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Sustainability approach in cropping intensity (CI) 400 through optimizing the dosage of compost and chemical fertilizers to early-maturing rice varieties based on multivariate analysis

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ABSTRACT

The development of early maturing rice varieties in the cropping intensity 400 program is one of the alternatives in overcoming the challenges of rice production against land conversion and dynamic climate change. Optimization of the program is feasible through composting and reduction of chemical and synthetic substances in order to avoid excessive soil damage. Therefore, evaluation in the combination of compost and chemical fertilizers is important with evaluation criteria through multivariate analysis. This research aimed to identify evaluation criteria, fertilizer packages and potential of early maturing varieties in supporting the cropping intensity 400 concept on rice. This research was conducted in two locations in South Sulawesi, Indonesia with different environmental conditions … This study employed a nested split-plot design with a group randomized design as the environmental design. The main plot was the fertilizer package (FP) consisting of 5 levels. The subplots consisted of 7 rice varieties. Each combination of fertilizer package and variety was repeated three times. The results showed that reducing the dose of NPK fertilizer together with compost application is generally effective in the growth of early maturing rice. This study also revealed the characters of chlorophyll *a*, harvest age, panicle length, 1000-grain weight and yield were effective in evaluating the effect of fertilizer packages on early maturing varieties. The 75 % dose of N:P:K and 3 tons.ha^{-1} of compost is effective fertilizer packages to the growth and production of early maturing rice in supporting cropping intensity 400. The Cakrabuana, and Inpari 13 varieties are good early maturing varieties used with the FP3 fertilization packages. Conclusively, the results of this research are important for recommending optimization of rice cultivation with the CI 400 concept, especially in the South Sulawesi region.

1. Introduction

Rice is a main food and has been the main source of carbohydrates for most of the world's population, especially in Asia. , Asia dominates the top five largest rice production countries by contributing to 72.6 % of the world production. These countries are China (29.5 %), India (23.8 %), Bangladesh (7.0 %), Indonesia (6.9 %), and Vietnam (5.4 %) [1]. Moreover, the development of rice in Asia has always been a priority issue for the sake of food security. In Indonesia, rice production has experienced a relatively fluctuating increase every year [2]. However, this increase in production is still considered insignificant and unstable, consequently, Indonesia occasionally must import to cover the shortage

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of rice demand [2–4]. This phenomenon is caused by the rapid development and population growth every year, which has an impact on the decrease in rice planting area [5–7]. In addition, the challenge of climate change is also an obstacle for stable rice production [5]. Climate change can trigger various abiotic and biotic stresses that can be detrimental and result in crop failure in various regions [8–10]. Therefore, optimizing solutions to increase rice production in Indonesia always become priority effort to adapt to these two challenges.

The assembly of early maturing rice varieties is one option to face the challenges of development and climate change. Early maturing varieties yields under 100 days after planting; hence they are potential for optimizing the planted area per year [11–13]. According to Sutardi et al. [2], the development of early maturing varieties can optimize the potential harvest index four times per year (cropping intensity (CI) 400) in a farm. It enables the farmland to be more productive in supporting food security and the economy. In addition, early maturing varieties are alternative tolerance to avoid and minimize the impact of climate change [11,13]. Some early maturing rice varieties that have been developed are Inpari 13, Inpari 19, Cakrabuana, Padjajaran, and M70D. The five varieties have been reported to be optimal for achieving CI 400 in Indonesia, so they have become a favorite choice in supporting rice production in several regions [14–17]. However, the development of CI 400 on these varieties does not guarantee positive response. There are several issues that are taken into consideration in the optimization of CI 400. One of them is the aspect of environment and sustainability.

Intensive cultivation under the CI 400 concept causes soil properties to decline, especially physical [18–20] and biological [21–23]. Intensive cultivation makes tillage more frequent [18]. This causes soil structure to deteriorate and organic matter to decrease [19,20,24,25], so that high clay soils become increasingly sticky during the rainy season and hard during the dry season [26]. These conditions make it difficult for rice crops to grow and produce [24]. In addition, the process of mineralization and decomposition by microorganisms becomes faster, so that the potential of ecosystems and nutrients in supporting plant growth cannot be optimized [23,27]. Therefore, optimization through the concept of cultivation needs to be supportive to the genetic potential of early maturing varieties in the CI 400 concept.

The use of compost is one solution to improve soil quality and plant growth. Compost is the result of residual organic matter decomposed by soil microorganisms [28–30]. The description of organic matter can improve soil aggregates, so that the soil structure becomes crumblier with an optimal proportion between soil micro and macro pores [19,20, 31,32]. In addition, the compost will enrich the availability of essential nutrients that are easily absorbed by plants, especially microelements [18,27,30,33]. The decomposition that occurs will also indirectly multiply the colonies of decomposer microorganisms, so that when compost is applied it will further enrich the diversity of soil microorganisms that support the decomposition process in soil organic matter [27,34,35]. These advantages are expected to strengthen the concept of CI 400, especially when combined with a reduction in chemical fertilizer doses. The application of a combination of compost and reduced doses of chemical fertilizers has also been reported to be effective in several rice varieties [2,32,36,37]. However, these tests on early maturing varieties have not been reported comprehensively. Therefore, it is necessary to apply a combination of compost and chemical fertilizer doses to support the growth and production of early maturing rice varieties.

