Integration of water management and phosphate dosage as an applicative approach to growth, productivity, and inter parameter relationships in upland rice (*Oryza sativa* L.)

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Abstract. Global climate change has had a significant impact on the availability of water for rice cultivation. Phosphorus plays a vital part in root development, energy production and the efficient use of water. This study aims to integrate water management and phosphorus application to enhance the growth and yield of upland rice (*Oryza sativa* L.) and understand the relationship between parameters. The study employed a factorial design comprising 16 combinations of two main factors: water stress level (100%, 75%, 50% and 25% of field capacity) and phosphorus dose (0, 50, 100 and 150 kg of SP-36 per hectare). Urea (200 kg/ha) and KCl (50 kg/ha) were applied as a basal fertiliser to all treatments. The paddy variety used was Situ Bagendit. Treatment C1P2 (75% field capacity and 100 kg SP-36/ha) produced the highest yield of milled rice compared to all other treatment combinations. This result was not significantly different to those of treatments C0P2 (100% field capacity and 100 kg SP-36/ha) and C0P3 (100% field capacity and 150 kg SP-36/ha). These findings were supported by multivariate and univariate analyses. Correlation analysis showed that components of yield, dry milled grain weight, grain weight per plant and number of panicles, were closely related and collectively influenced the final grain yield. This approach highlights the potential for implementing integrated, practical cultivation strategies to support sustainable paddy rice farming systems.

1 Introduction

Global climate change, characterized by rising temperatures and unpredictable rainfall patterns. This situation has reduced the availability of water for agriculture [1]. Climate change has a direct impact on food production systems, especially in tropical regions such as Indonesia. Agricultural activities require stable climatic conditions and a continuous supply of water. Water shortages are now one of the main challenges in maintaining agricultural productivity [2]. Water shortages hinder nutrient absorption. Therefore, adaptive strategies

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are needed to ensure sustainable production. One such strategy is to use drought-resistant plant varieties [3] or another option is to implement efficient water use techniques in agriculture [4].

Rice (*Oryza sativa* L.) is a staple food for much of the population in the world, including in Indonesia. In order to increase rice production, irrigated paddy fields and upland rice are important, especially by developing drought-tolerant varieties of upland rice [5]. Upland rice contributes to support national food security because it can grow in areas where water is scarce. Although in global rice production upland rice cultivation only contributes around 8% [6], this crop significantly increases total rice production and has a positive role in improving food security for communities [7]. However, some environmental factors may reduce the upland rice productivity. These factors are drought, soil acidity, and low soil fertility as the main abiotic factors hindering the cultivation of upland rice [5,6,8].

Upland rice productivity remains low [8] due to the negative effect of abiotic stress, particularly drought and limited nutrients such as phosphorus (P). Phosphorus is one of essential macronutrients for root formation of the plant and energy synthesis (ATP). In addition, phosphorus has effects on the formation of panicles and grain filling in rice plant. In Indonesia, the soil is generally acidic. This situation causes phosphorus to be easily fixed by ions such as Al^{3+} and Fe^{3+}, resulting in low availability for plant. Therefore, considering problem of water and phosphorus effect on plant, integrated water and phosphate fertilizer management is an applicable approach.

This study aims to evaluate the combination of treatments between water stress levels and phosphate fertilizer doses on the vegetative performance, generative performance, and interrelationships between parameters of upland rice (*Oryza sativa* L.). This approach is designed to determine the most effective combination of treatments directly so that the results can be applied to water management and fertilization practices in the field for farmers. The analysis was conducted comprehensively using univariate analysis (ANOVA) andmultivariate analysis [9] (PCA with MetaboAnalyst 5.0). Pearson's correlation analysis was used to understand the relationship among parameters. These findings are expected to form an important basis for the integrated application of water and phosphate fertilizer management in current climate change environment.

