

# Integration of univariate and multivariate analysis in evaluating irrigation efficiency and nitrogen fertilization in upland rice cultivation

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**Abstract.** Upland rice (*Oryza sativa* L.) has emerged as a potential solution for global warming condition to its ability to grow on dry land. However, the productivity of upland rice is generally lower than that of irrigated rice, necessitating efforts to improve yields through proper agronomic management. The integration of univariate and multivariate analysis provides a robust framework for evaluating plant performance. This study aims to investigate the effects of irrigation intensity and nitrogen fertilization rates on upland rice using integrated univariate and multivariate data analysis. The experiment used a completely randomized block design (CRBD) with combination from two factors using Situ Bagendit variety. The treatments consisted of four levels of irrigation intensity (433, 477, 560, and 610 ml/polybag) and four nitrogen fertilizer doses (0, 100, 200, and 300 kg Urea/ha). The N4P1 treatment (300 kg N/ha with daily irrigation of 433 ml/polybag) provided the most optimal results for most of the upland rice yield parameters. The number of panicles and the number of grains per plant, are the main factors determining the productivity of milled dry grain. Univariate and multivariate tests confirm that the combination of nitrogen availability and adequate irrigation is a key factor in optimizing upland rice yields.

## 1 Introduction

Rice is major important food commodity. A sufficient supply of paddy rice and upland rice is important for global food security [1]. Upland rice has a high potential for adaptation to water shortages, but its productivity is still low compared to irrigated paddy rice. Upland rice plays an important role in food and environmental sustainability. Therefore, a scientific approach is needed to optimize water use and nutrient inputs through the integration of irrigation management and nitrogen fertilization.

Nitrogen is an indispensable nutrient that contributes significantly to vegetative production and the quality of rice yields [2]. However, its effectiveness is often diminished due to losses through soil leaching, denitrification, and volatilization, especially in dry soil

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conditions. On the flip side, the efficient use of water is also a challenge in agricultural systems that are vulnerable to fluctuations in soil moisture. The complex relationship between water availability, nitrogen uptake, and plant growth requires a comprehensive analytical approach to understand the interactions between these factors more accurately and systematically.

The integration of univariate and multivariate analysis provides a robust framework for evaluating irrigation and nitrogen fertilization efficiency. Univariate analysis allows the identification of the direct influence of each factor on growth parameters and yield, while multivariate analysis is capable of revealing patterns of simultaneous interaction between variables to uncover complex physiological and agronomic relationships [3]. Univariate data analysis has been widely used in agricultural research. However, this analysis focuses at the effect on one parameter, which is sometimes inconsistent and difficult to use in decision making. In addition, this analysis also sometimes requires researchers to determine the main parameter, which is usually production. In fact, crop performance can be said to be superior in many parameters. Multivariate data analysis, on the other hand, is data analysis to evaluate the overall performance of a treatment or object by looking at multiple parameters comprehensively. This is in line with studies in agriculture that evaluate the performance of a plant from a particular treatment as the combined effect of many parameters.

This experiment aimed to investigate the impacts of irrigation intensity and nitrogen fertilization rate on the growth and yield of upland rice using integrated univariate and multivariate data analysis. This integrated approach is expected to provide a deeper understanding of the response of upland rice to combinations of irrigation and nitrogen fertilizer, as well as to produce recommendations for more efficient, adaptive, and sustainable cultivation management amid the challenges of climate change.

## 2 Materials and methods

This experiment used a CRBD (complete randomized block design) with a combination of two factors. The first factor was the dose of nitrogen (N) fertilizer, which was given in the form of urea fertilizer (46% N) and consisted of four levels, namely N1 = 0 kg Urea/ha, N2 = 100 kg Urea/ha, N3 = 200 kg Urea/ha, and N4 = 300 kg Urea/ha. The second factor was irrigation intensity, which consisted of four levels, namely P1 = once a day with a dose of 433 ml/polybag, P2 = every two days with a dose of 477 ml/polybag, P3 = every three days with a dose of 560 ml/polybag, and P4 = every four days with a dose of 610 ml/polybag. The two factors combined resulted in 16 treatment combinations with 3 repetitions.