Evaluation of a combination of compost and chemical fertilizer dose-based fertilizer packages requires a systematic approach. The evaluation needs to consider the environmental effects of the study, so testing more than one environment is necessary [36,37]. However, multi-environment-based evaluation leads to a more comprehensive and complex level of data complexity. This requires a precise approach in assessing such evaluations, one of which is through multivariate analysis. Multivariate analysis can simplify, describe, categorize and reduce data with large dimensions to be more easily understood [38,39]. This analysis is very instrumental in determining potential character traits that represent the diversity of data to be examined in the evaluation process [39,40]. Several studies have reported the effectiveness of the multivariate analysis concept in the evaluation and selection process, both for strains [39,41–43] and combinations of cultivation technology packages [30,44]. Therefore, the use of multivariate analysis becomes necessary to be applied in the evaluation of fertilizer packages of compost and chemical fertilizer doses on the growth and production of early maturing rice. This concept will determine optimal evaluation characteristics in assessing the potential interaction between compost and chemical fertilizers on early maturing varieties, both in general and specific terms. This means the results of this interaction can be recommended as a fertilization basic for cultivating early maturing varieties in supporting CI 400. The purpose of this study is to identify evaluation criteria fertilizer packages and early maturing varieties that are potential in supporting rice growth and production, especially in the CI 400 concept.

2. Materials and methods

This research was conducted in two locations with different environments from August to November 2022. The first location was Tangke Bajeng village, Limbung sub-district, Gowa Regency, South Sulawesi provience, Indonesia at an altitude of 20 m above sea level, with coordinates 5°18′03.98 ″S 119°26′30.85 ″E. Tropical climate type which has a temperature of 30°-33 °C with andosol soil type. The second location was Apala village, Barebbo sub-district, Bone Regency at coordinates 4°36′40 ″S 120°17′52 ″E. Precipitation of the two locations were shown in Table 1. The selection of the two locations was based on the representation of climate zones in South Sulawesi, namely the western and eastern zones. Apart from that, both had farmers who are experts in aspects of cultivation, including organic farming. Therefore, these two optimal environments were applied as a first step in optimizing crop intensity 400. Table 2 showed the description of both environments.

2.1. Research design

This study employed a nested split-plot design, where replicates were nested within locations, with a group randomized design as the environmental design. The main plot was the fertilizer package (FP) consisting of 5 levels, namely P1 = Nitrogen (N), Phosphorus (P), and Potassium (K) (200:100:100), P2=NPK (200:100:100) + 2 tons.ha^{-1} of compost, P3 = 3/4 NPK (150:75:75) + 3 tons.ha^{-1} of compost, P4 = 1/2 NPK (100:50:50) + 4 tons.ha^{-1} of compost, and P5 = 1/4 NPK (50:25:25) + 5 tons.ha^{-1} of compost. The subplots consisted of 7 rice varieties (V), namely Padjajaran (V1), Cakrabuana (V2), Inpari 13 (V3), Inpari 19 (V4), M70D (V5), Ciherang (V6), and Inpari 32 (V7). Each combination of fertilizer package and variety was repeated three times, resulting in 105 experimental units. Each experimental unit was planted with a plot size of 3.5 m × 3.5 m.

2.2. Research procedure

The research procedure followed the general procedure in rice cultivation. First, soil preparation and tillage were carried out by tamping and plowing the land with a tractor. After that, beds were set for the nursery of each variety. The nursery started by soaking the rice seeds

Table 1
Precipitation of both environments (Bone and Gowa) during study in 2022.

Environment	Precipitation (mm) in 2022			
	August	September	October	November
Bone	231	297	296	80
Gowa	41.7	47.9	389.6	337.1

Table 2
Description of experimental locations.

Parameter	Unit	Bone		Gowa	
		Before	FP3	before	FP3
Texture		Dusty Clay		Clay	
Clay	%	37	41	13	18
Dust	%	53	56	40	46
Sand	%	10	8	47	45
C-Organic	%	1.89	2.06	0.72	0.98
Total Nitrogen	%	0.15	0.17	0.13	0.15
pH		6.17	6.75	6.24	6.35
P Olsen	cmol (+) kg^{-1}	9.1	12.9	31	32
K	Ppm	0.24	0.24	0.14	1.56
Ca	cmol (+) kg^{-1}	6.01	8.75	7.96	12.42
Mg	cmol (+) kg^{-1}	2.51	3.01	3.3	3.39
Na	cmol (+) kg^{-1}	0.078	0.048	0.02	0.018
Cation Exchange Capasity	me $100g^{-1}$	20.46	21.42	11.42	18.36

with clean water for 24 h and then spread on the seedbeds according to the variety label. After the seedlings were 15 days old, they were planted with a spacing of 20 cm × 20 cm in each plot, where each planting point consisted of 3 seedlings. The seedlings were then maintained by replanting, weeding, irrigating, fertilizing, and controlling pests and diseases.

Replanting was performed at the age of 7–14 days after transplanting (DAP). Dead and discarded plants were replaced with new plants from the rest of the nursery according to the variety. Weeding was performed at 15 and 30 days after transplanting by pulling weeds and applying herbicides. Irrigation was carried out 20 days after transplanting (6 days after initial fertilization), water was flowed into the experimental field until the water level reached ± 5 cm. Irrigation was stopped at the time of the second fertilization and the soil was allowed to heavily saturated but un-inundated (local term: macak-macak). Watering was done again 5 days after fertilization. At the age of ±45 DAP, water level was raised to ±10 cm from the soil surface to suppress the growth of new tillers.

