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, and it 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·m^2)], 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 varieties and by improving the technological approach of water saving through irrigation level and wise scheduling. The judicious use of water not only limits losses but also improves productivity, particularly in scenarios 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 conditions[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 the human diet. Global wheat production was approximately 761 Mt in 2020. The scarcity of water and vulnerability to drought in the context of the 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 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 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 terms of photosynthetic efficiency and protein contents under various irrigation levels[15].

2 Materials and methods

In the 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/hm^2 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, Millet 2011, Galaxy 2013, and Gandum-1) were planted during the 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 the wheat, each rice variety was irrigated with varying amounts of water: 50 mL, 60 mL, 70 mL, 80 mL, 90 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) were measured with measuring tape after 60 days of 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 these 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 continued drying at 80°C till the constant weight. These values were used in following Equation (1) for recording net assimilation rate (NAR)[16].

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

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

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

Energy$_{\text{input}}$=Estimated solar energy striking a land area (1 m^2) 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/m^2[17].

2.2.4 Chlorophyll content

The chlorophyll contents were measured in leaves before reproductive phase and 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, transferred to 5 mL of 80% acetone in covered test tubes, and placed in a laboratory refrigerator for 24 h.

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).

$$\text{Total Chlorophyll} = 20.2A_{645} + 8.02A_{663} \tag{3}$$

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

2.2.5 Protein contents

The 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 confirming 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 seemed statistically insignificant. The results are listed in Table 2, which shows that Galaxy 2013 exhibited maximum leaf length when receiving 80 mL irrigation, while minimum leaf length was observed for the Faisalabad 2008 when grown in moist soil. Similarly, Chenab Basmati expressed the maximum value of this attribute after receiving 100 mL irrigation water, and it expressed the minimum value 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	Gandum-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 the wheat variety Millet 2011 expressed a maximum net assimilation rate when irrigated with 80 mL water; the same variety expressed minimum values at 40 mL. Similarly, Punjab Basmati exhibited maximum values of this attribute when irrigation of 80 mL was applied, and PS-2 cultivars showed minimum values in pot which remained moist during the experiment.

3.1.3 Photosynthetic efficiency

A significance difference was observed among the treatments regarding photosynthetic efficiency. Wheat variety Millet 2011 had the potential of highest photosynthetic efficiency at irrigation level of 80 mL, while the variety Faisalabad 2008 expressed minimum values at moist level of irrigation. Similarly, Punjab Basmati was more photosynthetically efficient when receiving 90 mL of moisture, and PS-2 had minimum values of this attribute when grown 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	Gandum-1	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 leaves of Faisalabad 2008 as well as of Millet 2011 at 50 mL irrigation level, and minimum values were observed in Galaxy 2013 which was planted in moist pots (Figure 1). Similarly, Chenab Basmati showed maximum values at either the 80, 90, or 100 mL irrigation level, while minimum values were expressed by B-515 grown in pot with 60 mL irrigation level (Figure 2).

3.1.5 Protein contents

The data calculated during the study showed significant differences among all the treatments. Figure 3 shows that maximum protein was observed in leaves of Gandum-1 at 50 mL irrigation level and Galaxy 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 Chenab 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	Gandum-1	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.

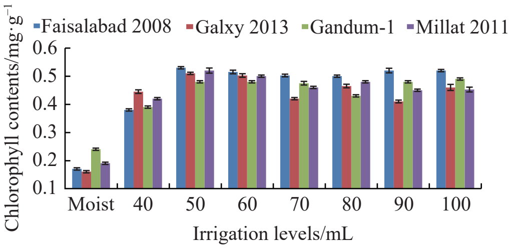

Figure 1 Evaluation of chlorophyll contents in different varieties of wheat in response to different irrigation levels

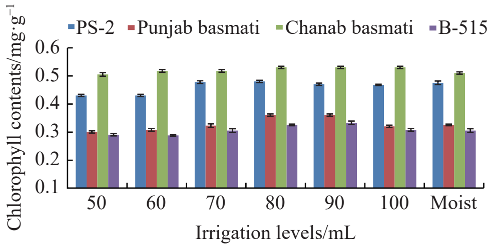

Figure 2 Evaluation of chlorophyll contents in different varieties of rice in response to different irrigation levels

