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Determination of Crop Coefficient of Hybrid Wheat under Arid Climate: A Pot Study

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DETERMINATION OF CROP COEFFICIENT OF HYBRID WHEAT UNDER ARID CLIMATE: A POT STUDY

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ABSTARCT

Climate change increases vulnerabilities for crop productivity in Pakistan. Water crises are increasing with an increase in temperature and change in precipitation patterns due to climate change which ultimately imposed a threat to the food security of the country. Water is indispensable for all plants to complete life cycle as the unavailability of water at critical growth stages drastically affects the development of the plant. The present pot study was conducted for the estimation of crop coefficient of hybrid wheat for irrigation scheduling at Muhammad Nawaz Shareef University of Agriculture, Multan during two growing seasons 2018-19 and 2019-20. In this experiment, three wheat varieties were used were Hybrid-1 (R26-3-1/DH-16), Hybrid-2(AR 7-5 / ZWB-14), and Galaxy-2013 as treatment. The soil moisture content was maintained between 50 to 100 % available water content (AWC) during both growing seasons. The crop coefficient (Kc) and actual evapotranspiration (Et_a) were maximum in galaxy-13 and minimum in hybrid wheat. The grain yield for Hybrid-1, Hybrid-2, and galaxy-13 was 1, 1.5, and 0.6 g plant^{-1}, respectively while the straw output was 4.8, 4.3, and 3 g plant^{-1}, respectively. The harvest index for Hybrid-1, Hybrid-2, and galaxy-13 were 20, 34, and 20% respectively. The water use efficiency (WUE) for Hybrid-1, Hybrid-2, and galaxy-13 was 0.2. 0.3 and 0.1 g plant^{-1}mm^{-1}, respectively. The Hybrid-1 and Hybrid-2 produced more grain yield, straw yield, more spikes, and more grains per spikes and showed more water use efficiency with short plant height as compared to galaxy-13. The results of the study revealed that Hybrid-2 is more water-efficient with low water requirement and it was followed by Hybrid-1. The growing of Hybrid-2 will enhance the wheat yield to meet the food requirements of the increasing population under the climate change scenario with less water.

Keywords: Hybrid wheat, harvest index, water use efficiency, crop water requirement, yield.

INTRODUCTION

Wheat is one of the very important cereal crops in many countries. About 20 % of total food calories are provided by wheat (Giraldo et al., 2019). The wheat contributes 1.7 % to the total Gross Domestic Product (GDP) and 9.6 % additional in agriculture. The area under the cultivation of wheat crop was 8,734 thousand hectares. The production of wheat is 25.5 million tonnes. The major limitations in the wheat production technology are fall in cultivating area, extended and late sugarcane crushing season, water scarcity, weed, smog, and fog in the country (Anonymous, 2018). Wheat water requirements varied with location and time of the season. Stem elongation and grain filling growth stages of wheat are very water sensitive. These stages required the highest and frequent irrigation than other stages (Memon et al., 2021; Dingre and Gorantiwar, 2021). Water is important for physiological requirements as well as for nutrients management and other management practices. The current situation, climate change, and water shortage play an important role in reducing wheat production. Although domestic, industrial, and agriculture sectors compete for water due to water scarcity. There is also a threat to future food security due to the shrinkage of natural water resources. Food shortage will be 70 million tons during 2025 (Sarwar and Qureshi, 2011; Ali et al., 2019; Muzammil *et al*., 2020). The availability of water for human use is 9,000-14,000 cubic kilometers. The annual water availability will decrease by 1,700 cubic meters per person. Developing countries consume the largest amount of water (90 %) but their contribution to the country's economy is low due to the absence of efficient management systems and water infrastructure (Doungmanee, 2016). The per capita storage capacity of water is less than 150 m^3 in Pakistan while for the US and Australia is 5000 m^3 and for China is 2200 m^3 (Rasul et al., 2021).

The time and amount of irrigation scheduling is the most important factor that affects the crop yield and water use efficiency (WUE). Irrigation scheduling is important in water shortage conditions to improve WUE. The waterlogging soils and reducing yields, low fertilizer use efficiency, and drainage are results of over-irrigation ((Gu et al., 2017). The use of water is at the lowest when the quantity of water supplied is just like the consumptive use and requirement of leaching (Gu et al., 2017). In Pakistan, Farmers irrigate their fields with the aim that more irrigation results in higher yield. Lack of farmer's knowledge about the requirement of crop water is the most important limitation for correct irrigation scheduling. Over-irrigation results in water loss, nutrients leaching out of the root zone and ultimately less crop productivity (Latif et al., 2016; Ashraf *et al*., 2018). There is a need to adopt new technologies, practices, and methods of irrigation to conserve water. Yield can be increased by enlarging irrigated area with the same quantity of available water. One of these practices is deficit irrigation (DI). DI decreased the rate of evapotranspiration and good water management practice under a shortage of water (Nikolaou et al., 2020). Actual crop evapotranspiration reduced 2-27 % by regulated deficit irrigation (Yang et al., 2017). There is a need to enhance the production per unit of water depletion as compared to production per unit area by changing the irrigation system to a highly efficient irrigation system. This will support the farmers to compete with the water shortage (Sarwar and Qureshi, 2011; Nikolaou et al., 2020). Hybrids varieties must show enhanced yield production, yield responsiveness and yield stability crosswise a wide array of production environments. Agriculture production has been studying hybrid wheat since 1981 and has developed pure line release history since 1978 (Iwańska et al., 2020). The ratio of maximum evapotranspiration of crop to reference evapotranspiration of crop is known as crop coefficient. The value of crop coefficient for wheat crop during the reproductivity cycle is 1 otherwise, it is less than 1. The crop coefficient value is minimum at early and maturity stage of wheat crop. The crop water consumption has linear relation with the amount of water evaporated as of open water surface (Salama et al., 2015). Evapotranspiration is affected by water contents of soil near to the surface and crop cover percentage. The soil water contents decreased with the increased of the percentage of crop cover. The transpiration increased and evaporation decreased with the growing season. This change in transpiration and evaporation is the result of shading of soil with the increase in crop cover percentage and turbulent air mixing near the surface of the soil (Bhatt and Hossain, 2019; Hatfield and Dold, 2019)