Fertilization was done by applying compost and Phonska® NPK fertilizer combined with Urea adjusted to the dose of the fertilization package treatment. Compost was given 2 weeks before planting according to the treatment. Meanwhile, NPK fertilizer was given 2 times in stages. The first fertilizer was given after 14 DAP of planting and the second fertilizer was given after 45 DAP according to the treatment dose. Pest and disease control was carried out in the morning by spraying Regent® insecticides with fipronil 50sc active ingredient when an attack occurred. Rat pest control is carried out by mechanical control by destroying rat nests around rice field bunds and applying rodenticides made from active kumatetralil 0.75tp. Disease control was applied by spraying each experimental plot evenly with Explore® Fungicide with Difenoconazole active ingredient at the age of ±45–60 DAP.

Harvesting was done when 2/3 of the panicle has entered the physiological maturity phase (yellowing straw) and the rice grains at the base of the panicle have hardened. Harvesting was performed manually with a sickle and threshed using a rice thresher. Sample plants were harvested first, before harvesting the rest of the plot. The observed characters include plant height, number of productive tillers, harvest age, chlorophyll *a*, chlorophyll *b*, panicle length, total grain number, percentage of filled grain, flag leaf length, 1000-grain weight, and the yield.

2.3. Data analysis

The determination of evaluation criteria was based on three multivariate analyses, namely factor analysis, PCA biplot analysis, and cluster gram heatmap. The use of the three analyses together has not been widely reported in determining evaluation criteria. However, some research reports show the effectiveness of each analysis in determining selection or evaluation criteria. In general, factor analysis can reduce the diversity of big data to parameters with low internal covariance in influencing a multivariate dimension [39,45,46]. This advantage is very instrumental in determining characters that have a variety of characteristics in the process of evaluating treatment combinations [38,39]. The reduction is further sharpened by PCA biplot and clustergram analysis. Both analyses are often used together in the identification of clustering of objects and parameters [47–50]. PCA biplot analysis can show how the direction and magnitude of variance of one parameter is with respect to another in two dimensions [50]. This makes it possible to see the relationship and clustering of variance between characters in a multivariate manner. In addition, clustering is further supported by clustergram heatmap analysis. This analysis is able to map and visualize simply the grouping pattern of interactions between objects and parameters based on the accumulation of similarity of the middle value, so that information on the parameters that determine the grouping of objects can be identified [49,51]. The combination of the two analyses can recommend characters that can effectively reflect the diversity of data in the evaluation process. Therefore, the combination of the three analyses in determining evaluation criteria is considered effective, especially in evaluating the effect of fertilizer packages on the growth and production of early maturing rice. The use of the three analyses utilized Rstudio 3.6.1 software with factoextra and gplots package.

The predetermined evaluation criteria were deepened by further analysis based on the results of analysis of variance (ANOVA). Further analysis used the least significant distance (LSD) test at the 5 % error level. The evaluation was more focused on the source of diversity of the interaction, especially the interaction between the three. However, characters that do not have significant interactions between the three factors will continue with further tests on the interaction between the remaining two factors. ANOVA and further tests were conducted using STAR 2.0.1 software.

3. Results

3.1. Identification of agronomy evaluation criteria toward fertilizer technology package to variety growth

The factor analysis results show a total variance percentage of 70 %. Based on this analysis, there are 4 main factors with different characteristics of the characterizing parameters (Table 3). Factor 1 is characterized by chlorophyll *a* and chlorophyll *b* which have variance factor

Table 3
Factor analysis to rice growth and yield component on the combination of fertilizer package and varieties.

Variable	Factor1	Factor2	Factor3	Factor4	Communality
PH	0.131	0.23	0.101	0.018	0.665
NPT	0.218	−0.04	−0.004	−0.01	0.42
DH	0.137	0.074	−0.356	0.113	0.613
Chl_a	0.313	−0.058	−0.101	−0.069	0.859
Chl_b	0.309	−0.059	−0.052	−0.047	0.833
FFL	0.067	0.279	0.028	−0.398	0.686
PL	−0.074	0.399	0.123	0.147	0.797
NTG	−0.123	0.364	−0.087	0.013	0.663
PFG	−0.201	0.142	−0.366	−0.268	0.598
W1000	−0.008	0.023	0.082	0.817	0.836
Yield	0.026	−0.096	−0.711	−0.059	0.805
Variance (Var)	3.0774	2.2928	1.2879	1.1168	7.7749
% Var	0.28	0.208	0.117	0.102	0.7

Notes: PH = plant height, NPT = number of productive tillers, DH = days to harvesting, Chl a = chlorophyll *a*, Chl b = chlorophyll *b*, FFL = flag leaf length, PL = panicle length, NTG = number of total grains, PFG = percentage of filled grains, W1000 = Weight of 1000 grains.

loading values of 0.313 and 0.309, respectively. Factor 2 is characterized by the characters of panicle length and total grain number which have variance factor loading values of 0.399 and 0.364, respectively. Factor 3 is characterized by three characters namely harvest time, percentage of filled grains, and the yield. the three characters have loading values of −0.356, −0.366, and −0.711, respectively. Meanwhile, Factor 4 is only characterized by one character i.e. 1000-grain weight, with a loading factor value of 0.817.

The clustering of selected characters in the factor analysis was done by principal component analysis (PCA) and clustergram heatmap. Based on the PCA (Fig. 1), the yield had a low variance contribution compared to the eight selected characters in the factor analysis. In contrast, the highest contribution of diversity belonged to chlorophyll *a and b*, but the variance of both was not in the same direction as the variance of the yield. The characters of total grain number, panicle length, harvest age, and 1000-grain weight have the same direction of variation as the yield. Among these characters, total grain number and panicle length have a large degree of diversity in the group.