The determination of urea fertilizer dosage per polybag was based on a population of 250,000 plants per hectare. Based on these calculations, the urea fertilizer requirement per polybag was: N2 (0.4 g/polybag), N3 (0.8 g/polybag), and N4 (1.2 g/polybag), while N1 (0 kg N/ha) was the control. The determination of irrigation water volume was conducted through empirical measurement of soil absorption capacity. The soil medium was dried first, then was given water until saturated and left overnight until the water begins to drip. The volume of water absorbed was calculated as the basis for determining the actual water requirement per polybag. Based on the measurement results, the water volume for each treatment was obtained, namely 433 ml/polybag (watering once every 1 day), 477 ml/polybag (every 2 days), 560 ml/polybag (every 3 days), and 610 ml/polybag (every 4 days). These volumes were used consistently during the growth period according to the watering schedule for each treatment.

The materials used included Situ Bagendit upland rice variety, SP-36 fertilizer/phosphate fertilizer (dose 100 kg/ha), KCl fertilizer/potassium fertilizer (dose 100 kg/ha), manure, and 30 × 30 cm polybags. The planting medium was made from a mixture of alfisol

soil and manure with a composition of 3.5 kg of soil and 80 g of manure per polybag. This dose was equivalent to 20 tons of manure per hectare.

There were 11 observation parameters, namely plant height (10 MST), weight of 1000 grains, leaf area, number of leaves, number of tillers, fresh crown weight, dry crown weight, number of panicles per hill, number of grains per hill, dry milled grain weight, and dry harvested grain weight. The observation data were analysed using Analysis of Variance (ANOVA) at a significance level of 5%. If there are any significant differences, the analysis is furthered with a Tukey post hoc test at a 5% significance level. Correlation analysis conducted using Pearson's correlation test. In addition to univariate analysis, multivariate analysis was also performed using MetaboAnalyst 6.0 software to identify overall patterns (PCA and Biplot) and relationships between variables.

### 3 Result and discussion

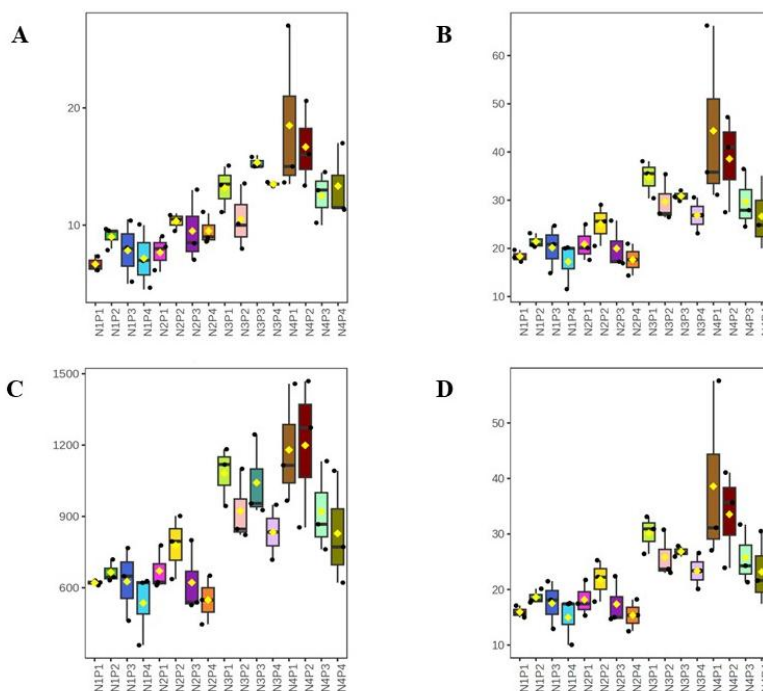
Univariate analysis using ANOVA was performed on 16 treatment combinations to assess their effect on the growth and production of upland rice. The analysis results showed that of the total 11 parameters, there were four parameters that were significantly different (number of panicles per hill, number of grains per hill, dry milled grain weight, and dry harvested grain weight). The four parameters were declared significant based on the F-value, p-value,  $-\text{LOG}_{10}(p)$ , FDR, and Tukey's HSD post hoc test results (**Table 1**). These four parameters were generative parameters that relate to production. Seven other parameters, mainly vegetative parameters, did not differ significantly in the univariate test. Significant differences in these four parameters indicated that the combination of treatments had a real effect on the yield components of upland rice.

