Estimation of the water productivity of different varieties of wheat and rice in the context of agronomic, physiological and nutritional attributes

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Abstract: Water shortage is a global concern, it also poses a particularly severe threat in Pakistan. It is estimated that over 60% of irrigation water is not efficiently applied or not efficiently utilized by crop depending upon genetic variability. The pot study was conducted to evaluate the water efficiency of various wheat varieties (Millat 2011, Galaxy 2013, Faisalabad 2008, and Gandum 1) and rice varieties (Punjab Basmati, Chenab Basmati, B-515, and PS-2) based on their photosynthetic efficiency and nutritional quality by measuring their protein and chlorophyll contents. The highest concentrations of protein and chlorophyll were observed in plants of both crops that were watered and cultivated with 50 mL of water. For wheat, the greatest leaf length (cm), net assimilation rate [g/(d·m²)], and photosynthetic efficiency were achieved when 80 mL of water was applied. Similarly, rice varieties (Punjab Basmati, Chenab Basmati, B-515, and PS-2) exhibited the highest photosynthetic efficiency, leaf length, net assimilation rate, and chlorophyll content when grown with 80 mL of water. Therefore, a conservative cultivation of wheat and rice is possible by selecting efficient variety and by improving technological approach of water saving through irrigation level and wise scheduling. The judicious use of water not only limit losses but also improve the productivity particularly in scenario of water scarcity.

Keywords: water productiviy, wheat, rice, agronomy, physiology, nutrition
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1 Introduction

In Pakistan, agriculture relies not only on rainfall but also on water sourced from melting snow and ice, as well as subsurface water. Many agricultural regions are irrigated when water from melting ice and snow reaches dams, rivers, and canals[1] However, water scarcity poses a significant environmental challenge for agriculture worldwide. One of the primary objectives of plant breeding is to enhance the crop yield under drought condition[2].

Wheat (*Triticum aestivum* L.) is one of the major crops and occupies an essential position in agricultural production, providing around 20% of the calories and protein in human diet. Global wheat production is approximately 761 Mt in 2020. The scarcity of water and vulnerability to drought in context to current climatic shift create variations in the quantity of available water for both irrigated and rain-fed agricultural land, resulting in changes in annual wheat output[3].

Rice crop is synonymous with sustenance. This staple crop is a cornerstone of the nation's food security and serves as the primary source of income for countless rural families. Cultivated rice fields under water contribute significantly to methane release, and nitrogen-based fertilizers emit nitrous oxide. Both gases are potent contributors to the greenhouse effect and global warming[4]. Conversely, climatic shifts such as rising temperatures, changes in precipitation patterns, and increasing sea levels can profoundly impact rice cultivation[5].

Elevating temperatures in tropical regions may reduce rice harvests, and unpredictable rainfall patterns increase the risk of extreme weather events like floods and drought, which can adversely affect rice yields[6]. The process of rice transplanting is known for being water-intensive, labor-intensive, and costly, involving as significant effort in nursery maintenance, seedling uprooting, and planting. The peak season for transplanting often sees a shortage of labor, unpredictable irrigation water supply, dwindling groundwater resources, and rising costs of production, prompting the need for an alternative to traditional puddled transplanting methods[7]. Rice cultivation is deeply intertwined with both water and land management, making it essential to manage rice ecosystems judiciously to safeguard the environment while also boosting the rice productivity to satisfy the increasing demand[8]. In the Indo-Gangetic Plains, the rice-wheat cropping system has experienced a plateau or decline in yields over the past two decades. Addressing this issue requires a balanced approach that enhances both productivity and profitability, while simultaneously preserving

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and improving the environmental quality that underpins agricultural production. One such, alternative method is dry direct-seeded rice, which is shown to require less water and labor[9].

Photosynthesis, a vital physio-biochemical process, sustains life on Earth. Water and carbon dioxide serve as the raw materials for this process. During photosynthesis, plants produce countless organic compounds[10]. After carbohydrates are formed through photosynthesis, the oxidation of these organic compounds releases energy, which other organisms consume to maintain their metabolism and homeostasis[11]. To address water scarcity, innovative irrigation techniques must be developed. Adopting effective irrigation water management systems is crucial. For instance, rice cultivation, which often occurs in flooded environments, demands a substantial amount of water. Rice typically requires more than twice of the water needed for maize or wheat. Globally, rice is grown on 160 million hectares (Mhm^2) and accounts for 35%-45% of the world's irrigation water usage[12].