The Food and Agriculture Organization (FAO) of the United Nations established a particular standard procedure for the studies of irrigation scheduling by estimation of water requirement of crop in the 1970s. The reference crop is defined as a hypothetical crop with 0.12 m height, 70 sm surface resistance, 0.23 albedo and resembling the evaporation of sufficiently irrigated and vigorously growing green grass of uniform height (Ewaid et al., 2019). Keeping in view the above facts, the objectives of this research were (i) to determine the value of crop coefficient (K_c) for wheat under arid climate, and (ii) determine the actual evapotranspiration at different growth stages for wheat.

MATERIALS AND METHODS

Experimental Site

The pot study was carried out during the rabbi season of the year 2018 and 2019 at the research area of Muhammad Nawaz Sharif University of Agriculture, Multan Pakistan at 30°9′54.79″N and 71°29′48.72″E.

The climate of the Study Area

The summer temperature of Multan is 52-50 ^{O}C and it turns as low as -1^{o}C in winter. The average precipitation is 127-186 mm. The area is alluvial plain and flat around the Multan city. The land is very fertile and plain in District Multan. However, during the monsoon season, the area near to Chenab River is flooded. The major crops are cotton, wheat, and sugarcane. The major fruits are mangoes and citrus.

Experimental Details

The pot experiment was conducted on the research Farm of MNS-University of Agriculture, Multan. Three wheat cultivars were used as treatment and soil moisture was maintained between 50 to 100 % AWC throughout the growing seasons during 2018-19 and 2019-20. The complete Randomized Design (CRD) was used with three replications. The varieties used were two was hybrid named as Hybrid-1 and Hybrid-2 and one as local Galaxy -13 as control.

Treatments

Three (3) wheat varieties were selected for the pot experiment as Treatments. In these three varieties, two (2) were hybrid cultivar and one (1) was a local cultivar of wheat. The varieties were: Hybrid-1 (R26-3-1/ DH-16), Hybrid-2 (AR 7-5 / ZWB-14) and Galaxy-2013.

Cultural Operations

All cultural operations were carried out at all the appropriate growth stages throughout the growing season. These cultural operations with appropriate headings are described as follows:

Pots Preparation and Sowing

The soil was mixed thoroughly before filling the pots. The soil was analyzed for physical and chemical properties (Table-3.1). Pots having the capacity of 2 kg soil were used. Plastic bags were used before filling the Pots to control the drainage. Pots were filled after weighing each pot individually. Before filling all the pots, the soil was sieved. The soil was level in each pot before sowing. Three seed was sown in each pot and after germination one plant were maintained per pot.

Fertilizer Application

The wheat crop was fertilized uniformly with recommended dose of 120-85-85 kg NPK per ha. Half the quantity of nitrogen was applied before sowing of seed as basal dose. The full dose of potash and phosphorus were applied before sowing of the seed as source of basal dose.

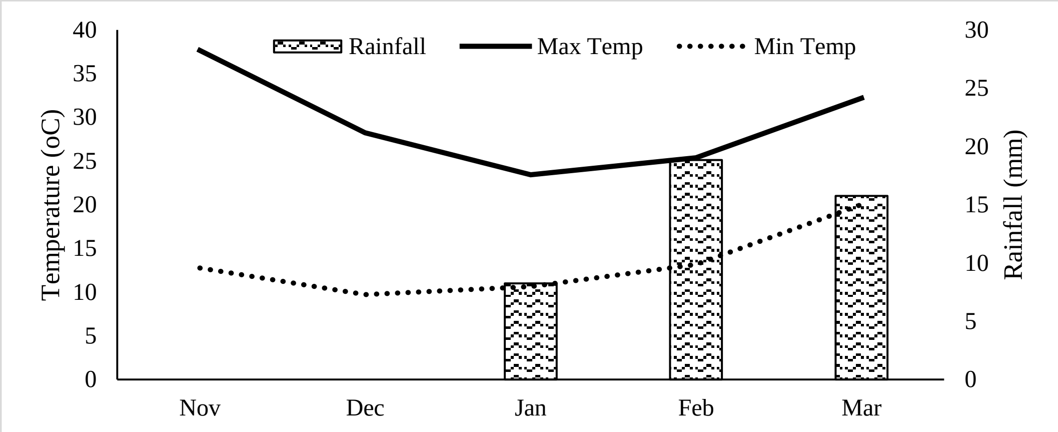

Figure 1: Monthly average climatic data regarding rainfall and temperature (Maximum and minimum) of two growing seasons.