From the ANOVA analysis, the highest value for harvested dry grain weight was obtained in the N4P1 treatment (N4 (300 kg Urea/ha), P1 (once a day with a dose of 433 ml/polybag)) at 44.38 g. The highest number of grains per hill was in the N4P2 treatment (N4 = 300 kg Urea/ha, P2 = every two days with a dose of 477 ml/polybag) at 1198.83 grains. The highest number of panicles per hill was also produced by the N4P1 with an average of 18.5. The N4P1 treatment produced the highest number of panicles per hill and was significantly different from the other treatments. The Tukey's test and boxplot visualization (**Table 1**. and **Fig. 1**.) showed that N4P1 produces the highest number of panicles per hill compared to all other treatments. The significant pairs that appeared, N3P3–N1P1, N3P3–N1P3, N3P3–N1P4, N3P4–N1P4, N4P2–N1P4, N4P4–N1P4, and N3P3–N2P1, indicated that treatments N1P1, N1P3, N1P4, and N2P1 had a lower number of panicles per hill compared to treatments with higher nutrient inputs.

**Table 1.** ANOVA analysis results for each parameter include F values, p values,  $-\text{LOG}_{10}(p)$  values, FDR values, and Tukey's HSD post hoc tests.

Parameter	F-value	p-value	$-\text{LOG}_{10}(p)$	FDR	Tukey's HSD
Number of panicles per hill	4.2648	0.00028	3.5525	0.0024289	N3P3-N1P1; N3P3-N1P3; N3P3-N1P4; N3P4-N1P4; N4P2-N1P4; N4P4-N1P4; N3P3-N2P1
Harvested dry grain weight	3.8532	0.000662	3.1793	0.0024289	N3P3-N1P4; N4P1-N1P4; N4P2-N1P4; N4P3-N1P4
Milled dry grain weight	3.8527	0.000662	3.1789	0.0024289	N3P3-N1P4; N4P1-N1P4; N4P2-N1P4; N4P3-N1P4

Parameter	F-value	p-value	$-\text{LOG}_{10}(p)$	FDR	Tukey's HSD
Number of grains per hill	3.3247	0.002109	2.676	0.0057985	N3P3-N1P4; N4P2-N1P4; N4P3-N1P4; N3P3-N2P4



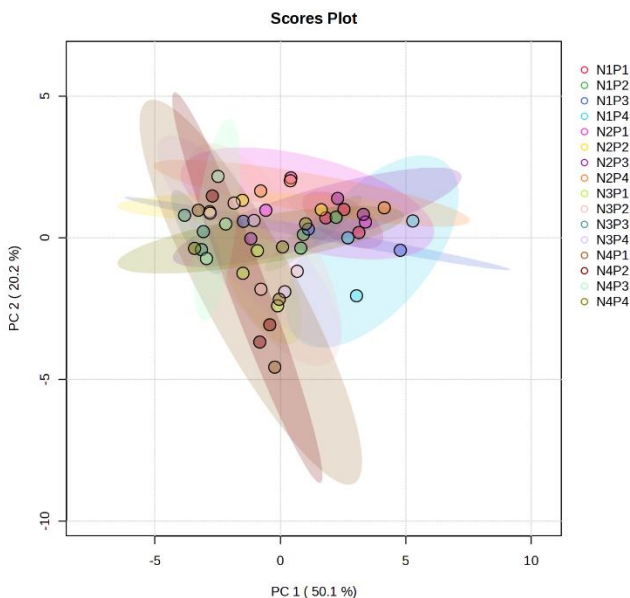
**Fig. 1.** ANOVA Analyses and Tukey Tests at a 5% significance level for four rice yield parameters, namely (A) number of panicles per hill, (B) dry grain weight, (C) number of grains per hill, and (D) milled dry grain weight for various combinations of nitrogen and irrigation treatments.