Modern irrigation management employs water-saving technologies to reduce consumption without compromising yield[13]. Deficit irrigation offers many advantages like enhanced irrigation efficiency, lower irrigation costs, and optimized water utilization, considering its opportunity cost[14].

The irrigated rice-wheat agricultural system faces challenges related to the declining water quality and diminishing resource availability. In response, an experiment was conducted, applying controlled amounts of water to wheat and rice to assess the impact on both crops productivity in term of photosynthetic efficiency and protein contents under various irrigation levels[15].

2 Materials and methods

In current study, the water productivity of various locally available wheat and rice varieties was assessed. Additionally, the nutritive values of leaves from these wheat and rice plants were also considered.

The experiment was conducted using a randomized complete block design, employing a factorial layout, and replicating the study four times. On May 10, 2022, rice seeds were sown in soil-filled earthen pots measuring 45 cm×30 cm. These pots were placed in a net house, where they were exposed to the natural environmental conditions. An analysis of the physicochemical properties of the experimental soil was carried out (Table 1). Initially, each pot received ten seeds, but three weeks after seedling emergence, the number of seedlings per pot was reduced to five. The recommended NPK fertilizer doses of 160, 100, and 70 kg/hm² were applied based on the soil weight. The entire quantity of phosphate, potash, and zinc, along with half of the nitrogen dose, was applied as the basal dose, while the remaining half of the nitrogen dose was administered during the tillering stage.

Table 1 Physio-chemical properties analyzed in soil before filling of pot for experiment

Characteristics	Textural class	pH	EC/dS·m^{-1}	Organic matter/%	Sand/%	Silt/%	Clay/%	N/%	P/mg·kg^{-1}	K/mg·kg^{-1}	Na/mmol·g^{-1}
Value	Sandy loam	8	0.3	0.8	40	25	45	0.04	7	100	5×10^{-3}

2.1 Details of experimental units

2.1.1 Wheat Experiment

Seeds of four different wheat varieties: Faisalabad 2008, Millat 2011, Galaxy 2013, and Gandum 1 were planted during first week of December 2022. The irrigations were scheduled as: no water, 40 mL, 50 mL, 60 mL, 70 mL, 80 mL, 90 mL, and 100 mL. The objective was to estimate the water productivity of wheat for each variety.

2.1.2 Rice varieties

Seeds of various rice varieties: Punjab Basmati, Chenab Basmati, B-515, and PS-2 were planted during the last week of May 2023. Similar to wheat, each rice variety was irrigated with varying amounts of water: 50 mL, 60 mL, 70 mL, 80 mL, 100 mL, and standing water. The objective was to determine the water productivity of rice for each variety.

2.2 Observations

To evaluate the nutritive values of leaves (specifically protein and chlorophyll concentration), the plants were exposed to different water levels. Leaves were selected for analysis because they play a crucial role in both wheat and rice plants.

2.2.1 Leaf length

Samples were collected from each experiment unit and leaf length (cm) was measured with the help of measurement tape after 60 days after sowing.

2.2.2 Net assimilation rate

Leaf samples from each experimental unit were collected after 30 days of sowing and 60 days of sowing for leaf area, fresh and dry weight. The leaf area of same samples was measured by scanner (Model: Aficio MP 7502; Ricoh, Tokyo, Japan).