The remaining dose of nitrogen was applied at initiation of crown root.

Irrigation

Irrigation was applied according to the soil available water content which was maintained between 50 to 100 % AWC. Water contents of soil were measured gravimetrically with the help of using digital weighing balance with weighing capacity about 200-35000 g on daily basis throughout the growing season. The depleted soil moisture content was replenished with irrigation up to the limit of AWC in all cultivars.

Plant Growth and Yield Parameters

The following plant growth and yield parameters were recorded throughout experiment.

Leaf Area and Leaf Area Index (Lai)

Leaf area was determined by using the meter scale. Leaf length and leaf width were measured at 15 days intervals (DAS). The following equation was used to determine the leaf area

Leaf area = Leaf length (L) × leaf width (W) × wheat factor (A) ………… (1)

Where: L = length of leaf (cm), W= width of leaf (cm), and A = factor with 0.85 value for wheat

After measuring the area of leaf following equation was used for calculation of leaf area index (LAI) (Ahmad et al., 2015).

$$LAI = \frac{Leaf\ Area\ (cm^2)}{Total\ Ground\ Area\ (cm^2)} \quad (2)$$

Plant Height (cm)

Height of plants was also recorded 15 days interval. The height of plants was measured with the help of meter-scale (cm) throughout crop growth season.

Crop Yield

Wheat was harvested on 28 March 2019 and 5 April 2020. After harvesting the wheat crop, the stem, leaves, and spikes were separated. These were primarily air-dried under a shade. The yield of wheat grains per pot was noted from each experimental pot. The actual grain quantity was recorded by weighing each pot plant of each variety separately.

Harvest Index (%)

The fraction of economic yield (grain) to biological yield (grain and straw) per pot is known as harvest index (HI). The following formula is used for calculation of harvest index (Dai et al., 2016).

$$\text{HI (\%)} = \left(\frac{\text{Economic Yield (g pot}^{-1})}{\text{Biological Yield (g pot}^{-1})}\right) * 100 \cdots\cdots\cdots (3)$$

Crop Water Requirement

Water balance equation was used to determine the Crop water requirement that was actual evapotranspiration . It was determined by using soil water contents measured on daily basis. The water balance equation is (Imran *et al*., 2015).

$$ET_a = (I + P) - \Delta S \cdots\cdots\cdots (4)$$

Where:

ET_a = actual evapotranspiration (mm), I = irrigation (mm), P = rainfall (mm) and ΔS = change in root zone storage (mm) as pots are covered with plastic bags at bottom, so there is no drainage.

Crop Coefficient (Kc)

The crop coefficient was calculated by ratio of evapotranspiration to reference evapotranspiration (Allen, 2000).

$$K_c = \frac{ET_a}{ET_0} \cdots\cdots\cdots (5)$$

Where: ET_a = actual evapotranspiration

ET_0 = potential evapotranspiration

Reference Evapotranspiration

Penman-Monteith equation was used to estimate the daily reference evapotranspiration (ET_o) for the hypothetical crop (Allen et al., 1998).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean}+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \cdots\cdots\cdots (6)$$

Where:

ET_0 = reference/potential evapotranspiration (mm/day)

R_n = net radiation at the surface of crop (M $jm^{-2}day^{-1}$)

G = heat flux density of soil (M $jm^{-2}day^{-1}$)

γ = psychometric constant (k pa °C^{-1})

T_{mean} = daily average temperature (2 m height (°$_C$))

μ_2 = speed of wind at 2 m height (ms^{-1})

e_s - e_a= for the saturation vapour pressure deficit (kPa)

e_a = actual vapour pressure (kPa)

e_s = saturation vapour pressure (kPa)

Δ =vapour pressure curve slop (k pa °C^{-1}).

Water Use Efficiency (g pot $^{-1}$mm)

Water use efficiency (WUE) was determined with the ratio of economic grain yield to actual evapotranspiration (Hussain et al., 1995).

$$WUE = \frac{GY}{ET_a} \cdots\cdots\cdots (7)$$

Where: WUE = water use efficiency for grain yield (g pot^{-1} mm^{-1}), GY = grain yield (g pot $^{-1}$), and ET_a = actual evapotranspiration (mm)

Soil Sampling and Analysis

The soil was collected for filling the pots and analyzed for Pre -sowing Physico-chemical properties of the soil as follows:

Statistical Design

The data collected from both growing seasons and pooled than average of both seasons was subjected to analysis of variance (ANOVA) and means were compared by least significant difference (LSD) test at 5% level of significance by using statical software Statistix 8.1 (Steel and Torrie, 1980).

Table 1: Physical and Chemical Characteristics of Soil.