Based on the clustergram heatmap analysis (Fig. 2), there are three main groups that divide the grouping of treatment combinations. The first group consisted of yield, panicle length and 1000-grain weight. The second group consisted of percentage of filled grains, chlorophyll *b*, harvest time and total grain number. Meanwhile, the third group consisted of only one member of the growth character i.e. chlorophyll *a*.

3.2. Evalution effectiveness of fertilizer technology package to variety growth based on selected agronomy evaluation criteria

The results of analysis of variance (ANOVA) showed that chlorophyll *a* had an interaction among location, fertilizer package and variety (Table 4). In the first location (Bone), FP2 and FP3 were the most varied fertilizer packages among varieties, while FP1 and FP5 had relatively unchanged responses among early maturing varieties. Variety of Padjajaran had the highest chlorophyll in FP2, but not significantly different from Cakrabuana, Inpari 13, and Inpari 19. Inpari 13 had the highest chlorophyll in FP3 but was not significantly different from almost all varieties, except Padjajaran. Based on the second location (Gowa), FP1 and FP3 were fertilizer packages with different response on chlorophyll *a* among early maturing varieties. For both fertilizer packages, Ciherang remained the variety with the highest chlorophyll content i.e. 234.68 for FP1 and 230.35 for FP3.

The results of ANOVA showed that harvest time had a significant interaction betweenlocation and fertilizer package, as well as between location and variety (Table 5). The fertilizer package treatment in Bone showed that the FP4 and FP5 treatments had a longer harvest age than the FP1, FP2, and FP 3 treatments. On the other hand, in Gowa, all fertilizer packages showed the same harvest time. In addition, based on the source of variance, variety M70D had the fastest average harvest time in both Bone (91.3 days) and Gowa (83.00 days).

The results of ANOVA for panicle length showed interaction among environment, fertilizer package and variety (Table 6). In Bone, FP2 and FP5 showed very varied responses compared to other treatments. However, the FP3 package still has good potential in explaining the diversity of responses between varieties based on panicle length characteristics. For the FP2, The Padjajaran variety was the variety with the longest panicles, while for FP5, the Inpari 19 was variety with the longest panicles compared to other varieties. Although, these results were not significant compared to most varieties. Meanwhile, in Gowa, FP1 and FP3 were optimal technology packages in explaining the diversity of responses of each variety to fertilizer treatment. At the FP1 level, Inpari 19 variety had the longest panicles, although the responses were not significant compared to most the varieties. At the FP3 level, Ciherang was the variety with the longest panicles, but it was not significantly different from Inpari 19 and Inpari 32.

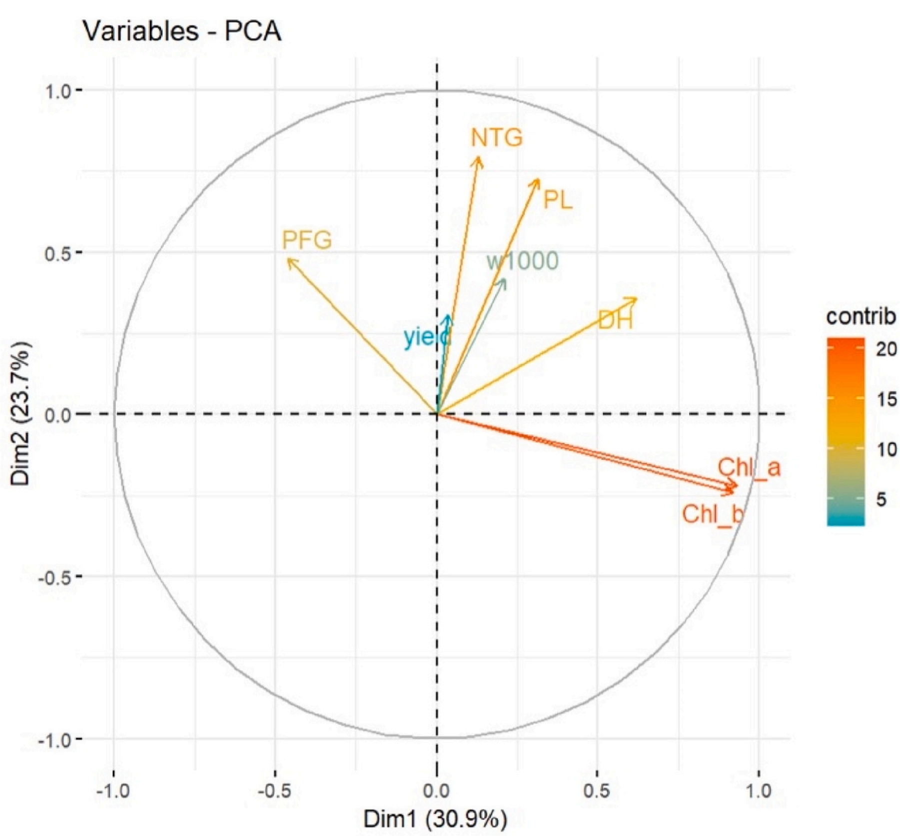

Fig. 1. Principal component biplot analysis on selected characters based on factor analysis. (DH = days to harvesting, Chl a = chlorophyll *a*, Chl b = chlorophyll *b*, PL = panicle length, NTG = number of total grains, PFG = percentage of filled grains, W1000 = Weight of 1000 grains).