Fresh weight was computed with the help of electrical balance (ML 204; Mettler Toledo Company, Greifensee, Switzerland; measurement accuracy 0.0001 g) and subsequently dried in oven (model: XMTD-8222; Jinghong Experimental Equipment Co., Ltd., Shanghai, China) at 105°C for 2 h and afterward continue drying at 80°C till the constant weight. These values were used in following Equation (1) for recording net assimilation rate (NAR)[16].

$$\text{NAR} = \frac{\log L_2 - \log L_1}{T_2 - T_1} \times \frac{W_2 - W_1}{L_2 - L_1} \tag{1}$$

where, L_2 is the final leaf area after 60 days of sowing; L_1 is the initial leaf area after 30 days of sowing; W_2 is the final dry weight of plants at grain development stage; W_1 is the previous dry weight of plants at milking stage; T_2 is the time in days after 60 days of sowing; T_1 is the time in days after 30 days of sowing.

2.2.3 Photosynthetic efficiency

While photosynthetic efficiency (%) was calculated by following formula based on sunlight energy received for a geographic site (Lahore, Punjab, Pakistan) and on dry matter produced.

$$\text{Photosynthetic efficiency} = \frac{\text{Energy}_{\text{output}}}{\text{Energy}_{\text{input}}} \times 100\% \tag{2}$$

where, $\text{Energy}_{\text{output}}$=Dry weight (Excluding 25% respiration loss)× Energy (energy required for synthesis of one kilogram of glucose);

$\text{Energy}_{\text{input}}$=Estimated solar energy striking a land area (1 m²) during the 177 days of growing season of wheat and rice at Lahore, Punjab Pakistan; The estimated solar energy at Lahore, Punjab Pakistan was 1600.35 MJ/m²[17].

2.2.4 Chlorophyll Content

The chlorophyll contents were measured in leaves before reproductive phase of collected randomly from each experimental unit by following the protocol of Watanabe et al[18].

0.2 g of fresh leaves were crushed by using a pestle and mortar and transferred to 5 mL of 80% acetone in covered test tubes and placed in a laboratory refrigerator for 24 hours.

After 24 h, the chlorophyll content was measured using a UV-visible spectrophotometer at wavelengths of 663 nm for chlorophyll *a* (A_{663}) and 645 nm for chlorophyll *b* (A_{645}). The concentration of chlorophyll *a* and chlorophyll *b* was determined (Total Chlorophyll, μg/mL)[19] using Arnon's Equation (3).

$$\text{Total Chlorophyll} = 20.2A_{645} + 8.02A_{663} \quad (3)$$

These analyses provided valuable insights into the protein and chlorophyll content of wheat and rice.

2.2.5 Protein contents

Bradford method was employed to determine soluble proteins in the leaves. Fresh leaves (0.2 g) were carefully cut into small pieces using scissors and were ground with 5 mL of 1x phosphate buffer (pH 7.6), homogenate and transferred into centrifuge tubes.

The homogenates were centrifuged at 8000 r/min for 20 min and, the upper phase was separated and placed in separate tubes. To ensure equal volume across all samples, phosphate buffer and 1 mL of Bradford reagent were added to all samples. The Bradford reagent binds to proteins, causing a color change to blue and confirmed the presence of protein in the samples.

The samples were transferred to glass cuvets and the absorbance of the samples at 595 nm was measured using a UV-visible spectrophotometer.

3 Results and discussion

3.1 Results

3.1.1 Length of leaves

The variation of length of leaves in response to treatments was seemed insignificance statistically. The results are listed in the Table 2 nominating that Galaxy 2013 exhibiting maximum leaf length when received 80 mL irrigation while minimum leaf length was observed for the Faisalabad 2008 grew in moist soil. Similarly, Chanab Banaspati expressed maximum value of this attribute after receiving 100 mL irrigation water and minimum values expressed at 70 mL.

Table 2 Effect of different irrigation levels on length of leaves (cm) of different varieties of wheat and rice