The N4P1 treatment (300 kg N/ha with daily irrigation of 433 ml/polybag) provided the most optimal results for most of the upland rice yield parameters (**Fig. 1.**). Based on the analysis results, this treatment produced the highest number of panicles per hill of 18.5, the highest dry grain weight of 44.38 g, and a milled grain weight of 38.52 g. This showed that the combination of the highest nitrogen fertilizer dose (300 kg N/ha) with a watering intensity of once a day (433 ml/polybag) had the most optimal effect on panicle formation in upland rice plants.

The N4P2 treatment (300 kg N/ha with irrigation every two days at 477 ml/polybag) produced the highest number of seeds per panicle, amounting to 1198.83 seeds. These results indicated that controlled mild water stress can stimulate the physiological efficiency of plants [4] especially in the process of spikelet differentiation and seed filling. Therefore, these two treatment combinations showed complementary patterns: N4P1 excelled in panicle formation and yield accumulation, while N4P2 excelled in grain formation efficiency per panicle. Overall, this confirmed that the synchronization between high nitrogen doses and irrigation intensity played an important contribution in determining the direction of plant response [5].

Multivariate analysis showed clustering of the treatments (**Fig. 2.**). In addition to PCA score plot, biplot showed the roles of each parameter (**Fig. 3.**). PCA analysis showed that the PC1 (principal component 1) explained 50.1% of the total variation, while the PC2 explained

20.2%. PC1 and PC2 covered 70.3% of the diversity between treatments. This showed that most of the data variation can be explained by these two principal axes (**Fig. 2.**). The PC1 axis described the main dimension related to total yield and grains productivity, while PC2 described the dimension related to vegetative activity and plant morphology. Parameters such as milled dry grain weight, harvested dry grain weight, and number of grains per hill contributed significantly to PC1, while parameters such as leaf area, number of shoots, and plant height contributed more to PC2. The direction and length of the vectors indicated that the longer the vector of a parameter, the greater its influence on the formation of variation between treatments. Therefore, yield parameters were the main determinants of differences between nitrogen and irrigation combinations, especially in the N4P1 and N4P2 treatments, which had high negative PC1 scores and were close to the direction of the yield vector (**Fig. 3.**).



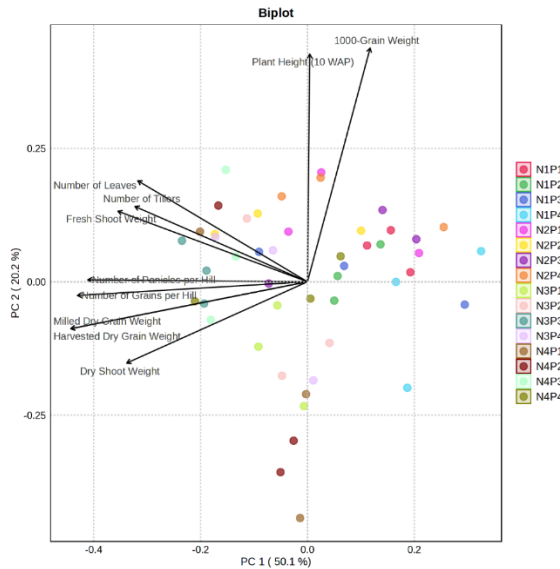
**Fig. 2.** Score plot of PCA results using 11 observation parameters, namely plant height (10 MST), leaf area, number of leaves, number of tillers, fresh weight of panicles, dry weight of panicles, number of grains per panicle, number of panicles per hill, milled dry grain, harvested dry grain, and weight of 1000 grains, with a total of 16 combinations of nitrogen and irrigation treatments.