2 Method

This research was conducted at the Experimental Garden of the Faculty of Agriculture, Universitas Sebelas Maret (UNS), Jumantono, Karanganyar, Central Java, Indonesia. This experiment site is located in 170 m above sea level; 07°37'831“S and 110°56'905” E. For conducting analysis, Laboratory of Ecology and Crop Production Management also used from November 2024 to February 2025. This study consisted of 16 treatment combinations, which were the result of combining two main factors. The combinations were constructed from water stress levels (C0 = 100% field capacity, C1 = 75% field capacity, C2 = 50% field capacity, and C3 = 25% field capacity) and phosphate fertilizer dose using SP-36 (P0 = 0 kg ha^{-1}, P1 = 50 kg ha^{-1}, P2 = 100 kg ha^{-1}, and P3 = 150 kg ha^{-1}). The combination of these two factors resulted in 16 treatments (C0P0, C0P1, C0P2, C0P3, C1P0, C1P1, C1P2, C1P3, C2P0, C2P1, C2P2, C2P3, C3P0, C3P1, C3P2, and C3P3). Urea fertilizer 200 kg ha^{-1} and KCl 50 kg ha^{-1} were applied evenly across all combinations. This experiment used Situ Bagendit upland rice variety planted in 30×30 cm polybags. This approach was created as an integrative and applicable practice. It directly evaluated treatment combinations to determine the most efficient strategy for water and phosphorus use in dryland farming. Observations were made during the vegetative and generative phases. The data were analysed using 5% ANOVA followed by DMRT if there were significant differences. Multivariate analysis (MetaboAnalyst 5.0) was applied to evaluate grouping and pattern from the combinations.

Pearson's correlation was used to explore the relationship patterns between growth and yield parameters and to identify the agronomic factors that most influence upland rice productivity. Determination of 100% field capacity water content was carried out using the saturation irrigation and gravity drying methods. Polybags containing soil media were first watered until water comes out from the bottom (saturated), then left for 24 hours to allow excess water to drain naturally. The weight of the polybag after 24 hours was determined as the field capacity weight (100% FC (Field Capacity)). Next, the initial dry weight of the polybag (without water) was measured to determine the difference between the saturated soil weight and the dry weight, so that the volume of water representing 100% FC could be determined. Water stress was controlled by maintaining the water volume according to the treatment: C0 = 100% FC, C1 = 75% FC, C2 = 50% FC, and C3 = 25% FC. Watering was carried out using a measuring cup by calculating the daily water requirement based on the difference between the actual polybag weight and the target weight according to the treatment.

Soil was analyzed at the beginning of the study to ensure that the experimental site truly had conditions that reflected phosphorus (P) deficiency. The parameters analyzed include pH (H_2O), organic C content, and macro nutrients, which include total nitrogen (N), total potassium (K), and total phosphorus (P).

3 Result and Discussion

The analysis of the soil showed that the total phosphorus content at the experiment site was 6 ppm, which is categorized as low. In addition, the soil had a neutral pH. This imply that there are no obstacles related to soil acidity that could interfere the nutrient availability or plant response to fertilization treatments. The total nitrogen nutrient was classified as high and the total potassium was in the moderate category. The nitrogen and potassium data reflects that there are no negative effects from N and K deficiencies on plant growth. Thus, the soil condition allowed for a clearer observation of the effects of phosphorus addition. Soil with low P is expected that an increase in fertilizer dose will have a significant impact on plant growth and yield. Conversely, in P-rich soils, the response to phosphorus fertilization tends to be minimal or undetectable. According to Fageria and Baligar [10], phosphorus-deficient soils are an ideal medium for studying fertilization efficiency because they allow for more accurate measurement of plant response and nutrient uptake dynamics under controlled phosphorus application conditions. Thus, the soil characteristics at the research site, neutral pH, high N, moderate K, and low P, strongly supported the research objective of evaluating the effectiveness of phosphorus fertilization on the growth and yield of upland rice (**Table 1.**).