Parameters	Units	Values
Texture class		clay loam
Permanent wilting point	-	0.17
Field capacity	-	0.32
Saturation	-	0.43
Available water contents	-	0.15
pH		8.15
Electrical conductivity (EC)	dsm^{-1}	3.3
Organic matter	%	1.10

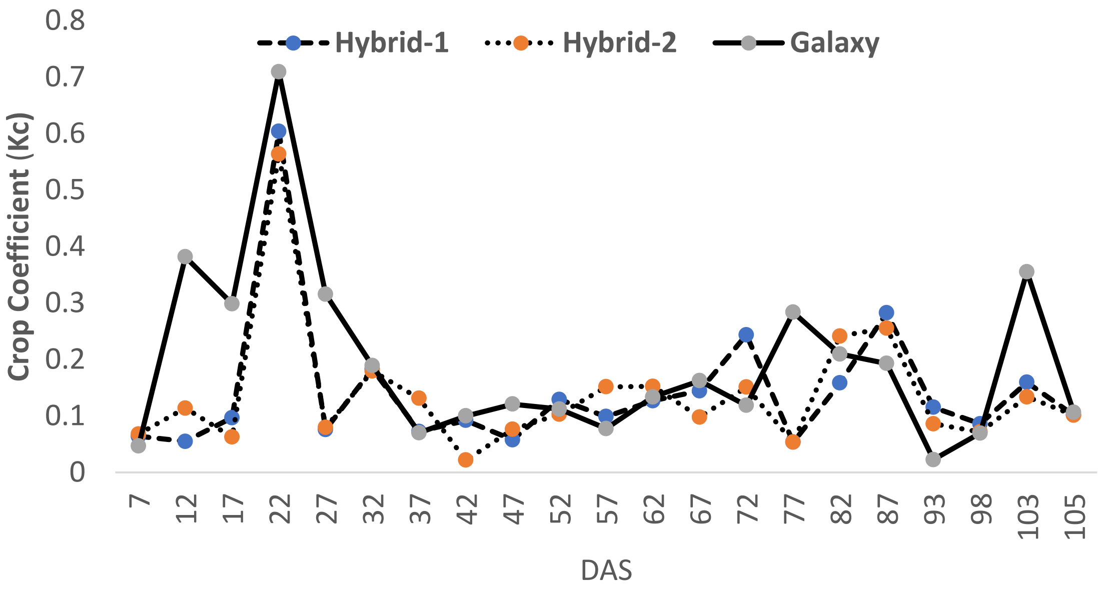

Figure 2: Determination of Kc of different wheat varieties.

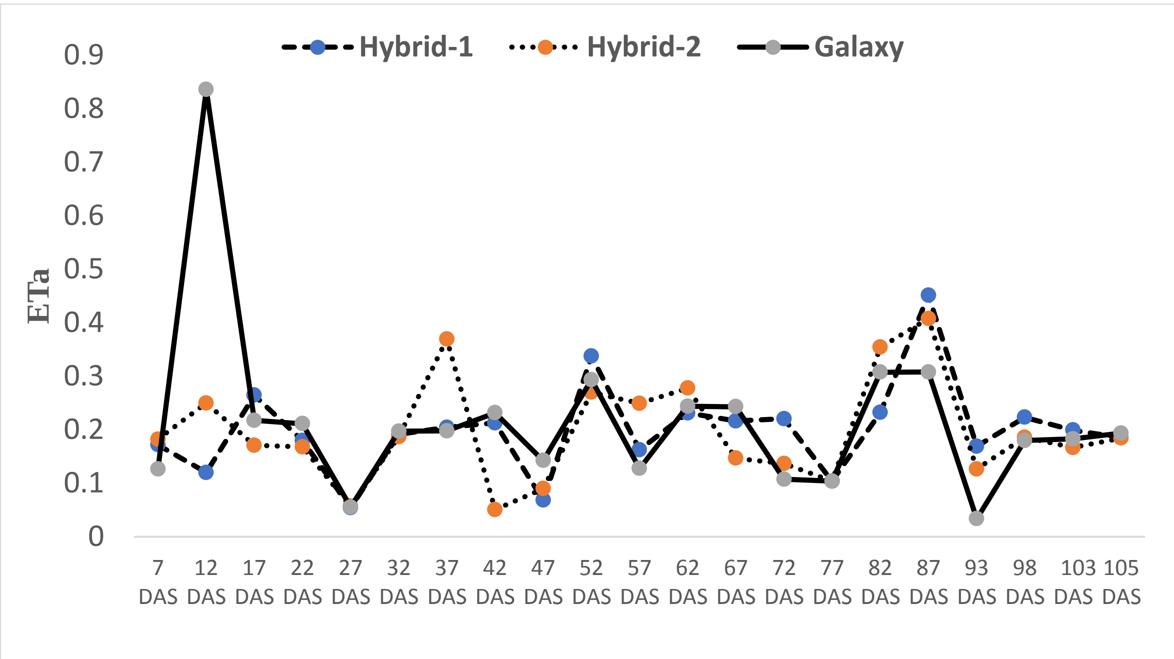

Figure 3: Determination of actual evapotranspiration (ETa) of different wheat varieties.

RESULTS AND DISCUSSION

Determination of Kc of Different Wheat Varieties

Kc values varied seasonally throughout the crop growth period. The crop coefficient has strong relationship with ET_a. In the starting month of crop growth, the crop has the lowest Kc. It was observed that Kc increased gradually with crop growth stages. At the stage of grain formation Kc was attained its peak value. The significant variation was observed in the Kc of different wheat varieties. During the research experiment, no variation in Kc values were observed on crop coefficient at the initial growth stage of the crop. At the heading point, the Kc was highest because the crop was at the full vegetative cover. Galaxy-13 was observed the highest Kc while Hybrid-2 was observed the lowest Kc at heading stage.