	Wheat					Rice				
Irrigation levels	Faisalabad 2008	Galaxy 2013	Millet 2011	Gandam 1	Mean	Punjab Basmati	Chenab Basmati	B-515	PS-2	Mean
Moist	30.48	38.01	33.02	34.29	33.95	33.02	30.48	31.50	33.27	32.11
40 mL	33.02	39.37	35.56	34.40	35.58	33.52	30.48	31.50	33.50	32.25
50 mL	33.02	40.13	35.56	35.54	36.10	33.78	30.51	31.75	33.52	32.39
60 mL	33.03	40.13	35.57	35.54	36.13	33.78	30.51	31.75	33.51	32.38
70 mL	35.56	40.38	35.56	35.54	36.76	33.78	30.68	31.76	33.52	32.43
80 mL	34.04	40.64	35.58	36.06	36.80	33.77	30.70	31.77	33.53	32.44
90 mL	33.04	40.64	36.06	36.06	36.81	33.76	30.70	31.77	33.53	32.44
100 mL	34.04	40.64	36.06	36.06	37.06	32.33	37.90	35.99	34.55	35.19
Mean	33.27	39.99	35.37	35.43	--	33.46	31.49	32.22	33.61	--

3.1.2 Net assimilation rate

The data of net assimilation rate was represented the non-significance variation in response to difference in treatments. Table 3 shows that variety of wheat Millet 2011 expressed maximum net assimilation rate when irrigated with 80 mL water and same variety expressed minimum values at 40 mL. Similarly, Punjab Basmati executed maximum values of this attributes when irrigation of 80 mL was applied and PS-2 cultivars showed minimum values in pot which was remain moist during experiment.

3.1.3 Photosynthetic efficiency

The significance difference was observed among the treatments regarding photosynthetic efficiency. Wheat variety Millet 2011 have potential of highest photosynthetic efficiency at irrigation level of 80 mL while variety Faisalabad 2008 expresses minimum values at moist level of irrigation. Similarly, Punjab Basmati is more photo synthetically efficient when received 90 mL moisture and PS-2 have minimum values of this character when grow under moist conditions (Table 4).

Table 3 Effect of different irrigation levels on Net assimilation rate [g/(day·m²)] of wheat and rice varieties

	Wheat					Rice				
Irrigation levels	Faisalabad 2008	Galaxy 2013	Millet 2011	Gandam	Mean	Punjab Basmati	Chenab Basmati	B-515	PS-2	Mean
Moist	0.35	0.64	0.86	0.71	0.64	1.02	1.07	0.89	0.89	0.96
40 mL	0.29	0.63	0.83	0.63	0.59	1.13	1.03	0.92	0.81	0.97
50 mL	0.45	0.72	0.89	0.73	0.69	1.17	1.12	1.23	1.03	1.13
60 mL	0.47	0.83	0.98	0.75	0.75	1.41	1.26	1.29	1.21	1.29
70 mL	0.82	1.13	1.45	1.21	1.15	1.51	1.62	1.31	1.27	1.42
80 mL	1.49	1.36	1.77	1.45	1.51	1.81	1.67	1.35	1.41	1.56
90 mL	1.51	1.23	1.62	1.40	1.44	1.62	1.47	1.23	1.35	1.41
100 mL	1.38	1.37	1.67	1.34	1.44	1.52	1.42	1.20	1.38	1.38
Mean	0.84	0.98	1.25	1.02	--	1.39	1.33	1.17	1.16	--

3.1.4 Chlorophyll concentration

The treatment impacts significantly on chlorophyll contents of both crops. The results of analysis revealed that maximum chlorophyll contents were observed in leaf of Faisalabad 2008 as well as Millet 2011 at 50 mL irrigation level and minimum values were observed in Glaxy 2013 which was planted in moist pots (Figure 1). Similarly, Chanab Basmati showed maximum values at either 80, 90 and 100 mL irrigation level while minimum values was expressed by B-515 grew in pot received 60 mL irrigation level (Figure 2).

3.1.5 Protein contents

The data calculated during study showed significant difference among all the treatments. Figure 3 shows that maximum protein was observed in leaf of Gandum-1 at 50 mL irrigation level and Glaxy 2013 carried minimum protein in its leaf at moist level. Alternatively, the data of treatments of rice study showed the non-significance variation in response to irrigation level and significant difference among varieties. The maximum protein contents were recorded in Chanab Basmati at all irrigation levels and minimum in PS-2 at 50 mL irrigation level (Figure 4).