The multivariate analysis results showed that weight of 1000 grains were the longest vector that clearly points to the upper right (PC1 positive, PC2 positive), indicating the largest contribution to data variation and a close relationship with grain size and plant morphological characteristics. Treatments such as N2P3, N3P3, and N3P4 were parallel to this vector, indicating that these combinations tend to produce larger grains even though total yield was not always high. Plant Height (10 WAP) also pointed to the upper right, parallel to weight of 1000 grains but with a shorter length, indicating a relationship between plant height and seed size. Some treatments such as N2P2 and N3P2 were close to the direction of this vector, indicating taller stem growth due to moderate nitrogen and adequate irrigation (**Fig. 3.**).

Leaf area, number of leaves, number of tillers, and fresh shoot weight showed a leftward upward direction (PC1 negative, PC2 positive), indicating a relationship with early vegetative activity such as leaf and shoot formation. Treatments such as N3P4, N4P4, and N4P3 appeared to be in line with this vector, indicating strong vegetative growth under high nitrogen conditions but with less frequent irrigation intervals. The parameters of panicle

number and grain number pointed almost horizontally to the left (PC1 negative, PC2 close to zero), indicating that these two variables represented productive yield components that were neutral to vegetative and morphological growth. The treatments N3P1, N4P1, and N4P2 were close to the direction of this vector, indicating that the combination of high nitrogen and adequate irrigation contributes to an increase in the number of panicles and grains. In addition, milled dry grain weight, harvested dry grain weight, and dry shoot weight pointed to the lower left (both PC1 and PC2 are negative), describing total yield indicators and biomass accumulation that played an important role in explaining yield components. Treatments such as N3P1, N4P1, and N4P2 were also located around this vector direction, indicating that the combination of high nitrogen with intensive irrigation provides the highest milled grain and harvested grain yields. Adequate nitrogen application, together with conventional irrigation, can improve the grain filling process. This improvement is thought to be influenced by adequate nitrogen and a stable water supply during this critical phase [6-9]. These data indicated that univariate and multivariate analysis supported the similar findings. Even though upland rice grow on land, water and nutrient requirements must still be met for optimal results.

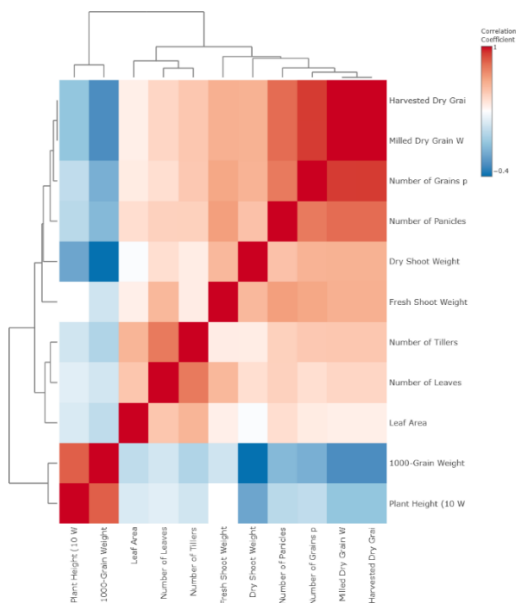
Conversely, treatments with longer irrigation intervals and low nitrogen, such as N1P3 or N1P4, tended to move away from the yield vector direction and were scattered in a quadrant reflecting lower production. Overall, this pattern confirmed that the lower left to left side of the biplot represented the treatment group with the highest grain and biomass productivity, while the upper right side more reflected morphological characteristics such as grain size in form off 1000-grain wight and plant height (Fig. 3.).