Table 1. Soil analysis result

Soil Properties	Unit	Result	Criteria
pH (H_2O)	–	6.85	Neutral
Organic C	%	0.14	Very low
Total N	%	0.70	High
Total K	ppm	157	Medium
Total P	ppm	6	Low

The results of multivariate analysis on the PCA Score Plot (**Fig. 1.**) and PCA Biplot (**Fig. 2.**) show that the first principal component (PC1) has a diversity of 47.1%, while the second principal component (PC2) has a diversity of 10.4%. The results of Principal Component Analysis (PCA) consist of two main parts, namely the scores plot and biplot, which together describe the pattern of relationships between treatments and growth parameters of upland rice (*Oryza sativa* L.).

Based on the scores plot (**Fig. 1.**), the distribution of treatment points shows clear variations between combinations of water stress levels and phosphate fertilizer doses. The PC1 axis explained 47.1% of the total data variation. PC2 explained 10.4% of the total data variation. These two principal components cumulatively represent most of the differences between treatments. Treatments C0P2, C0P3, and C1P2 tended to cluster on the right side of PC1. This cluster indicated similar growth characteristics and higher yields compared to other combinations. Conversely, treatments with severe water stress such as C3P0 and C3P1 were on the left side of PC1, which implied a different and relatively lower growth response. This separation pattern illustrated that the main variation between treatments was mainly influenced by differences in water availability and phosphate dosage.

Based on multivariate analysis involving 33 growth and yield parameters, the best treatment was obtained in C0P2 (100% field capacity and 100 kg P ha^{-1}), followed by C0P3 (100% field capacity and 150 kg P ha^{-1}), and C1P2 (75% field capacity and 100 kg P ha^{-1}). These findings indicate that optimal water availability with moderate to high phosphate doses provides the best growth and yield responses in upland rice under the conditions of this experiment.

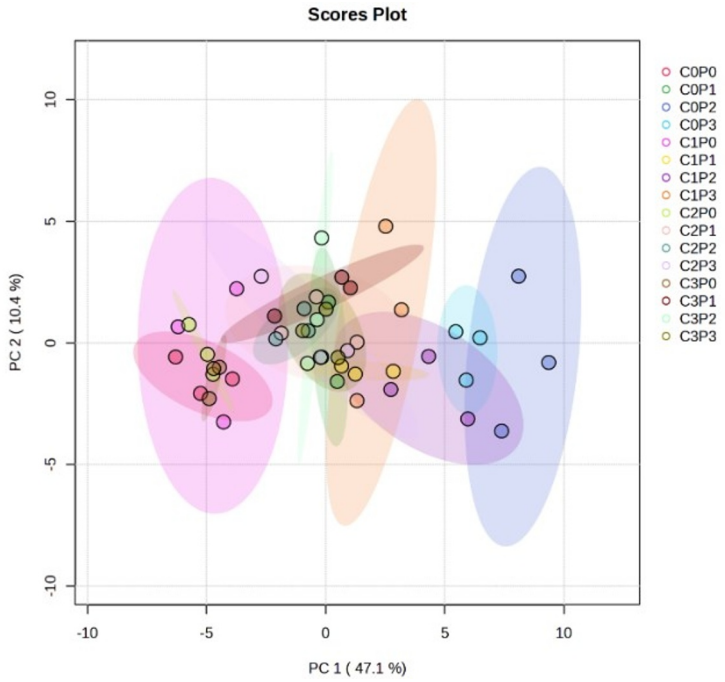

Fig. 1. PCA Scores plot.