Table 4 Photosynthetic efficiency (%) of different varieties of wheat and rice as affected by irrigation levels

	Wheat					Rice				
Irrigation levels	Faisalabad 2008	Galaxy 2013	Millet 2011	Gandam	Means	Punjab Basmati	Chenab Basmati	B-515	PS-2	Means
Moist	0.98^{d}	1.24^{c}	1.56^{b}	1.33^{c}	1.27^{c}	1.20	1.16	1.03	0.78	1.04^{NS}
40 mL	0.92^{d}	1.23^{c}	1.58^{b}	1.48^{bc}	1.30^{c}	1.23	1.14	0.97	0.74	1.02
50 mL	1.68^{ab}	1.72^{ab}	1.67^{b}	1.63^{b}	1.67^{ab}	1.29	1.17	1.13	1.02	1.15
60 mL	1.72^{ab}	1.68^{ab}	1.92^{a}	1.51^{bc}	1.70^{ab}	1.45	1.33	1.23	1.14	1.28
70 mL	1.23^{b}	1.88^{ab}	1.94^{a}	1.70^{ab}	1.68^{ab}	1.63	1.37	1.29	1.26	1.38
80 mL	1.81^{ab}	2.02^{a}	2.31^{a}	1.79^{ab}	1.98a	1.92	1.43	1.27	1.32	1.48
90 mL	1.67^{b}	1.73^{ab}	1.98^{a}	1.65^{b}	1.76^{ab}	2.21	1.34	1.25	1.16	1.49
100 mL	1.43^{bc}	1.65^{b}	1.49^{bc}	1.32^{c}	1.47^{c}	1.42	1.34	1.17	1.06	1.24
Means^{NS}	1.43	1.64	1.80	1.55		1.54^{NS}	1.28	1.16	1.06	

Note: Means express their differences significantly at (α=0.05) by Duncan's multiple range test if not followed by any letter in common.

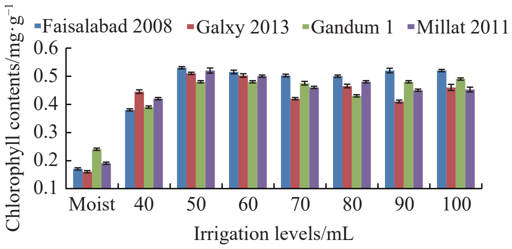

Figure 1 Evaluation chlorophyll contents in different varieties of wheat in response to different irrigation levels

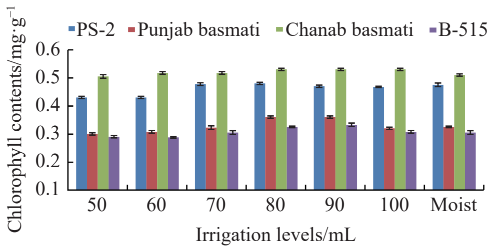

Figure 2 Evaluation chlorophyll contents in different varieties of rice in response to different irrigation levels

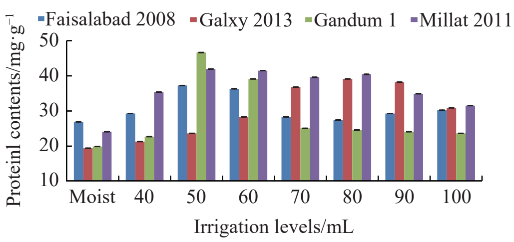

Figure 3 Evaluation Protein contents in different varieties of wheat in response to different irrigation levels

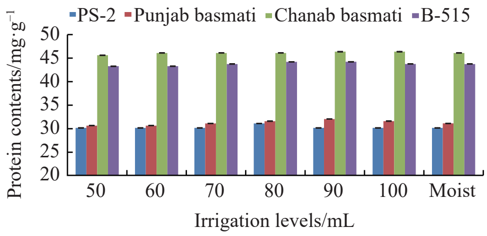

Figure 4 Evaluation Protein contents in different varieties of rice in response to different irrigation levels