**Fig. 3.** Biplot of principal component analysis (PCA) results using 11 observation parameters, namely plant height (10 MST), leaf area, number of leaves, number of tillers, fresh weight of panicles, dry weight of panicles, number of grains per panicle, number of spikelets per panicle, milled dry grain, harvested dry grain, and weight of 1000 grains, in 16 combinations of nitrogen and irrigation treatments. The analysis was supported by the [PERMANOVA] results with  $F = 2.8416$ ,  $R^2 = 0.57118$ , and  $p$ -value = 0.001 (based on 999 permutations), indicating significant differences between treatment combinations.

Correlation analysis results showed that eight observation parameters had a  $p$ -value < 0.05, which means that the relationship between milled dry grain weight and the eight growth and yield parameters was statistically significant (Fig. 4.). The correlation coefficient ( $r$ )

values for each parameter were as follows: 1000-grain weight ( $r = -0.341$ ), leaf area ( $r = 0.332$ ), number of leaves ( $r = 0.433$ ), number of tillers ( $r = 0.493$ ), fresh panicle weight ( $r = 0.587$ ), dry panicle weight ( $r = 0.580$ ), number of panicles per hill ( $r = 0.802$ ), and number of grains per hill ( $r = 0.925$ ) (**Fig. 4.**, **Table 2**, **Table 3**).



**Fig. 4.** Heat map of the results of Pearson's correlation analysis of 11 observation parameters, namely plant height (10 MST), leaf area, number of leaves, number of tillers, fresh panicle weight, dry panicle weight, number of grains per panicle, number of spikelets per panicle, milled dry grain, harvested dry grain, and weight of 1000 grains. The colors on the map indicate the strength and direction of the correlation between parameters, where red indicates a strong positive correlation and blue indicates a negative correlation.

The results of the study indicated that milled dry grains have a strong to very strong positive correlation with generative parameters, especially the number of grains per panicle ( $r = 0.925$ ) and the number of panicles per hill ( $r = 0.802$ ). This showed that increases in these two parameters directly contributed to an increase in the yield of milled dry grains. Fresh shoot weight ( $r = 0.587$ ) and dry shoot weight ( $r = 0.580$ ) showed moderate to strong positive correlations, indicating that good vegetative growth could support generative yield formation. The number of tillers ( $r = 0.493$ ) and number of leaves ( $r = 0.433$ ) showed a moderate positive correlation, while leaf area ( $r = 0.332$ ) showed a weak positive correlation, indicating that their effect on yield is indirect. Conversely, 1000-grain weight ( $r = -0.341$ ) showed a weak negative correlation, indicating that an increase in grain size is not always followed by an increase in total yield per plant. This is consistent with previous studies that the number of rice leaves is significantly related to morphological, physiological, and geometric characteristics, making this parameter important [10].

Overall, these results confirm that generative parameters, especially the number of panicles and grains per hill, were the main factors determining the productivity of milled dry grain in upland rice. The vegetative parameters played a supporting role in yield formation through optimal biomass growth (**Fig. 4.**, **Table 2**, **Table 3**). Plant architecture determines growth optimization, which can affect crop yields [10-11]. This study, with the findings on panicle and number of grains influence, complements previous research on rice that tillers are related to productivity [1].