The values of Kc were increased from germination stage to heading stage because of increase in crop growth parameters such as plant height and LAI which strongly effect the Kc values. While after the heading stage the values of crop coefficient were showed decline trend due to crop maturity. The minimum Kc value of local wheat Galaxy-13 might be due to the highest LAI and plant height. Our results correlated with Marin et al., (2016), they reported that crop coefficient also varied by seasons, location plant height, and others management. Hong et al., (2017) also examined the effect of Kc on different growth stages of sunflower under stress. They suggested the Kc values for rapid growth (Kc_2), middle (Kc_3), and mature (Kc_4) stages were 0.659, 1.156, and 0.324, respectively. Similarly, Ko et al., (2009) calculated similar Kc results. They reported that throughout the growing period the kc varied from 0.1 to 1.7.

Determination of ETa of Different Wheat Varieties

Daily evapotranspiration from the date of planting to harvesting indicates that evapotranspiration was low initially of Hybrid wheat and increased gradually. It was decreased toward harvest due to the physiological maturity of the crop. Results showed a significant difference on ETa of different wheat cultivars. The water requirement of wheat decreased at maturity. The ETa was low in November and December because of the low crop canopy at the germination stage. The ETa was high in March because of higher temperature and crop maturity. The higher rate of ETa was because of more temperature, wind speed and low moisture contents. The low rate of evapotranspiration of hybrid wheat might be due to narrow leaf and low plant height as compared to Galaxy-13. The local wheat Galaxy-13 showed maximum ETa and Hybrid-1 showed minimum ETa. The minimum ETa of hybrid wheat due to its less surface area and its good genetic potential for water storage.

Our results are in contrast with Allen, (2000). The evapotranspiration is significant of the water balance study that determined the schedules of irrigation. It also plays an important role in water efficiency and is assessed by a Kc plus reference evapotranspiration method. Same results were also observed in Abdelkhalek et al., (2015) study.

Plant Height of Different Wheat Varieties

It was observed that plant height of the three wheat varieties was significantly affected by genetic characteristics. The data regarding plant height of three wheat varieties was recorded on 15, 30, 45, 45, 60, 75, 90 and 105 DAS. Galaxy-13 wheat variety was highest plant height as compared to hybrid wheat varieties Hybrid-1 and Hybrid-2 at different growth stages. The hybrid wheat recorded shorter height of plant than the local wheat

Galaxy-13. The short plant height is also due to its genetic hysteresis. This shorter plant height is highly responsive to water use efficiency, yield and nutrients use efficiency. The results of this pot study are in line with Aslam et al. (2014). The study revealed that hybrids varieties have shorter plants while inbred varieties have taller plants in his experiment.

The Effect of Irrigation Scheduling on Leaf Area Index (LAI) of Different Varieties of Wheat

The irrigation scheduling showed significant effects on LAI of different wheat varieties. The data regarding of leaf area index (LAI) of three wheat varieties was recorded on 15, 30, 45, 60, 75, 90 and 105 days after sowing (DAS). Galaxy-13 wheat variety showed highest LAI than hybrid wheat varieties Hybrid-1 and Hybrid-2 at different growth stages. Hybrid-2 showed highest leaf area index (LAI) than Hybrid-1 throughout the growing season. It was recorded that LAI of Hybrid-1, Hybrid-2 and Galaxy-13 at 15 DAS was 0.30, 0.32 and 0.28 respectively. The height LAI was recorded at 75DAS in all cultivars and then a slight decline was observed. The LAI of Hybrid-1, Hybrid-2 and Galaxy-13 at 75 DAS was 0.99, 0.98 and 0.75, respectively. The similar trend of LAI of hybrid-1, hybrid-2 and galaxy in ascending order was observed after 30, 45, 60, 90 and 105 DAS.

Our study results are in contrast with (Bashir et al., 2017).

Grain yield of different varieties of wheat

The significant difference in yield was observed in different wheat cultivars. It was recorded that different wheat varieties have the different number of spikes and grain numbers and weight. The results showed that Hybrid-2 has maximum grain yield and Galaxy-13 showed lowest grain yield. The grain yield of Hybrid-1, Hybrid-2 and galaxy was 1, 1.5 and 0.6 g pot^{-1}, respectively. The yield of hybrid wheat was high due to more numbers of spike and ability of efficient water use. It was also recorded that number of grains were also maximum in Hybrid-1 and Hybrid-2 as compared to Galaxy-13. The maximum crop yield of hybrid might be due to its shorter height and its resistance to lodging. The highest grain yield of hybrid wheat was due to its highest genetic potential for crop yield and efficient use of water.