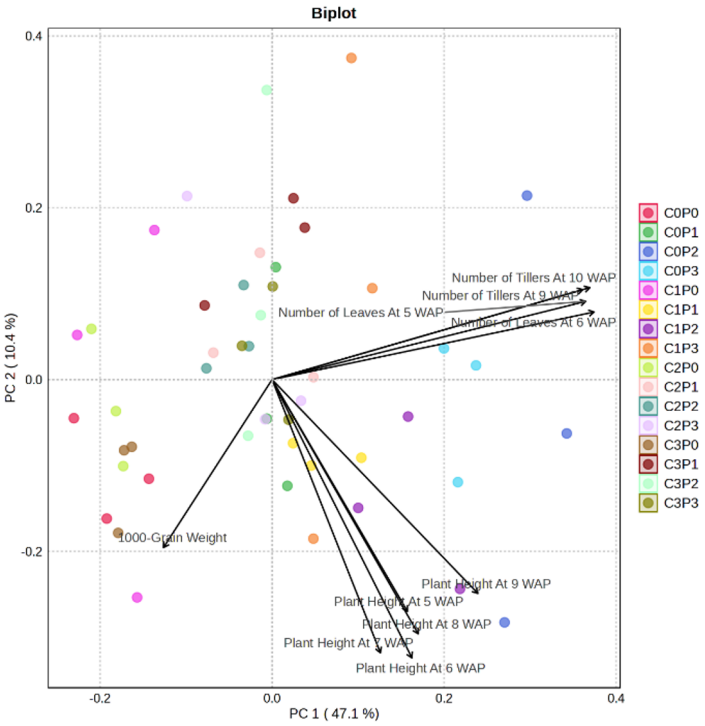

Fig. 2. PCA biplot.

The PCA biplot (**Fig. 2.**) showed that the direction and length of the vectors indicated the parameters that contributed most to the variation between treatments. The parameters of tiller number at 9–10 weeks after planting (WAP), number of leaves at 5–6 WAP, and plant height at 6–9 WAP had long vectors pointing to the right side of PC1. This information indicated that these three parameters were the dominant variables in distinguishing growth patterns between treatments. These three parameters were essential because they physiologically reflected vegetative growth capacity, photosynthetic efficiency, and yield potential [2]. In a multivariate data analysis context, these parameters acted as key driving variables that were most influential in explaining the overall structure of data variation. The strong relationship between these parameters and treatments C1P2 (75% field capacity and 100 kg P ha^{-1}), C0P2 (100% field capacity and 100 kg P ha^{-1}), and C0P3 (100% field capacity and 150 kg P ha^{-1}) indicated that these three treatment combinations had the most stable, consistent, and dominant vegetative performance compared to all other treatments. These three treatments did not only show stronger growth and higher vegetative parameters, but also were in a position that reflected the optimal synergy between water availability and phosphate dosage in supporting upland rice growth.

Table 2. ANOVA test results, F values, and significance (p-values) for each observation parameter.

Number	Parameter	F-value	p-value
1	Plant Height At 6 WAP	2.362	0.020248
2	Number of Leaves At 2 WAP	9.1903	9.73E-08
3	Number of Leaves At 3 WAP	7.5506	9.35E-07
4	Number of Leaves At 4 WAP	11.928	3.97E-09
5	Number of Leaves At 5 WAP	6.48	4.92E-06
6	Number of Leaves At 6 WAP	9.3425	8.00E-08
7	Number of Leaves At 7 WAP	5.0627	5.87E-05
8	Number of Leaves At 8 WAP	3.8645	0.00064601
9	Number of Tillers At 2 WAP	5.3814	3.26E-05
10	Number of Tillers At 3 WAP	9.9111	3.94E-08
11	Number of Tillers At 4 WAP	3.1841	0.0029008
12	Number of Tillers At 5 WAP	3.4002	0.0017801
13	Number of Tillers At 6 WAP	3.9276	0.00056498
14	Number of Tillers At 7 WAP	5.2549	4.11E-05
15	Number of Tillers At 8 WAP	10.55	1.84E-08
16	Number of Tillers At 9 WAP	5.896	1.31E-05
17	Number of Tillers At 10 WAP	7.0015	2.15E-06
18	Dry Biomass Weight	4.5971	0.00014382
19	Grain Weight Per Hill	6.7646	3.11E-06
20	Number of Panicles	7.0854	1.89E-06
21	Milled Dry Grain	11.62	5.52E-09

The results of the analysis of variance (ANOVA) (**Table 2.**) showed that of the total 33 parameters observed, there were 21 parameters that differed significantly between treatment combinations. The parameters that showed significant differences included both the vegetative and generative phases. In the vegetative phase, significant differences were detected in plant height (6 MST), number of leaves (2–8 MST), and number of tillers (2–10 MST). In the generative phase, the parameters that differed significantly included dry panicle weight, number of panicles, grain weight per hill, and milled dry grain.

