
I_8= 10 mm at Feeks Scale = 2.00 and Feeks Scale = 10.5.1
I_9= 25 mm at Feeks Scale = 2.00
I_{10}= 25 mm at Feeks Scale = 2.00 and Feeks Scale = 10.5.1
I_{11}= 25 mm at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5
I_{12}= 25 mm at Feeks Scale = 2.00 and Feeks Scale = 10.5.1

Agronomic and physiological traits like plant height (cm), spike length (cm), chlorophyll contents, leaf area (cm^2), number of tillers/m^2, 1000 grain weight (g), biological yield kg/ha, grain yield kg/ha and harvest index (%) were recorded and analyzed. Chlorophyll contents from five randomly selected leaves from a plant of wheat by using SPAD chlorophyll meter having non-destructive approach of measuring contents. During the farming season, climate data of the crop months were also collected. In the field, many phenological stages were observed (Fig. 1). All other agronomic measures were applied consistently across all treatments. During the field trial broad leaf and narrow leaf weedicides were applied to control the weeds. A composite soil sample was collected from the field before sowing and analyzed for its physiochemical properties at NARC, Islamabad (Table 1).

Table 1 Physiochemical properties of soil

Properties	Unit	Value
pH	-	7.5
EC	dSm^{-1}	0.88
Organic matter	%	0.8
Total N	%	0.05
Available P	mg kg^{-1}	7.9
Available K	mg kg^{-1}	108
Texture	-	Sandy loam

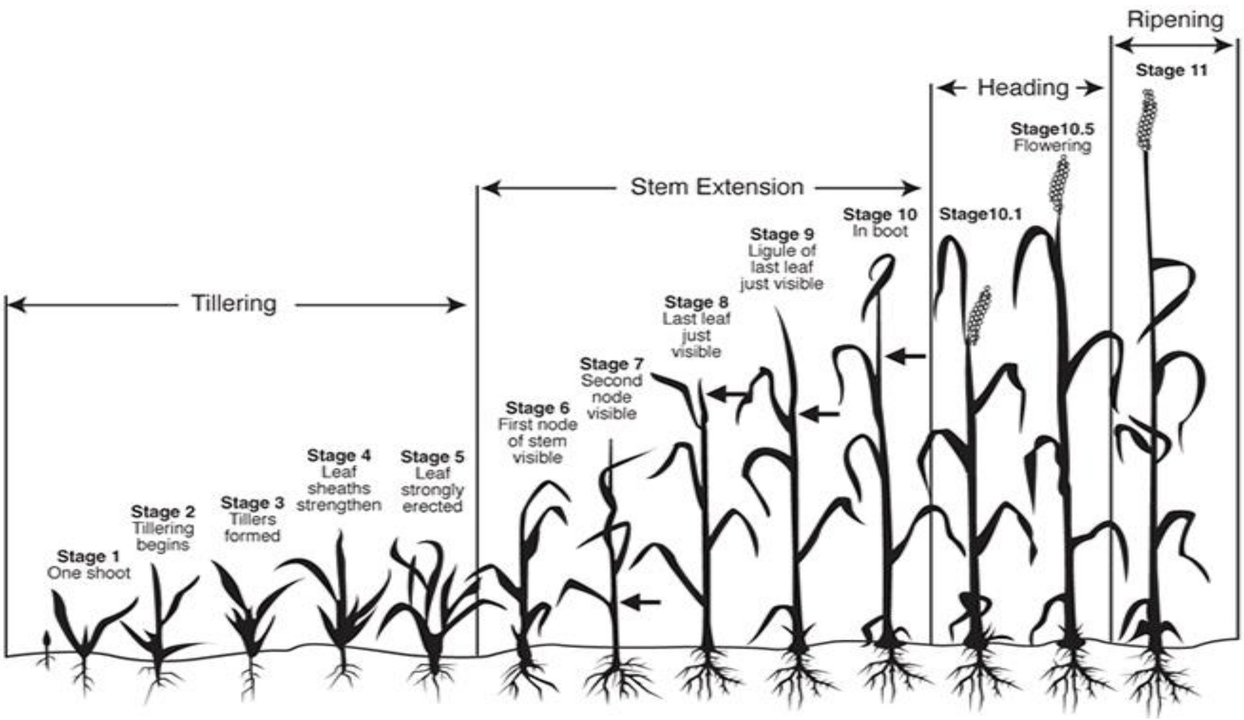

Fig. 1 Wheat phenological stages (Feeks Scale)