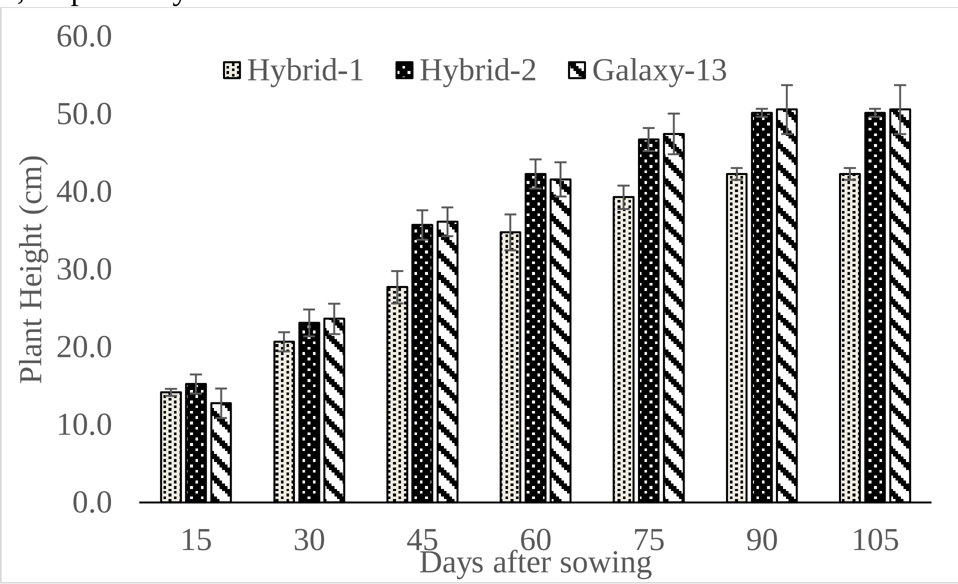

Figure 4: Plant height of different varieties of wheat.