3.2 Discussion

According to the results, the length of leaves of all varieties of wheat and rice were not expressed impressive change on impact of different varieties or irrigation levels. Hasnain et al.[20] findings were inclined with these results that application of 75 mL irrigation increased grain yield of rice and ensured better economic returns. Similar results were reported similar findings by similar study[21]. However, some literature review showed that osmotic stress decrease leaf length upto some limit, because with increase in solute capacity, the length of the leaf decreased by changing the angle of leaf[22]. Hussain et al.[23] recognized the NAR as quality attributes in increasing grain yield in cereals like wheat and rice with high protein content. Millet 2011 proved that the variety received more water to be superior over other cultivars of wheat. Amount of water supplied have significant impact over all treatments. Similar trends of NAR were determined in rice but amount of water supplied have no statistically influenced the NAR value. 80 mL of water supplied to rice have maximum observed data about NAR. Hasnain et al.[20] also recognized that 75 mL irrigation depth in the rice gave the maximum NAR as compared to other irrigation regimes.

Photosynthesis efficiency is the ability of a crop to manufacture a given quality of food such as proteins, carbohydrates and fats. Water is uptake from the soil by roots of terrestrial plant and by general body surface by hydrophytes. As a source of energy, sunlight is utilized and carbon dioxide (CO_2) is absorbed depending upon sizes of the leaves[24]. While mean data about the amount of water and their interaction with cultivars of wheat have significant impact in wheat. Rice cultivars and amount of water in interaction or in their respective means provided non-significant results. Photosynthetic efficiency increased from minimum level to optimum level (40 mL to 80 mL) and decreased in maximum level (90 mL and 100 mL) in wheat and rice varieties Gandam 1 and PS-2 respectively. Similar trend of photosynthetic efficiency may be due to C3 pathway of photosynthesis and similarly in their anatomy.

Both crops showed less photosynthetic efficiency as compared to the upper limit of photosynthetic efficiency 2.5% as reported by researchers[25]. However, Millet 2011 of Wheat and Punjab Pasmati of rice proved the best photosynthetic efficient cultivars over others. Similar outcomes were also reported in many other study[26]. It might be due to their better genetic makeup in response to water and CO_2 availability. Moreover, the relationship of photosynthetic efficiency with genetic variability, availability of water for irrigation and diffusion of gasses was also documented by different studies by Hussain et al.[23] and Afzal et al.[27]. Hasnain et al.[21] described the factors influenced on rice photosynthetic efficiency. During the growth and development of rice, maximum leaf area index (LAI), optimum amount of water and soil nutrition with proper solar energy caused high photosynthetic efficiency.

Chlorophyll contents are also fluctuated with the amount of water supplied[28]. The protein content partially depends upon the genotype, nutrition and environment. Abundant rainfall during the period of grain development results in low protein content, whereas dry conditions during those period results in high content[29] This study proved the study of Souza et al.[29] that water has a major role in maintaining protein and chlorophyll content in leaves of wheat and rice. Less water given to wheat plants than their requirement affects total protein and chlorophyll content of wheat leaves. Similarly, overwatering cuts off the oxygen supply and disrupts the protein structures that results in low protein content. Results of our study also showed that standing water is not necessary to grow rice crop. Kaya and Akcura[30] found negative correlation between environment, amount of water supplied and grain protein content of wheat. The same authors reported that protein content seemed to controlled by cultivars and drought spell of the season.

Drought stress exposure results in a substantial impact on the content of chlorophyll *a* and chlorophyll *b* in cereals[31]. One of the important products of gene expression is protein; expression of a large number of genes is inhibited or induced by drought stress[32].

4 Conclusions

Different levels of irrigation affect the agronomic, physiological and nutritional attribute of crop. Different cultivars of wheat and rice respond differently to different levels of irrigation. The selection of wheat variety like millet 2011 can be good option to harvest maximum benefits from available water. Conventionally rice is grown in standing water, and in scenario of climate change, the drought is expanding and availability of fresh water is getting limiting. Therefore, by selecting efficient variety like Punjab Basmati or Chanab Basmati and rational scheduling irrigation can provide satisfactory production with eliminating continuous dependency of standing water.

Statistical analysis

Analysis of Variance (ANOVA) will exercised by SPSS 13.0 statistical package and Tukey's range test to determine the significant difference between groups with a probability level of $p \leq 0.05$. Overall statistical analysis of the present study was done following Gomez et al.[33]

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