Fig. 2 Portable sprinkler irrigation raingun

Several growth and development features, as well as grain yield, were observed. The plots which are the ½ of the plots was preserved for the above said traits measurement, while the ½ part other was used to calculate grain production. The artificially applied water and production function describes the relationship between irrigation and crop yield.

Statistical analysis

Significance ($p \leq 0.05$) was computed employing Fisher Analysis of Variance technique and means of treatments were compared using Tukey's Honestly Significant Difference (HSD) test at 5% probability level. Means were statistically analyzed with Statistix-8.1 software for (ANOVA) by analytical software company Steel et al., (1997) find the inferences and drawing the conclusion.

Results

Rainfall and temperature during 2010-11

Fig. 3 summarizes the weather conditions for the study period. During crop, the total rainfall received was 257.7 mm. According to Fig. 2 (a), soil moisture % age ranged between 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 prior to wheat crop sowing. The maximum percentage of soil moisture age was observed in 90-120 cm depth i.e. 12.5%. During the crop period maximum rainfall was observed in the month of February and minimum was recorded in November the result are in line with the rainfall data because where the more rainfall more percentage of soil moisture and access to more depths.

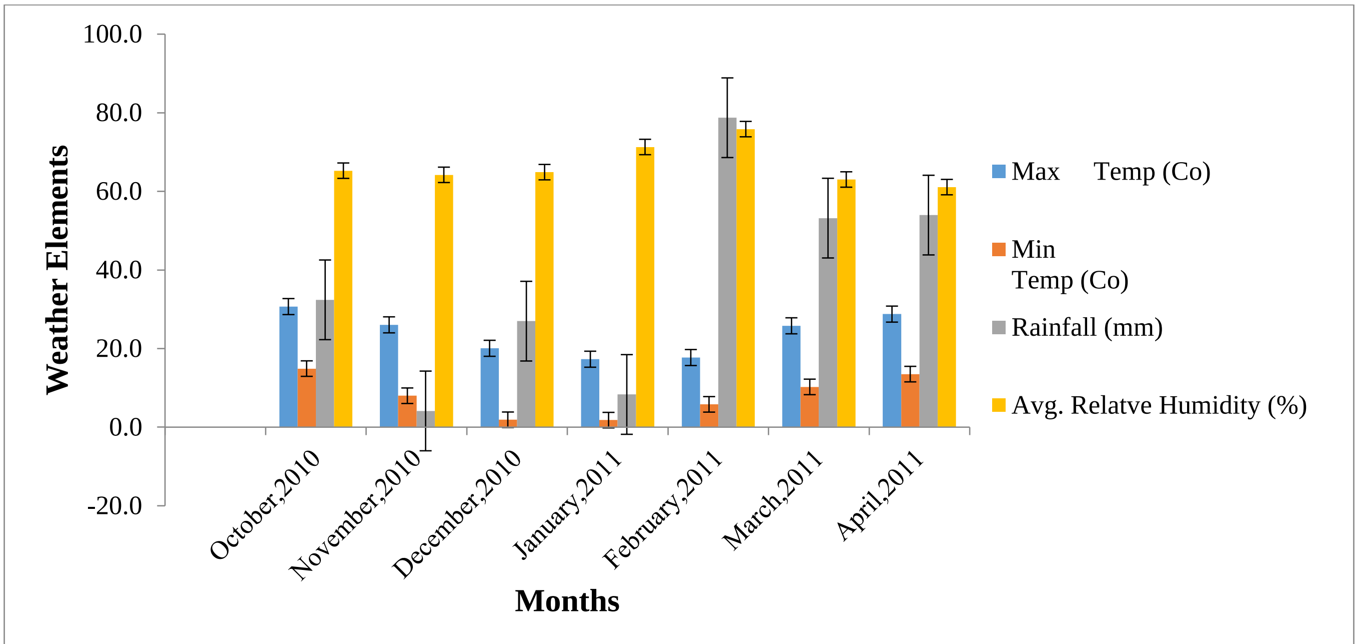

Fig. 3 Agro climatic conditions during 2010-2011 under NARC, Islamabad

Agronomic traits

Plant height (cm)

The importance of plant height (cm) is a significant aspect, particularly under barani situations, when assessing the ratio of wheat straw and grain output (Table 2). The data given revealed that there was no change in plant height between irrigation depths. Highest plant was noted at 25 mm depth at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5 (90.8 cm) followed by 10 mm depth at Feeks Scale = 2.00 and Feeks Scale = 10.50 (90.4 cm). Whereas, the shortest plant was lowest plant was seen in barani state at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (75 cm).

Spike length (cm)