Treatment C1P2 (75% field capacity and 100 kg SP-36 ha^{-1}) produced the highest milled grain yield compared to all other treatment combinations (**Fig. 3.**). This result was not significantly different from several other combinations, namely C0P2 (100% field capacity and 100 kg SP-36 ha^{-1}), C0P3 (100% field capacity and 150 kg SP-36 ha^{-1}), C1P3 (75% field capacity and 150 kg SP-36 ha^{-1}), and C2P2 (50% field capacity and 100 kg SP-36 ha^{-1}). The 75% field capacity condition was able to produce the highest milled grain yield (29.5 g per clump) when accompanied by phosphate fertilization of 100 kg ha^{-1}. In the C1P2 treatment (C1 = 75% field capacity and P2 = 100 kg SP-36 ha^{-1}), the average milled grain obtained was 29.48 g per plant, which was equivalent to approximately 4.72 tons per hectare ((*C0P2 (100% field capacity and 100 kg SP-36 ha^{-1}) = 27.44 g per plant equivalent to approximately 4.39 tons per hectare). These findings indicated that a slight decrease in water availability below full capacity did not reduce yields if phosphate nutrients were optimally available. Conversely, the lowest yield was obtained under full water conditions (100% field capacity) without phosphate fertilization, which was 13.3 g per plant. This indicated that even though water availability was sufficient, phosphate limitations still restricted grain formation and filling. The milled grain yield in this study was higher than the upland rice production in the study by Hairmansis et al. [11]. However, the productivity of upland rice in this experiment was still lower than that reported by Effendi et al. [12], who obtained a milled dry grain weight of 44.62 g per hill in the treatment combining liquid organic fertilizer and NPK on ultisol soil.

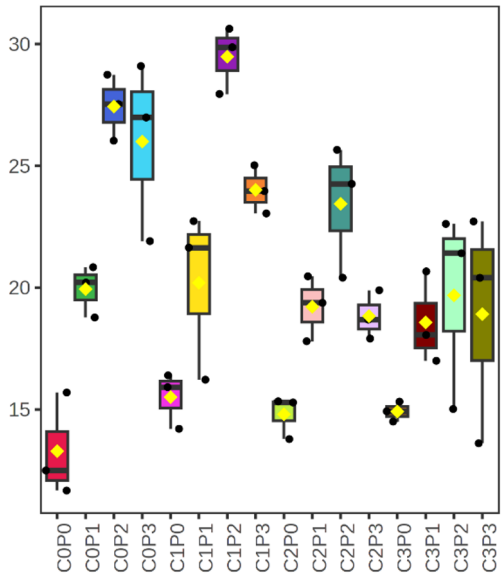

Fig. 3. Results of ANOVA tests on milled dry grain parameter.