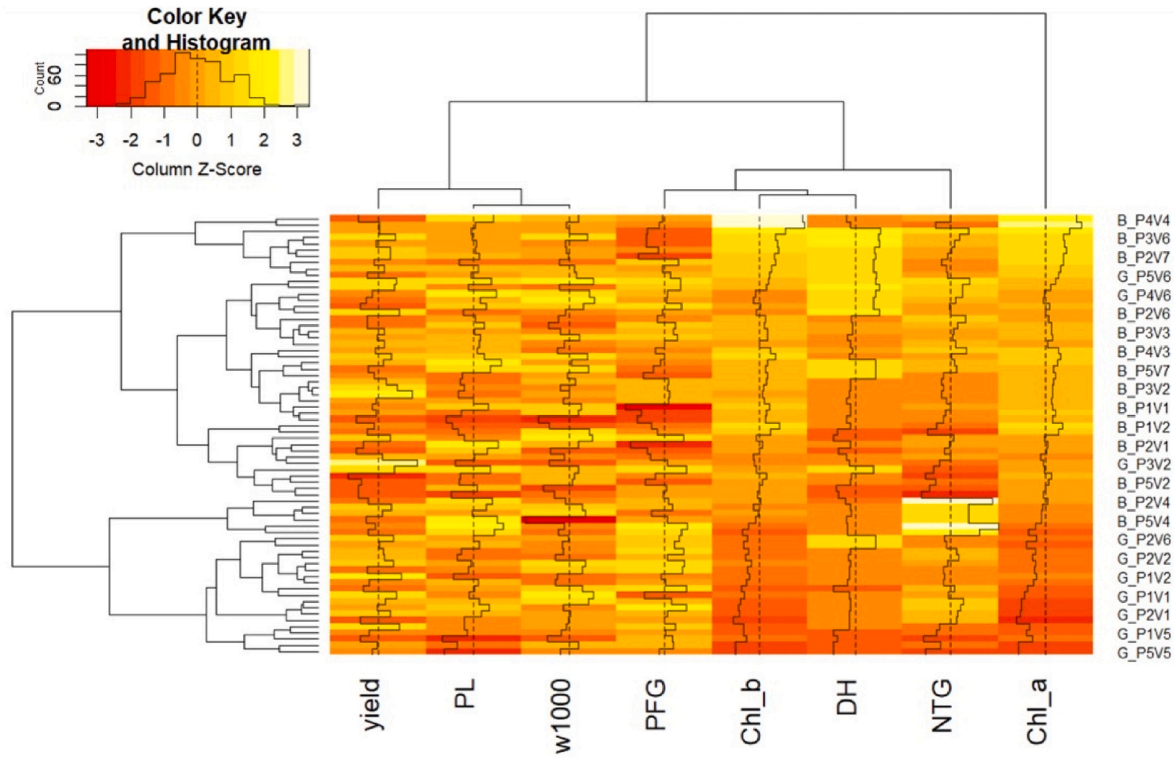

Fig. 2. heatmap clustergram analysis to the combination of fertilizer package and varieties based on selected characters of factor analysis. (DH = days to harvesting, Chl a = chlorophyll *a*, Chl b = chlorophyll *b*, PL = panicle length, NTG = number of total grains, PFG = percentage of filled grains, W1000 = Weight of 1000 grains).

Table 4
Chlorophyll *a* performance is based on interaction of environment, ferilizer package and variety.

Variety	Fertilizer Packages									
	FP1		FP2		FP3		FP4		FP5	
	chl a	notif	chl a	notif	chl a	notif	chl a	notif	chl a	notif
Bone										
Padjajaran	277.25	p	262.65	p	238.44	q	314.32	p	258.65	p
Cakrabuana	274.14	p	236.9	pqr	245.81	pq	255.39	q	249.43	p
Inpari 13	258.21	p	259.77	pq	271.63	p	249.44	q	250.97	p
Inpari 19	252.39	p	248.65	pqr	262.87	pq	311.55	p	238.92	p
M70D	255.75	p	228.96	r	259.42	pq	244.63	q	243.6	p
Ciherang	268.6	p	229.38	qr	255.79	pq	273.47	q	256.45	p
Inpari 32	259.19	p	254.91	pqr	262.62	pq	258.72	q	248.04	p
Gowa										
Padjajaran	166.23	bcd	211.29	a	225.02	ab	129.22	c	133.09	c
Cakrabuana	136.94	d	164.63	b	196.79	bc	179.13	b	174.25	b
Inpari 13	176.07	bc	201.65	a	154.75	d	124.64	c	139.83	c
Inpari 19	158.45	cd	189.21	ab	172.04	cd	171.1	b	173.79	b
M70D	139.39	d	159.74	b	195.69	bc	134.66	c	144.6	bc
Ciherang	234.68	a	202.7	a	230.35	a	188.14	b	139.84	c
Inpari 32	196.74	b	198.58	a	186.96	c	237.13	a	243.92	a

Notes: FP = fertilizer package, chl a = chlorophyll *a*, notif = notifications, the same letter in one column has same response.

The results of ANOVA of weight of 1000-grain showed that there was an interaction among location, fertilizer package and variety (Table 7). The fertilizer package treatments had relatively similar patterns of variation among genotypes. However, FP1, FP2 and FP3 were fertilizer packages that supported a potential weight of 1000 grains. In Bone, Padjajaran was the variety with the heaviest 1000-grain weight in the FP1 treatment. For FP2, Inpari 13 was the variety with the heaviest 1000-grain weight and for FP3, Inpari 32 had the heaviest 1000-grain weight. However, the best varieties in each FP were not significantly different from almost all varieties. Meanwhile, in Gowa, Inpari 32 was the variety with the heaviest 1000-grain weight at the FP1 level. However, this weight was not significantly different from all varieties, except Inpari 13. At the FP2 level, Padjajaran was the variety with the heaviest 1000-grain weight and was not significantly different from all varieties, except Cakrabuana. At FP3 level, M70D was the variety with the heaviest 1000-grain weight, but was not significantly different from Padjajaran, Inpari 13 and Ciherang.