Different watering/irrigation plans have a significant effect on spike length (Table 2). Longer spike was measured with 25 mm depth at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (9.3 cm) followed by 25 mm depth at Feeks Scale = 2.00 (8.6 cm). Rainfed had the shortest spike length (6.7 cm) at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1.

Chlorophyll contents

No significant differences were obtained for chlorophyll contents. The highest was recorded at 25 mm applied at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (36.3), whereas the lowest was observed in rainfed conditions at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (29.3).

Leaf area (cm^2)

Similarly in leaf area (cm^2) the recorded data was statistically at par, however maximum area was noted in 25 mm applied at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (19.7 cm^2), In rainfed areas at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (14.7 cm^2) produced the short leaf area.

Number of tillers/m^2

The number of tillers/m^2 differed significantly between irrigation plans (Table 2). The more tillers/m^2 was recorded at 25 mm irrigation depth throughout wheat Feeks Scale = 2.00 to 10.5.1 (362 tiller/m^2), followed by 25 mm depth Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (318 tillers/m^2). Wheat Feeks Scale = 2.00 produced the lesser No. of tillers per meter square (176 tillers/m^2).

1000-grain weight (g)

Table 2 data revealed that there were substantial disparities across irrigation plans in terms of thousand grain weight (g) 40.9 g was obtained at 25 mm irrigation depth when applied at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 followed by 25 mm applied at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (37.9 g), whereas lowest was noted in rainfed at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (24.3 g).

Biological yield (kg/ha)

Table 2 data revealed that there were substantial differences in biological yield amongst irrigation strategies. The highest biological yield was obtained with irrigation depth of 25 mm at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (10392 kg/ha) followed by 25 mm depth at Feeks Scale = 2.00 stage (8887 kg/ha). Rainfed site area at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 produced least possible biological mass (3783 kg/ha).

Table 2 Table of means showing impact of various irrigation levels at different phonological stages of wheat (Chakwal-50)