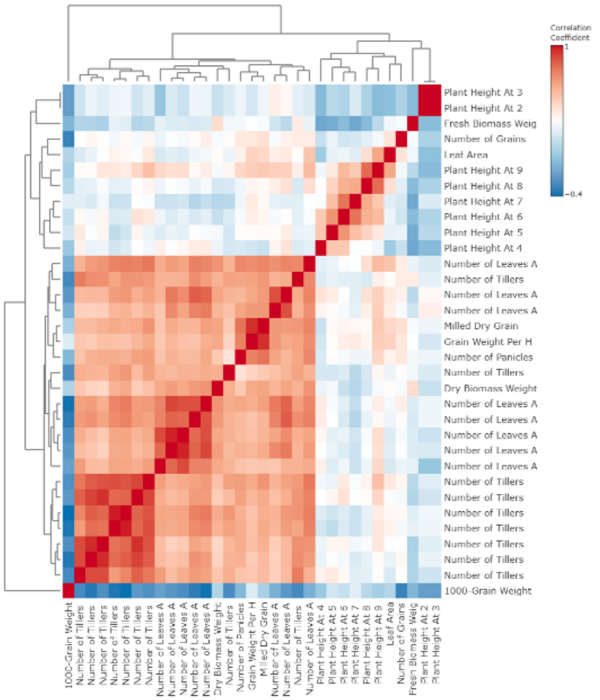

Fig. 4. Heatmap of the correlation between 33 vegetative and generative parameters.

Pearson's correlation analysis at a significance level of 5% aims to identify the strength and direction of the relationship between agronomic parameters. In addition, Pearson's correlation analysis can produce information related to the parameters that most influence rice paddy yields. The analysis focused on parameters directly related to crop yield, namely milled dry grain, grain weight per panicle, number of panicles, dry biomass weight, weight of 1000 grains, and number of grains. This approach provides a deeper understanding of the

interaction patterns between variables and has the potential to be used as a basis for predicting production outcomes under various water stress conditions and phosphate availability levels [13]. The results of the analysis were presented in the form of a heatmap in **Fig. 4.**, which showed the correlation between 33 vegetative and generative parameters in upland rice plants. Additionally, **Table 3** presented the main parameters along with other parameters that were significantly correlated (r; $p < 0.05$, sorted by p-value). This data provided more structured information about the key parameters that contribute most significantly to crop yield and their close relationship with other agronomic characteristics.

The results of Pearson's correlation analysis showed that milled dry grain has a very strong relationship with grain weight per panicle (r = 0.949; p = 3.34E-11) and number of panicles (r = 0.787; p = 3.34E-11). This positive correlation indicated that these two parameters were the main determinants of production yield. Vegetative parameters such as the number of tillers at 6–10 weeks after planting (WAP) and the number of leaves at 5–6 WAP also correlated strongly to moderately with milled dry grain yield. This relationship confirmed that optimal vegetative growth has an important role in the formation of the generative yield of upland rice [14,15].

Additionally, a strong correlation found between grain weight per panicle and number of panicles, each of which had a close relationship with milled dry grain. The dry biomass weight parameter showed a strong correlation with the number of leaves in the 5–9 MST phase (r = 0.622–0.693). This phenomenon indicated the importance of leaf area in biomass accumulation. In contrast, 1000-grain weight had a moderate negative correlation with the number of leaves and tillers in the late phase. This phenomenon implied a compromise between grain size and vegetative growth intensity (**Table 3**.). Thus, the combination of optimal treatment and integrative data analysis is an important basis for the application of adaptive cultivation strategies. This approach is applicable in sustainable agricultural systems.

Table 3. Main parameters and other significantly correlated parameters (r; $p < 0.05$, sorted by p-value).