**Table 2.** *p*-value results of Pearson correlation analysis between observation parameters in upland rice.

	Plant Height (10 WAP)	1000-Grain Weight	Leaf Area	Number of Leaves	Number of Tillers	Fresh Shoot Weight	Dry Shoot Weight	Number of Panicles per Hill	Number of Grains per Hill	Milled Dry Grain Weight	Harvested Dry Grain Weight
Plant Height (10 WAP)	NA	1.27E-13	0.36964	0.27507	0.48134	0.067297	0.10791	0.85832	0.74135	0.51081	0.51079
1000-Grain Weight	1.27E-13	NA	0.75794	0.46339	0.97681	0.50159	0.000782	0.3066	0.18967	0.017806	0.017783
Leaf Area	0.36964	0.75794	NA	0.000312	2.46E-05	0.022581	0.087463	0.005009	0.016634	0.021218	0.021149
Number of Leaves	0.27507	0.46339	0.000312	NA	2.98E-10	4.04E-05	0.005312	0.001221	0.005224	0.002136	0.002137
Number of Tillers	0.48134	0.97681	2.46E-05	2.98E-10	NA	0.017824	0.017997	0.001185	0.000441	0.000377	0.000376
Fresh Shoot Weight	0.067297	0.50159	0.022581	4.04E-05	0.017824	NA	4.62E-05	5.56E-07	2.39E-06	1.17E-05	1.18E-05
Dry Shoot Weight	0.10791	0.000782	0.087463	0.005312	0.017997	4.62E-05	NA	0.000174	1.92E-05	1.55E-05	1.54E-05
Number of Panicles per Hill	0.85832	0.3066	0.005009	0.001221	0.001185	5.56E-07	0.000174	NA	3.26E-10	7.05E-12	6.99E-12
Number of Grains per Hill	0.74135	0.18967	0.016634	0.005224	0.000441	2.39E-06	1.92E-05	3.26E-10	NA	0	0
Milled Dry Grain Weight	0.51081	0.017806	0.021218	0.002136	0.000377	1.17E-05	1.55E-05	7.05E-12	0	NA	0
Harvested Dry Grain Weight	0.51079	0.017783	0.021149	0.002137	0.000376	1.18E-05	1.54E-05	6.99E-12	0	0	NA

Note: Cells with a gray background indicate parameter pairs that have a significant correlation ( $p < 0.05$ ), including Leaf Area, Number of Leaves, Number of Tillers, Fresh Shoot Weight, Dry Shoot Weight, Number of Panicles per Hill, Number of Grains per Hill, Milled Dry Grain Weight, and Harvested Dry Grain Weight.

**Table 3.** r-value results of Pearson correlation analysis between observation parameters in upland rice.

	Plant Height (10 WAP)	1000-Grain Weight	Leaf Area	Number of Leaves	Number of Tillers	Fresh Shoot Weight	Dry Shoot Weight	Number of Panicles per Hill	Number of Grains per Hill	Milled Dry Grain Weight	Harvested Dry Grain Weight
Plant Height (10 WAP)	1	0.836887	0.132411	0.160747	0.104102	0.26632	-0.23498	0.026459	0.048902	-0.09725	-0.09726
1000-Grain Weight	0.836887	1	0.045663	0.108383	-0.00431	0.099372	-0.46858	-0.1507	-0.19261	-0.34071	-0.34077
Leaf Area	0.132411	0.045663	1	0.498408	0.568865	0.328616	0.249324	0.398646	0.344088	0.331829	0.331996
Number of Leaves	0.160747	0.108383	0.498408	1	0.762674	0.55624	0.396174	0.453104	0.396878	0.432587	0.432563
Number of Tillers	0.104102	-0.00431	0.568865	0.762674	1	0.340654	0.340172	0.454165	0.48751	0.492506	0.492543
Fresh Shoot Weight	0.26632	0.099372	0.328616	0.55624	0.340654	1	0.552789	0.650634	0.621824	0.586716	0.586606
Dry Shoot Weight	-0.23498	-0.46858	0.249324	0.396174	0.340172	0.552789	1	0.515957	0.574881	0.580114	0.580215
Number of Panicles per Hill	0.026459	-0.1507	0.398646	0.453104	0.454165	0.650634	0.515957	1	0.761639	0.802359	0.802452
Number of Grains per Hill	0.048902	-0.19261	0.344088	0.396878	0.48751	0.621824	0.574881	0.761639	1	0.92501	0.925067
Milled Dry Grain Weight	-0.09725	-0.34071	0.331829	0.432587	0.492506	0.586716	0.580114	0.802359	0.92501	1	1
Harvested Dry Grain Weight	-0.09726	-0.34077	0.331996	0.432563	0.492543	0.586606	0.580215	0.802452	0.925067	1	1

## 4 Conclusion

Application nitrogen fertilizer dose 300 kg Urea/ha with a watering intensity of once a day had the most optimal effect on upland rice plants. The synchronization between high nitrogen doses and irrigation intensity plays crucial role in determining the direction of plant response. The number of panicles and grains per hill were the main factors determining the productivity of milled dry grain. The integration of univariate and multivariate analyses is essential to strengthen the validation, that appropriate nitrogen and irrigation management strategies play a crucial role in enhancing upland rice productivity.