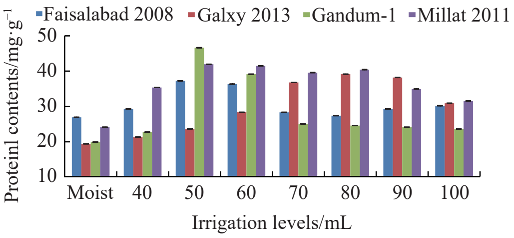

Figure 3 Evaluation of protein contents in different varieties of wheat in response to different irrigation levels

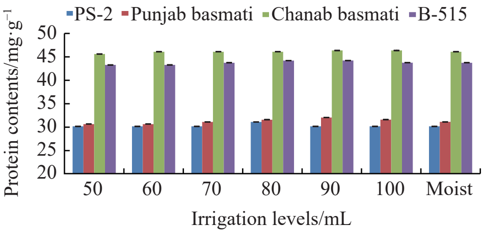

Figure 4 Evaluation of protein contents in different varieties of rice in response to different irrigation levels

3.2 Discussion

According to the results, the length of leaves of all varieties of wheat and rice did not express impressive change on impact of different varieties or irrigation levels. The findings of Hasnain et al.[20]were in agreement with the result that application of 75 mL irrigation increased the grain yield of rice and ensured better economic returns. Similar results were also reported in a similar study[21]. However, one literature review showed that osmotic stress decreased leaf length up to some limit, because with increase in solute capacity, the length of the leaf decreased by changing the leaf angle[22]. Hussain et al.[23]recognized the NAR as a quality attribute in increasing grain yield in cereals like wheat and rice with high protein content. Millet 2011 proved that the variety which received more water was superior over other cultivars of wheat. The amount of water supplied had a significant impact over all treatments. Similar trends of NAR were determined in rice, but the amount of water supplied had no statistical influence on the NAR value. 80 mL of water supplied to rice resulted in the maximum observed value of NAR. Hasnain et al.[20]also recognized that75 mL irrigation depth for rice resulted in 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 uptaken from the soil by the roots of the terrestrial plant and by the general body surface by hydrophytes. As a source of energy, sunlight is utilized and carbon dioxide (CO_2) is absorbed depending upon the size of the leaves[24]. Mean data showed that the amount of water had a significant impact on different cultivars of wheat, while mean data on the amount of water used with rice cultivars showed 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 Gandum-1 and PS-2, respectively. The similar trend of photosynthetic efficiency may be due to the C3 pathway of photosynthesis and similarity in their anatomy.

Both crops showed less photosynthetic efficiency as compared to the upper limit of photosynthetic efficiency of 2.5% as reported by researchers[25]. However, the Millet 2011 wheat variety and the Punjab Basmati rice variety proved to be the most photosynthetically efficient cultivars as compared to others. Similar outcomes have also been reported in many other studies[26]. This 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 gases was also documented in different studies by Hussain et al.[23] and Afzal et al.[27] Hasnain et al.[21] described the factors influencing 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 also fluctuate 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 this period result in high content[29]. This study confirmed the finding of Souza et al.[29] that water has a major role in maintaining protein and chlorophyll content in leaves of wheat and rice. Insufficient water given to wheat plants affects the total protein and chlorophyll content of wheat leaves. Similarly, overwatering cuts off the oxygen supply and disrupts the protein structures, which results in low protein content. The results of our study also showed that standing water is not necessary to grow rice crop. Kaya and Akcura[30] found a negative correlation between environment, amount of water supplied, and grain protein content of wheat. The same authors reported that protein content seemed to be controlled by cultivars and seasonal drought spells.

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 attributes of crops. Different cultivars of wheat and rice respond differently to different levels of irrigation. The selection of a wheat variety like Millet 2011 can be a good option to harvest maximum benefits from available water. Rice is conventionally grown in standing water, but in the current scenario of climate change, droughts are expanding and the availability of fresh water is becoming more limited. Therefore, by selecting efficient varieties like Punjab Basmati or Chenab Basmati and rationally scheduling irrigation, satisfactory production can be achieved while also eliminating the continuous dependency on standing water.

Statistical analysis

Analysis of Variance (ANOVA) was carried out 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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