Main Parameter	Significant Correlated Parameters (r; p < 0.05, sorted by p)
Milled Dry Grain	• Grain Weight Per Hill (r = 0.949; p = 3.34E-11) → very strong • Number of Panicles (r = 0.787; p = 3.34E-11) → very strong • Number of Tillers At 8 WAP (r = 0.695; p = 4.23E-08) → strong • Number of Tillers At 7 WAP (r = 0.621; p = 2.54E-06) → strong • Number of Tillers At 6 WAP (r = 0.593; p = 8.8E-06) → strong • Number of Leaves At 6 WAP (r = 0.578; p = 1.66E-05) → moderate • Number of Leaves At 5 WAP (r = 0.577; p = 1.74E-05) → moderate • Number of Tillers At 4 WAP (r = 0.552; p = 3.75E-05) → moderate • Number of Tillers At 3 WAP (r = 0.672; p = 9.83E-08) → strong • Number of Grains (r = 0.411; p = 0.0037) → moderate
Grain Weight Per Hill	• Milled Dry Grain (r = 0.949; p = 0) → very strong • Number of Panicles (r = 0.745; p = 1.26E-09) → very strong • Number of Leaves At 2 WAP (r = 0.647; p = 1.60E-08) → strong • Number of Tillers At 8 WAP (r = 0.621; p = 2.52E-06) → strong • Number of Tillers At 9 WAP (r = 0.534; p = 9.42E-05) → moderate • Number of Leaves At 5 WAP (r = 0.524; p = 1.33E-04) → moderate • Number of Grains (r = 0.378; p = 0.0081) → moderate
Number of Panicles	• Grain Weight Per Hill (r = 0.745; p = 1.26E-09) → very strong • Milled Dry Grain (r = 0.787; p = 3.34E-11) → very strong • Number of Tillers At 8 WAP (r = 0.665; p = 2.59E-07) → strong

	• Number of Tillers At 7 WAP (r = 0.652; p = 5.27E-07) → strong • Number of Tillers At 6 WAP (r = 0.611; p = 3.94E-06) → strong • Number of Leaves At 6 WAP (r = 0.561; p = 3.40E-05) → moderate • Number of Leaves At 5 WAP (r = 0.561; p = 3.34E-05) → moderate • Number of Grains (r = 0.375; p = 0.0087) → moderate
Dry Biomass Weight	• Number of Leaves At 6 WAP (r = 0.693; p = 1.38E-07) → strong • Number of Leaves At 5 WAP (r = 0.676; p = 1.88E-06) → strong • Number of Leaves At 7 WAP (r = 0.665; p = 2.50E-07) → strong • Number of Leaves At 9 WAP (r = 0.622; p = 2.36E-06) → strong • Number of Tillers At 4 WAP (r = 0.513; p = 0.00019) → moderate • Number of Tillers At 5 WAP (r = 0.460; p = 0.0010) → moderate • Number of Panicles (r = 0.499; p = 0.0003) → moderate • Fresh Biomass Weight (r = 0.261; p = 0.0029) → moderate
Number of Grains	• Milled Dry Grain (r = 0.411; p = 0.0037) → moderate • Grain Weight Per Hill (r = 0.378; p = 0.0081) → moderate • Number of Leaves At 6 WAP (r = 0.355; p = 0.0057) → moderate • 1000-Grain Weight (r = –0.346; p = 0.0161) → negative moderate
1000-Grain Weight	• Number of Leaves At 6 WAP (r = –0.415; p = 0.0034) → negative moderate • Number of Leaves At 5 WAP (r = –0.373; p = 0.0090) → negative moderate • Number of Tillers At 10 WAP (r = –0.425; p = 0.0026) → negative moderate • Number of Tillers At 9 WAP (r = –0.398; p = 0.0050) → negative moderate • Number of Grains (r = –0.346; p = 0.0161) → negative moderate

4 Conclusion

The results showed that the best treatment was obtained in C0P2 (100% field capacity and 100 kg SP-36 ha^{-1}), C0P3 (100% field capacity and 150 kg SP-36 ha^{-1}), and C1P2 (75% field capacity and 100 kg SP-36 ha^{-1}). This combination of treatments shows that an integrated approach between water management and phosphate fertilizer dosage can be applied to increase the growth and productivity of upland rice in drylands. This strategy is not only able to balance water and phosphate fertilizer requirements, but also results in higher fertilizer efficiency under moderate water stress conditions. In addition, an integrated data processing approach through multivariate analysis and correlation strengthened the understanding of the relationship between growth parameters and yield components. The analysis results show that yield components such as milled dry grain, grain weight per hill, and number of panicles are significantly interrelated and mutually supportive in determining the final productivity of the crop. Thus, the combination of optimal treatment and integrative data analysis is an important basis for the application of adaptive cultivation strategies in global climate change situation.

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