TREATMENTS	**Plant height (cm)**	**Spike length (cm)**	**Chlorophyll contents**	**Leaf area cm^2**	**Tillers/m^2**	**1000-Grain weight**	**Biological yield kg/ha**	**Grain yield kg/ha**	**Harvest index %**
I_1	79.6	7.8^{ab}	31.0	16.1	176^{b}	29.3^{de}	5267^{cde}	2043.7^{ab}	40.9
I_2	87.3	7.9^{ab}	32.0	15.0	206^{b}	27.3^{de}	4368^{de}	1831.7^{b}	42.4
I_3	75.0	6.7^{b}	29.3	14.7	243^{ab}	24.5^{e}	3783^{e}	1592.3^{b}	42.8
I_4	79.8	7.5^{ab}	29.7	16.0	193^{b}	31.4^{cd}	4087^{de}	1704.7^{b}	42.2
I_5	79.2	8.3^{ab}	32.7	18.6	269^{ab}	35.7^{bc}	7395^{abcd}	2662.7^{ab}	36.9
I_6	90.4	8.2^{ab}	34.3	16.4	276^{ab}	35.4^{bc}	5504^{cde}	2482.7^{ab}	44.7
I_7	86.6	8.1^{ab}	33.0	17.4	300^{ab}	36.3^{abc}	6318^{bcde}	2467.7^{ab}	40.4
I_8	90.0	8.5^{ab}	32.3	17.5	305^{ab}	36.4^{abc}	7172^{abcd}	2638.3^{ab}	36.3
I_9	89.4	8.6^{ab}	32.3	16.7	264^{ab}	36.6^{abc}	8887^{ab}	2960.7^{ab}	33.3
I_{10}	89.9	8.1^{ab}	32.0	18.1	269^{ab}	37.5^{ab}	6412^{bcde}	2640.3^{ab}	41.0
I_{11}	88.4	8.4^{ab}	33.3	17.3	318^{ab}	37.9^{ab}	8507_{abc}	3032.3^{a}	35.9
I_{12}	90.8	9.3^{a}	36.3	19.7	362^{a}	40.9^{a}	10392^{a}	3534.3^{a}	34.1
HSD 5%	**N.S**	2.07	**N.S**	**N.S**	154.2	5.04	3351.5	1493.10	**N.S**
p values	**0.2486**	**0.0027**	**0.3801**	**0.8211**	**0.0089**	**0.0005**	**0.0007**	**0.0027**	**0.7717**

Grain yield (kg/ha)

Water supplied through artificial irrigation application significantly enhanced economic yield kg/ha of wheat (Table 2). The depth level of artificially applied water at the rate of 25 mm at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (3534.3 kg/ha) which was followed by 25 mm depth at Feeks Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (3032.3 kg/ha). Grain yield was at bottom at Scale = 2.00, Feeks Scale = 10.50 and Feeks Scale = 10.5.1 (1592.3 kg/ha) under rain dependent conditions.

Harvest index (%)

Maximum HI recorded with 10 mm at wheat Feeks Scale = 2.00 and Feeks Scale = 10.5.1 (44.7%). Lowest HI was recorded in 25 mm at Feeks Scale = 2.00 (33.3%). Harvest index (HI) was statistically at par at different irrigation depths (Table 2). Regression analysis between 1000-grain weight and grain yield kg/ha shown that there was moderate value of logarithmic analysis (0.66%).