The ANOVA of the yield characters showed that there was a significant interaction among environment, fertilizer packaging and variety (Table 8). For this character, all levels of fertilizer packages had relatively similar varying response patterns. However, FP1, FP2 and FP3 were fertilizer packages with good productivity potential. In Bone, Inpari 13 (6.51 tons ha-1, 7.38 tons ha-1), Ciherang (7.89 tons ha-1, 8.11 tons ha-1), and Inpari 32 (7, 22 tons ha-1, 7.55 tons ha −1) 1) showed

Table 5
Days to harvesting performance is based on interaction of environment x ferilizer package and environment x variety.

Treatment	Bone		Gowa	
	Days	notif	Days	notif
Fertilizer Package				
FP1	100.9	q	97.6	p
FP2	100.9	q	97.6	p
FP3	101.0	q	97.6	p
FP4	101.4	p	97.6	p
FP5	101.5	p	97.6	p
Variety				
Padjajaran	97.4	d	95.0	b
Cakrabuana	97.1	d	95.0	b
Inpari 13	99.1	c	95.0	b
Inpari 19	93.2	e	95.0	b
M70D	91.3	f	83.0	c
Ciherang	117.0	a	110.0	a
Inpari 32	112.9	b	110.0	a

Notes: FP = fertilizer package, notif = notifications, the same letter in one column has same response.

good yield response to FP1 and FP2 fertilizer packages. Inpari 32 variety (7.33 tons ha-1) had the highest yield in FP3 but was not significantly different from Cakrabuana (5.71 tons ha-1), Inpari 13 (6.56 tons ha-1), and Ciherang (7 0.11 tons ha-1). Meanwhile, based on the results in Gowa, all varieties had almost the same relative response to each fertilizer package regarding yield. For FP1 fertilizer package, Inpari 19 variety (4.81 tons ha-1) showed the highest yield response, but was not significantly different from all other varieties. For FP2, FP3 fertilizer packages, the Cakrabuana variety (7.05, and 8.20-tons ha-1) was the variety with the highest yield, but was not significantly different from the Padjajaran variety (6.56, 7.46-, and 5.81-tons ha-1).

4. Discussion

Based on factor analysis, PCA biplot, and clustergram heatmap; the characters of harvest time, chlorophyll *a* content, panicle length, 1000-grain weight and the yield are characters that can be used in evaluating the effect of fertilizer packages on the growth and production of early maturing rice. The five characters meet the standards of characterization on factor analysis along with the characters of chlorophyll *b* content, total grain number, and percentage of filled grains. The determination is based on the loading factor value that exceeds 0.3. This is in line with the

Table 6
Panicle length performance is based on interaction of environment, ferilizer package and variety.

Variety	Fertilizer Packages									
	FP1		FP2		FP3		FP4		FP5	
	PL (cm)	notif	PL (cm)	notif	PL (cm)	notif	PL (cm)	notif	PL (cm)	notif
Bone										
Padjajaran	24.82	p	26.24	p	23.81	pq	24.28	p	24.11	pqr
Cakrabuana	21.59	q	24.3	pqr	25.92	p	23.26	p	21.96	qr
Inpari 13	24.05	pq	24.68	pq	24.33	pq	25.00	p	24.5567	pq
Inpari 19	22.38	pq	24.81	pq	23.63	pq	25.62	p	25.5133	p
M70D	23.47	pq	21.39	r	22.61	q	24.45	p	21.2733	r
Ciherang	24.48	pq	21.99	qr	23.38	pq	22.81	p	22.4667	pqr
Inpari 32	24.41	pq	24.61	pq	25.88	p	22.98	p	24.9667	pq
Gowa										
Padjajaran	22.11	c	24.55	ab	21.66	bc	24.22	ab	23.77	a
Cakrabuana	23.89	abc	22.66	b	19.55	c	22.66	b	22.77	a
Inpari 13	23.11	abc	24.11	ab	23.33	b	23.44	b	25.11	a
Inpari 19	25.88	a	24.33	ab	24.11	ab	26.89	a	23.55	a
M70D	22.33	bc	24.44	ab	23.11	b	22.55	b	24.11	a
Ciherang	25.33	ab	26.67	a	26.56	a	24.88	ab	23.33	a
Inpari 32	24.67	abc	24.89	ab	24.66	ab	24	ab	22.33	a

Notes: FP = fertilizer package, PL = panicle length, notif = notifications, the same letter in one column has same response.

Table 7
Weight of 1000 grains performance is based on interaction of environment, ferilizer package and variety.