## References

1. A. Kalaitzidis, K. Kadoglidou, I. Mylonas, S. Ghoghoberidze, E. Ninou, D. Katsantonis, Investigating the impact of tillering on yield and yield-related traits in European rice cultivars. *Agriculture* **15**, 616 (2025). <https://doi.org/10.3390/agriculture15060616>
2. Y. Xu, X. Guan, Z. Han, L. Zhou, Y. Zhang, M.A.U. Asad, Z. Wang, R. Jin, G. Pan, F. Cheng, Combined effect of nitrogen fertilizer application and high temperature on grain quality properties of cooked rice. *Front. Plant Sci.* **13**, 874033 (2022)
3. L. Li, D. Lin, J. Wang, L. Yang, Y. Wang, Multivariate analysis models based on full spectra range and effective wavelengths using different transformation techniques for rapid estimation of leaf nitrogen concentration in winter wheat. *Front. Plant Sci.* **11**, 755 (2020). <https://doi.org/10.3389/fpls.2020.00755>
4. X. Liu, Q. Ma, H. Yu, Y. Li, L. Zhou, Q. He, Z. Xu, G. Zhou, Responses of plant biomass and yield component in rice, wheat, and maize to climatic warming: A meta-analysis. *Planta* **252**, 90 (2020). doi:10.1007/s00425-020-03495-y
5. M.T. Islam, A.A. Ferdaus, J.N. Lia, N. Jahan, M.S.A. Queen, M.G. Kibria, A.K.M. Adham, Rice yield, water and nitrogen use efficiencies, and soil physicochemical properties as influenced by alternate wetting and drying coupled with N-fertilizer interactions in Bangladesh. *Paddy Water Environ.* (2025). <https://doi.org/10.1007/s10333-025-01037-4>
6. N.K. Fageria, Yield physiology of rice. *J. Plant Nutr.* **30**, 843–879 (2007)
7. D.R. Carrijo, M.E. Lundy, B.A. Linquist, Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Res.* **203**, 173–180 (2017). <https://doi.org/10.1016/j.fcr.2016.12.002>
8. X.C. Cao, L.L. Wu, R.H. Lu, L.F. Zhu, J.H. Zhang, Q.Y. Jin, Irrigation and fertilization management to optimize rice yield, water productivity and nitrogen recovery efficiency. *Irrig. Sci.* **39**, 235–249 (2021). <https://doi.org/10.1007/s00271-020-00700-4>
9. A. Arouna, I.K. Dzomeku, A.G. Shaibu, A.R. Nurudeen, Water management for sustainable irrigation in rice (*Oryza sativa* L.) production: A review. *Agronomy* **13**, 1522 (2023). <https://doi.org/10.3390/agronomy13061522>
10. M.K. Vishal, R. Saluja, D. Aggrawal, B. Banerjee, D. Raju, S. Kumar, V. Chinnusamy, R.N. Sahoo, J. Adinarayana, Leaf count aided novel framework for rice (*Oryza sativa* L.) genotypes discrimination in phenomics. *Plants* **11**, 2663 (2022)
11. T. Watanabe, J.S. Hanan, P.M. Room, T. Hasegawa, H. Nakagawa, W. Takahashi, Rice morphogenesis and plant architecture: Measurement, specification and the reconstruction of structural development by 3D architectural modelling. *Ann. Bot.* **95**, 1131–1143 (2005). doi: 10.1093/aob/mci136