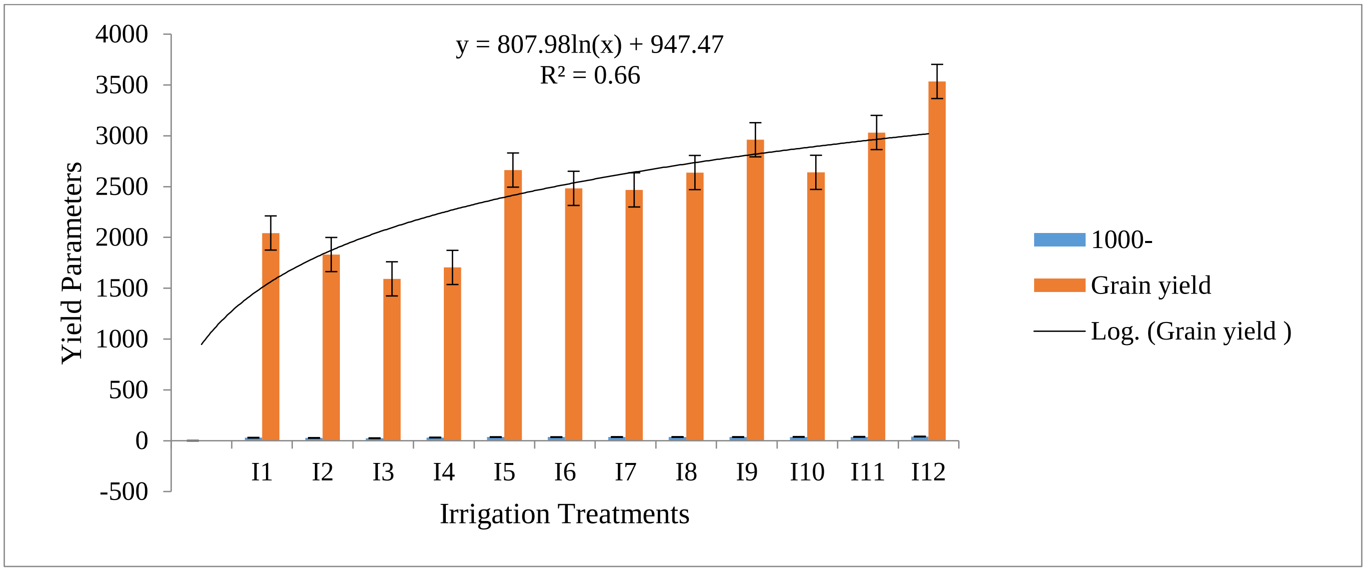

Fig. 4 Regression analysis of 1000 grain weight and grain yield kg/ha at various irrigation depths

Discussion

The current study's findings revealed that moisture stress is one of the primary limiting factors to achieving sustainability in agricultural crop production, particularly in wheat crop. It was discovered that irrigation supply by sprinkler raingun is an excellent method of minimizing the negative effects of water stress on wheat, finally meeting the crop's water requirements. The results of plant height in this trial are in contrast with the conclusion of Montazar (2011) who stated that when the amount of profile stored water grew, plant height increased dramatically. Water stress considerably lowered the height of winter wheat. The drop in winter wheat height was mostly due to lower photosynthesis and osmotic potential (Taiz et al., 2015). The decrease in photosynthesis affects winter wheat growth and development, resulting in a plant height decrease. We discovered that the jointing stage had the greatest influence on winter wheat height of plants, which corresponded to the period of vigorous mitotic cell division. Water stress during the jointing stage is expected to limit plant organ growth, which is determined by the degree of cell division during this phenological stage (Samarah et al., 2009).

The findings of spike length are in contrast with the work of Montazar, 2011 who revealed that due to supplemental irrigation depths there was significant effect on spike length. Moisture stress is known to reduce values for morphological features (shoot length, root length, number of tillers, days to heading, spike length, plant height, and thousand grain weights) as well as alter biological yield (Bayoumi et al., 2008). Moisture stress reduced the amount of chlorophyll *a* and *b* in plants such as beans, chickpeas, and wheat, which was consistent with the results of this experiment (Mathobo et al., 2017). Total chlorophyll concentration falls as drought stress and PEG concentration increase (Guo et al., 2013). Drought stress lowered chlorophyll *b* while increasing the chlorophyll b/a ratio (Ashraf et al., 1994). The leaf area is greatest during the heading period and decreases in different phases. The leaf area reduces during the filling period and rapidly declines with leaf ageing during the maturation period. Continuous stress has a stronger effect on the leaf area of winter wheat, and the leaf area is approximately 30% lower than the typical irrigation supply (Sun et al., 2015). Number of tillers per m^2 data revealed that if no irrigation was available or applied at tillering stage, there was loss in wheat yield traits. Water has a positive relationship with the reproductive phases of the wheat crop. Moisture stress has been shown to lower biomass, tillering ability, grains per spike, and grain size. As a result, the degree and duration of moisture stress affect the total outcome (Siyal et al., 2021). The formation related to 1000-grain weight,