Variety	Fertilizer Packages									
	FP1		FP2		FP3		FP4		FP5	
	W1000 (g)	notif	W1000 (g)	notif	W1000 (g)	notif	W1000 (g)	notif	W1000 (g)	notif
Bone										
Padjajaran	28.07	p	27.43	pq	25.33	q	24.33	pq	26.90	pq
Cakrabuana	25.50	pq	27.63	pq	24.43	q	27.33	p	24.63	pq
Inpari 13	24.17	pq	29.13	p	25.63	q	22.87	q	23.84	qr
Inpari 19	22.50	q	26.33	pq	26.37	q	27.27	p	19.67	s
M70D	22.90	q	23.93	q	27.40	pq	22.93	q	20.43	rs
Ciherang	26.23	pq	27.33	pq	27.83	pq	27.47	p	23.37	qrs
Inpari 32	25.60	pq	27.60	pq	30.77	p	26.23	pq	28.20	p
Gowa										
Padjajaran	29.11	ab	31.11	a	29.44	ab	27.44	ab	30.11	a
Cakrabuana	29.33	ab	26.66	b	25.55	b	23.55	b	24.11	b
Inpari 13	26.33	b	30.89	a	28.89	ab	28.89	a	27.33	ab
Inpari 19	27.00	ab	28.66	ab	25.89	b	26.11	ab	25.44	b
M70D	30.22	ab	30.00	ab	31.55	a	28.00	a	26.44	ab
Ciherang	30.64	a	28.64	ab	28.30	ab	25.64	ab	25.30	b
Inpari 32	30.97	a	28.97	ab	26.97	b	26.64	ab	26.30	ab

FP = fertilizer package, W1000 = weight of 1000 grains, notif = notifications, the same letter in one column has same response.

Table 8
The yield performance is based on interaction of environment, ferilizer package and variety.

Variety	Fertilizer Packages									
	FP1		FP2		FP3		FP4		FP5	
	Yield (t/ha)	notif	Yield (t/ha)	notif	Yield (t/ha)	notif	Yield (t/ha)	notif	Yield (t/ha)	notif
Bone										
Padjajaran	5.71	qrs	5.18	q	4.98	q	4.87	pq	3.87	q
Cakrabuana	5.31	rs	5.35	q	5.71	pq	5.29	pq	4.78	pq
Inpari 13	6.51	pqr	7.38	p	6.56	pq	6.47	p	5.98	p
Inpari 19	4.22	s	5.51	q	5.29	q	4.33	q	4.67	pq
M70D	4.89	rs	5.38	q	5.00	q	4.89	pq	4.62	pq
Ciherang	7.89	p	8.11	p	7.11	p	6.56	p	6.33	p
Inpari 32	7.22	pq	7.55	p	7.33	p	6.33	p	6.11	p
Gowa										
Padjajaran	4.50	a	6.56	ab	7.46	a	5.41	ab	5.81	ab
Cakrabuana	4.05	a	7.05	a	8.20	a	6.10	a	6.47	a
Inpari 13	4.55	a	5.07	bc	5.49	b	4.32	b	3.83	c
Inpari 19	4.81	a	5.15	bc	5.60	b	4.58	ab	4.76	bc
M70D	4.64	a	3.85	cd	5.80	b	4.42	b	4.27	bc
Ciherang	3.89	a	4.15	cd	5.12	b	5.03	ab	4.22	bc
Inpari 32	3.61	a	3.39	d	5.60	b	4.52	ab	4.33	bc

FP = fertilizer package, notif = notifications, the same letter in one column has same response.

concept of Yong and Pieace [52], Farid et al. [42], Sakinah et al. [40], Momen et al. [38] and Anshori et al. [39]. Furthermore, the determination of the five selected characters is based on the interaction of PCA biplot analysis and clustergam heatmap. The selection of 1000-grain weight and panicle length as evaluation criteria is due to the fact that both characters have a strong relationship with the yield as the main evaluation criteria. This is the main supporting basis in the evaluation process in this study. The choice of chlorophyll *a* as an evaluation criterion is due to the wide diversity of this character compared to other characters. Although, the direction of chlorophyll *a* diversity is different from the yield. In addition, this character is independent in the process of grouping objects in clustergram analysis, so the use of chlorophyll *a* can be taken into consideration in the evaluation process. In contrast, chlorophyll *b* was not included as an evaluation criterion, although the diversity of the character was also high and became one of the determinants of object grouping. This is based on the fact that chlorophyll *b* has a pattern and the amount of variation that is relatively the same as chlorophyll *a*. This is ineffective considering that the ratio of chlorophyll *b* is also lower than chlorophyll *a*, which is 3:1 [53,54]. Meanwhile, harvest age was chosen as an evaluation criterion because this character has a diversity that is relatively in the same direction as the yield and has a grouping pattern that is relatively similar to chlorophyll *a and b*. In addition, harvest age is also in line with the special characteristics of early maturing rice [11–13], so this character is prioritized as an evaluation criterion. Therefore, these five characters are considered suitable to be the evaluation criteria in this study.

Based on the results of further tests on chlorophyll *a* content, the interaction between the environment, fertilizer package and varieties have a very dynamic pattern. There is no consistent pattern and effect between each combination. However, in general, there are two things that characterize the results of this study on chlorophyll *a* character, namely the influence of the environment and the application of compost fertilizer. The diversity of chlorophyll content patterns is more dynamic in the Bone environment compared to Gowa environment. This is due to the different rainfall between the two environments, especially in the vegetative phases. Rainfall affects the solubility and mobility of elements from soil to plants and plant cell division [55,56]. However, the main aspect that determined the pattern of variation was the fertilizer package. Compost fertilizer application shows a very diverse pattern, especially in supporting chlorophyll content due to changes in chemical fertilizer doses. In general, compost contains complete nutrients for growth, especially in the microelements Fe, Mn and Mo [57–59]. These three elements are very instrumental in supporting the potential chlorophyll content along with nitrogen [60–62]. In addition, compost also contains many microorganisms that are good for plant growth [63–66]. The advantages of compost make the chlorophyll content pattern more dynamic, especially when combined with chemical fertilizers, such as in FP3 with enough high consistent in both environments. This fertilizer packages were able to relatively increase the potential chlorophyll content in early maturing rice (V1–V5). Based on the overall explanation, the application of compost fertilizer, especially in FP3, can be recommended to increase the chlorophyll content of early maturing rice, especially under optimal rainfall.