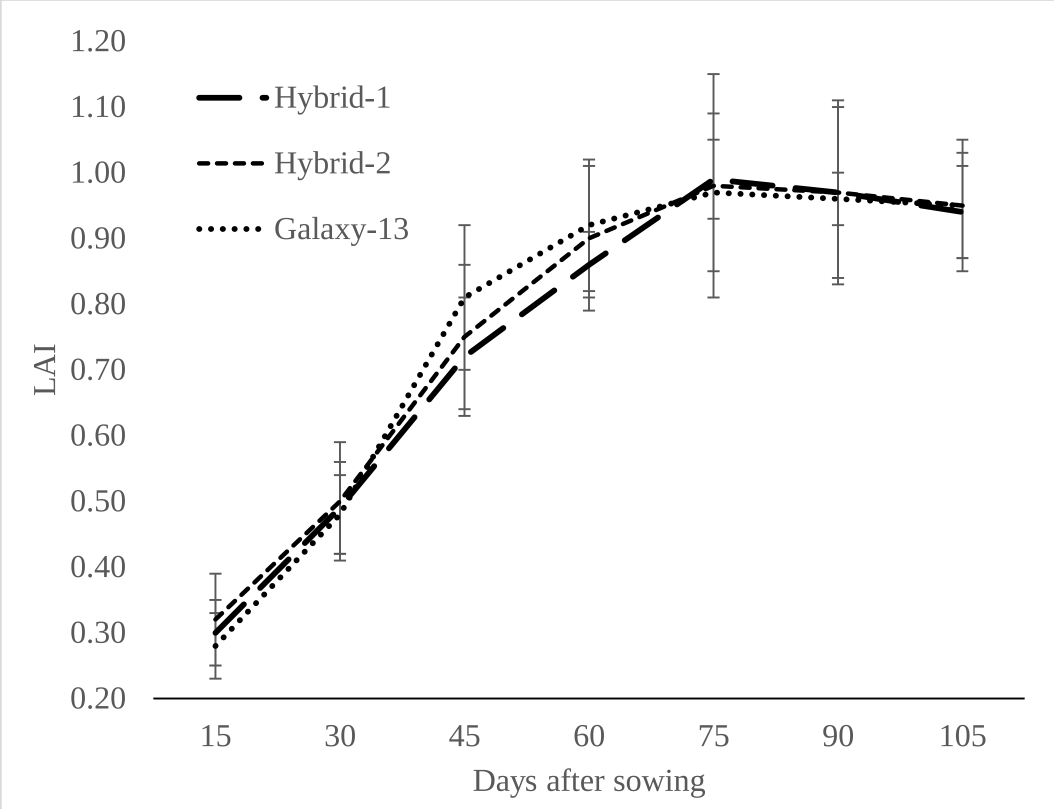

Figure 5: Leaf area index (LAI) of different varieties of wheat

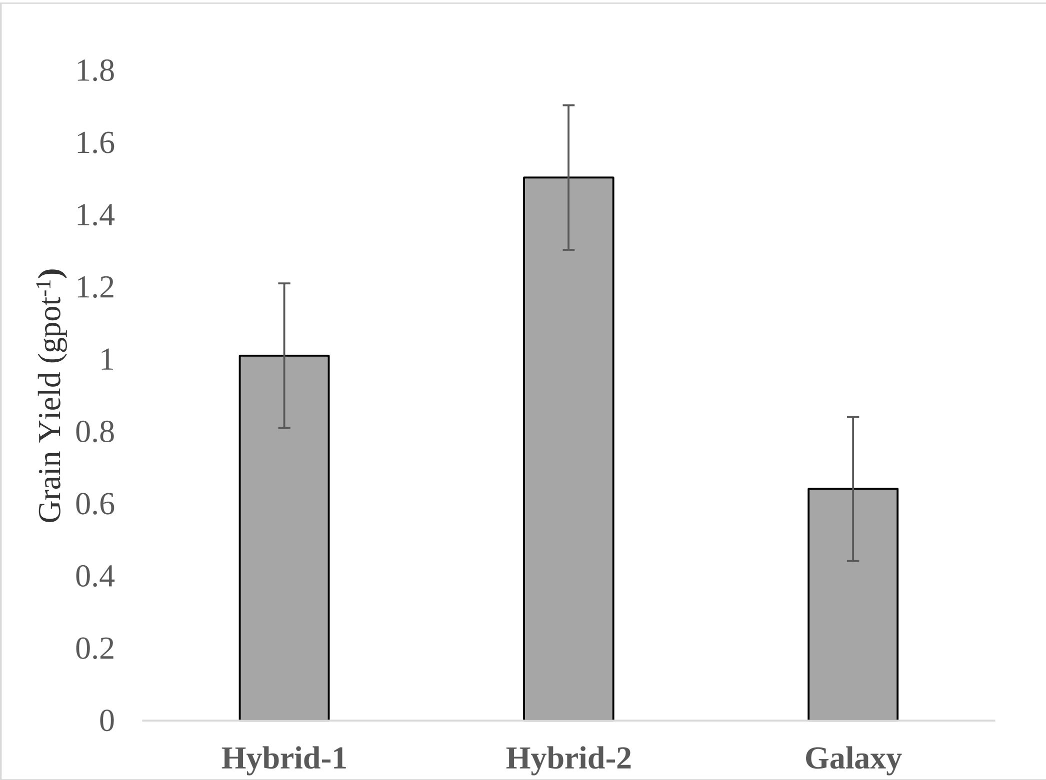

Figure 6:. Grain yield of different varieties of wheat

This study results contrasted with Kazemeini and Edalat (2011) who observed that at all growth stages full irrigation has a maximum crop yield of about 4333 kg ha^{-1} and a minimum crop yield of about 1,377 kg ha^{-1} was observed at 50 % level of irrigation.

Harvest Index (%) of Different Wheat Varieties

The significant difference was observed in Harvest Index (HI) of different wheat varieties. The harvest index of hybrid wheat was more than the local wheat Galaxy-13. The maximum HI was observed in Hybrid-2 and the minimum HI was observed in the local wheat Galaxy-13. The HI of Hybrid-1, Hybrid-2 and Galaxy-13 was 17.5, 11.5 and 20.7 %, respectively. The hybrid wheat utilized the irrigation water more efficiently than the galaxy wheat. So, the same quantity of water was not a good solution for improving growth and yield of wheat crops. Each cultivar has a set of specific crop coefficient that will predict water use for different crops for different growth stages. So, these results were help full for irrigation scheduling which ultimately improved tillers and grains quantity, grain protein, HI and grain production increased 20.58 %, 26.07 %, 3.31 %,16.71 % and 42.72 % by irrigation scheduling (Ngwako and Mashiqa, 2013).

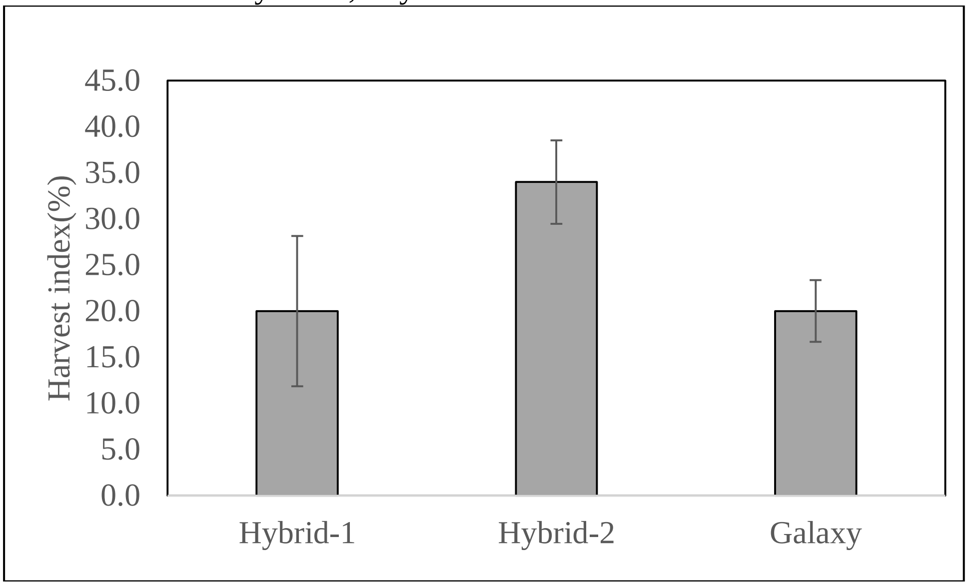

Figure 7: Harvest index of different varieties of wheat.