Wajid et al. (2002) reported that varying irrigation depths had a substantial effect on grain weight. Plants close their stomata abruptly in response to drought stress or limited water conditions, resulting in reduced CO_2 fixation, photosynthates and as a result, 1000-grain weight (Yu et al., 2017). The result of biological yield is in line with the study of Montazar (2011) who narrated that supplemental irrigation was used in all three ways to boost grain and biological yields. Daryanto et al. (2017) discovered yield decline in wheat owing to water deficit stress. Drought reduced wheat biomass and yield by 25% and 27.5%, respectively, according to other authors Zhang et al. (2018). According to the investigation, the above ground biological yield fell due to unfavorable conditions (water stress) at the vegetative stage; as a result, the crop became thinner and produced fewer tillers, which decreased the biological yield. Mirbahar et al. (2009) Water deficiency stress is known to have cumulative impacts on wheat crop growth stages, manifested the biomass decline when linked to well water circumstances (Mirbahar et al., 2009).

The results of grain yield is in line with the work of Weiwei et al. (2015) who also narrated that it was significant difference for grain yield at various irrigation regimes. These findings contrast with the findings of Tadayon et al. (2012) who found a significant difference in wheat grain yield at jointing stages when comparing deficit irrigation and full irrigation depths. Higher yields in plots received 25 mm of extra watering throughout the tillering and grain filling phases. Increases in thousand grain weight, plant height, spike length, and the number of tillers per square meter are linked to phases. Irrigation supplementation aided growth and development characteristics, as well as water productivity, which increased agricultural productivity. Water is the elixir of life, and drought reduces grain yield by altering anthesis and grain filling phase. Water stress has a significant impact on wheat anthesis and grain filling. It reduces the crop's development and yield by reducing the crop's water potential, turgor, and stomatal conductance, and ultimately photosynthesis (Bhandari et al., 2021).

The grain production and harvest index decline dramatically as the intensity of the increase in moisture stress (Khalili et al., 2013). The negative correlation of the harvest index may be attributable to a decline in grain and biological yields as a result of less moisture (Kumari and Rana, 2020). The N uptake is fundamental for plant N metabolism and growth and is readily affected by available water in the soil. Generally, soil N cannot be absorbed unless it is present in a soluble form. Therefore, plant N absorption is affected by soil water availability that, in turn, affects the capacity and/or absorption by the plant. Irrigation is a critical management strategy to produce more crop yield (Li et al., 2021b). Irrigation through raingun sprinkler improves the grain yield of wheat by improving the water productivity and also significantly improves the water use efficiency.

Conclusion

Supplemental irrigations, through sprinkler at different phonological growth stages of wheat, which applied small amounts of canal/tube well water applied through irrigation with high efficiency irrigation system SIS, played a critical role in raising water efficiency and economic yield of wheat under barani conditions when 225.3 mm rain at wheat season. When managed at Feeks Scale = 2.00 and Feeks Scale = 10.5.1, with a level of 25 mm irrigation regime yielded the highest grain yield of wheat per acre. As a result of the findings, it can be concluded that if little water is available in rainfed areas, applied as extra water to wheat crop at Feeks Scale = 2.00 and Feeks Scale = 10.5.1, resulting in higher yields (grain and straw), and WUE depending on (soil, varietal, and climatic) conditions in the specific region. Supplemental irrigation may be necessary in areas of Pothowar, Pakistan, if just a little amount of irrigation water is available under rainfed conditions (through sprinklers) at Feeks Scale = 2.00 and Feeks Scale = 10.5.1 might promote growth and development of wheat crop, hence increasing grain productivity. Sprinkler irrigation of wheat produced 18% more yield, while reducing consumption of water to 35% of that used in the traditional irrigation system. Sprinkler irrigation of wheat resulted in a water use efficiency of 5.21 kg of grain per cubic meter of water used compared to 1.38 kg/m^3 in the adjacent flooded basins. This technology is very helpful to improve the WUE of wheat crop at different feeks stages.

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