Based on the results of the follow-up test, the environment with less rainfall had an earlier harvest time than the environment with more rainfall. This also influenced the insignificant effect of the fertilizer package on harvest time. In contrast, areas with high rainfall affected harvest time, where fertilizer packages with optimized nutrition, such as FP1 and FP2, had a relatively earlier harvest age. In general, harvest time is highly dependent on the heat unit received by the plant [67–70]. In the presence of high intensity rain, the heat unit per day becomes lower [67,68,70], so that the plant growth becomes slower than areas with low rainfall intensity. In addition, the effect of fertilization also affects the optimization of the interaction between nutrients and their heat unit capacity. This makes the harvest age pattern between fertilizer package levels different. However, the optimization does not affect the interaction between the fertilizer package and the variety or in other words, the changes in harvest time are static or additive. In contrast, the harvest time in areas with low rainfall is largely determined by its genetic potential. This causes the effect of fertilizer packages to have no significant effect on harvest time [71,72]. The variety with a consistent early harvest time in both environments is the M70D variety. According to Monica et al. [17] and Rismawati et al. [16], this variety is known to have a super early age, so the harvest age is consistently faster than other varieties in both environments.

Based on the results of further tests on panicle length characters, compost fertilizer application showed the best interaction on several varieties in both environments (Bone and Gowa). The response was clearly visible when compared to the fertilizer package level without compost application (FP1). This pattern also occurred in the 1000-grain weight character. Compost application relatively increased the 1000-grain weight potential compared to no compost application in both environments, especially in the FP2 and FP3 fertilizer packages. In general, compost dosing will affect the potential of yield components, such as panicle length and 1000-grain weight [73–75]. Both characters are highly related as part of the yield components. Several studies have also reported the relationship between panicle length and 1000-grain weight and the closeness of both to the main character of the yield

[39,76], so the interaction pattern of the two characters is relatively similar in this study. Although specifically, the best varieties on both characters are different in the interaction analysis. In the character of panicle length, varieties Inpari 13, and Ciherang are stable potential varieties in FP2 and FP3 fertilization packages in both environments. Conversely, on the character of 1000-grain weight, Varieties Inpari 13, and M70D became potential early maturing rice varieties in fertilization packages FP2 and FP3 in both environments. In addition, the decrease in chemical fertilizer doses on the growth of both characters can still be supported by compost fertilization [30,77,78] especially in FP3. This indicates that compost can make up for the lack of NPK chemical fertilizer doses in early maturing rice varieties. Based on this, the FP2 and FP3 fertilization packages can be recommended in supporting the yield components of early maturing rice varieties.

Based on further tests of the yield character, FP2 and FP3 fertilization packages are the best fertilization packages on both environments. In addition, varieties Cakrabuana and Inpari 13 became early maturing rice varieties with the same or higher yield potential than check varieties Ciherang and Inpari 32 in both fertilizer packages (FP2 and FP3). This result further confirms the application of compost fertilizer to be critical for early maturing rice varieties that have been described in the characters of chlorophyll *a*, panicle length and 1000-grain weight. Compost fertilizers that are rich in micro-nutrients and positive microorganisms for crops will support the production of these crops, despite a decrease in the dose of chemical fertilizers [30,77]. In addition, these results can also strengthen the design of the CI 400 concept in paddy fields, especially in the FP3 fertilization package. Reducing the dose of NPK chemical fertilizer by 25 % with the addition of compost by 3 tons/ha can balance the loss of potential from chemical fertilizers in supporting plant growth and productivity. Futhermore, these results are also supported by changes in the soil physicochemical properties which showed changes in several aspects for the better (Table 2). This fertilization package can also minimize the risk of damage to the physical properties of rice fields in the CI 400 concept [2,29,79]. Based on the explanation above, compost application in FP2 and FP3 is recommended in the cultivation of early maturing rice. Meanwhile, the combination of FP3 fertilization package with Cakrabuana, or Inpari 13 varieties is recommended in supporting rice cultivation in optimizing the CI 400 concept.

5. Conclusion

The results of this study concluded that the chlorophyll *a*, harvest age, panicle length, weight of 1000 grains, and the yield can be used to increase the effectiveness of agronomical evaluation in early maturity rice variety. FP2 (100 % dose of N:P:K and 2 tons.ha^{-1} of compost) and FP3 (75 % dose of N:P:K and 3 tons.ha^{-1} of compost) packages are recommended as effective fertilizer packages in supporting the growth and production of early maturing rice. For FP3 package, it is also effective to be applied in CI 400 planning. Varieties of Cakrabuana and Inpari 13 are early maturing varieties that are well used in FP2 and FP3 fertilization packages. Although this research shows good results, this research has limitations in the number of seasons and locations that do not represent the middle climate zone in South Sulawesi. Further research regarding these limitations needs to be carried out to support an effective policy in optimizing the development of early maturing rice, including the concept of CI 400 in Indonesia.

Credit authorship contribution statemen

Yunus Musa: Conceptualization, software, validation, formal analysis, writing-original draft preparation.

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Ahmad Fauzan Adzima: validation and investigation.

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Amran Sulaiman: supervision, and funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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