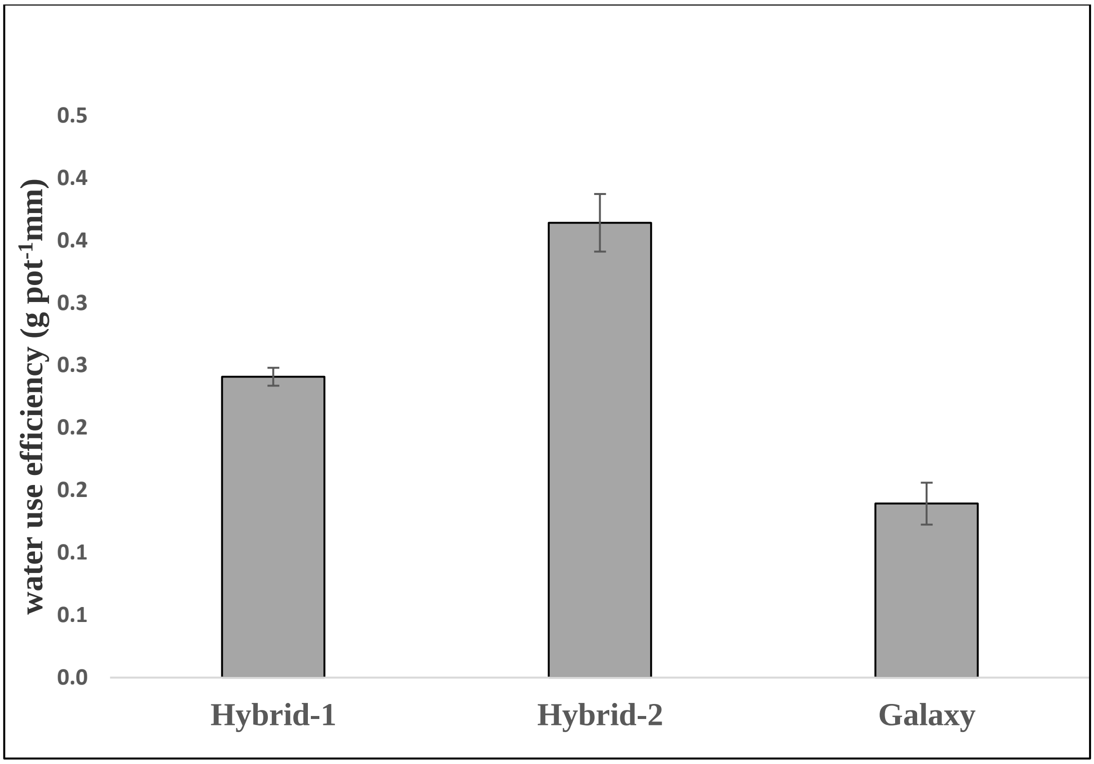

Figure 8: Effects of irrigation on water use efficiency (WUE) of different varieties of wheat

Effects of Irrigation Scheduling on Water Use Efficiency (WUE) of Different Varieties of Wheat

It was recorded that WUE was influenced by irrigation scheduling. The highest WUE was observed in hybrid-2 while the lowest WUE was observed in Galaxy-13. The average WUE of Hybrid-1, Hybrid-2 and Galaxy-13 were 0.2, 0.3 and 0.1 g pot^{-1} mm, respectively. A linear relation was observed between the efficiency of water, grain and straw yield of different wheat varieties. The Hybrid-2 was observed the highest grain yield with the highest water use efficiency while the Galaxy-13 showed the lowest grain and straw yield with the lowest WUE.

This study results agreed with Xu et al. (2016) reported that the highest WUE was observed in the limited-irrigation treatment (60 mm water applied at elongation), achieving a relatively high grain yield, whereas sufficient irrigation (a total of 180 mm water applied) increased grain yield but decreased WUE. Similarly, WUE can be enhanced by improving the irrigation scheduling (Dabach et al., 2013)

CONCLUSION

In present study, the Kc and ET_a were maximum in galaxy-13 and minimum in hybrid wheat varieties. The Hybrid-1 and Hybrid-2 showed more grain yield, more grains per spikes and water use efficiency with short plant height as compared to Galaxy-13. The time and amount of irrigation scheduling is the most important factor that affects the crop yield and irrigation efficiencies. The irrigation scheduling is important in water shortage conditions and soil conditions which restrict root development and movement of water. The use of water is at the lowest when the quantity of water supplied is just alike to the consumptive use and requirement of leaching. Lack of farmer's knowledge about the requirement of crop water is the most important limitation for correct irrigation scheduling. So, hybrid wheat has more potential for efficient use of water. Under harsh environmental conditions, hybrid wheat is very helpful to enhance grain productivity, straw productivity, and yield stability than local wheat. Hybrid wheat is also advantageous to agronomic, economic, environmental, and technological aspects for wheat production and cultivation. The Kc values for Hybrid verities are available now for irrigation scheduling and precise application of water.

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CONFLICT OF INTEREST:

None

AUTHOR'S CONTRIBUTION:

Saba Wajid, Muhammad Imran, Hafiz Shahzad Ahmad, Muhammad Zeeshan Gulzar, Tanveer-Ul-Haq and Abdul Ghaffar designed and conducted experiment. Muhammad Imran, Tanveer-ul- Haq and Abdul Ghaffar supervised the experiment. Sarmad Farogh Arshhad and Kashif Bashir prepared the initial draft. Zulqarnain Khan and Hasan Riaz reviewed and finalized the article.

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