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Agronomic and morphological characteristics of two rice genotypes plant in open land and under two years of sengon (*Paraserianthes falcataria*)

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Abstract. *Dulbari, Mutaqin Z, Sutrisno H, Nuryanti NSP, Yuriansyah, Sudrajat D, Ahyuni D, Saputra H, Budiarti L, Priyadi, Rochman F, Rahmadi R, Firmansyah MA, Saijo. 2023. Agronomic and morphological characteristics of two rice genotypes plant in open land and under two years of sengon (*Paraserianthes falcataria*). Biodiversitas 24: 4927-4933.* The increase in population is the biggest challenge for the agricultural sector in providing food needs. The main problem in increasing food production in Indonesia is the limited agricultural land. There is a need to explore alternative land options to address this issue and enhance production capacity, specifically for rice at the national level. One of the potential solutions is to use land currently occupied by plantation crops and forests that can be managed through agroforestry. Sengon (*Paraserianthes falcataria* (L) I.C.Nielsen) is a forestry plant that offers a comparative advantage for investigation in agroforestry systems due to its relatively open canopy cover and classification as a legume. Therefore, this research aimed to determine the response of the morphological and agronomic characters of two rice genotypes planted in open land under 2-year-old sengon stands. The experiment was conducted from October 2017 to March 2018 in the Sengon community forest of Cikarawang, Bogor, with coordinates 06° 33.061' S and 106° 43.987' E. The results showed that two rice genotypes grown under one-year-old sengon stands experienced decreased productive tillers, plant height, stem strength, and the number and weight of grains per panicle. The IR 64 genotype decreased by 40.65% in grain weight per panicle, while the Situ Patenggang genotype experienced a 56.21% decrease.

Keywords: Adaptation, agroforestry, constraint, *sengon,* shade

Abbreviations: RBD: Randomized Block Design; G1: Genotype 1 IR46; G2: Genotype 2 Situ Patenggang; WAP: Weeks After Planting; O: Open land cultivation; A: Agroforestry system cultivation under 2-year-old *sengon* plants with a spacing of 2.5 m × 2.5 m

INTRODUCTION

The population of Indonesia in 2021 is more than 270 million, with a growth rate of 1.22 per year (BPS 2022). This growing population challenges adequate food sufficiency, crucial to achieving people's welfare. The adequacy of food, specifically rice, is a significant indicator of economic and political stability. Despite this significance, many efforts to maintain food availability and stability face various obstacles, including reduced productive agricultural land due to conversion for non-agricultural purposes. The land conversion for housing, factories, and industrial facilities significantly impacts agricultural land availability. Therefore, to maintain production stability and food security, alternative solutions are important to increase the area of agricultural land.

Therefore, one solution is planting food crops, specifically rice, on the plantation and forestry; this agroforestry practice involves using forests for agricultural activities. According to Korneeva (2022), agroforestry is a land-use system where forest stands and crops are planted on the same land. Octavia et al. (2022) stated that agroforest, with broad connotations, is the main driving technique in implementing social forestry. Furthermore, the objectives of agroforestry or intercropping in forest areas (Nair et al. 2021) include (i) increasing food supply, (ii) expanding employment opportunities, (iii) increasing the income and welfare of the community around the forest, and (iv) increasing the success of forest plantations.

Agroforestry is supposed as optimal and sustainable land use by combining forestry and agricultural activities on the same land management, considering the participating communities' physical, social, economic, and cultural conditions (de Mendonça et al. 2022). The main purpose of agroforestry and the intercropping system is to improve the welfare of village communities around the forest. This provides communities or *pesanggem f*armers opportunities to grow food crops to increase their income. Through this approach, villagers around the forest are expected to play an active role in conserving and protecting the forest and land from damage.

Moreover, research on adapting rice plants to low light stress conditions under plant stands is required. One suitable forestry vegetation for agroforestry with a light canopy is *sengon* (*Paraserianthes falcataria* (L) I.C.Nielsen syn. *Falcataria falcata* (L.) Greuter & R.Rankin), which is a native to Indonesia and thrives on well-drained, non-flooded land (Danarto et al. 2019). *Sengon* is frequently incorporated into agroforestry systems due to its relatively open canopy cover and leguminous characteristics. The *sengon* (Leguminoceae) roots form symbiotic relationships with Rhizobium, resulting in root nodules that bind free Nitrogen from the air. This phenomenon contributes to the plant's significant role in maintaining nutrient availability, specifically N, in the soil (Binkley and Fisher 2019).

Increasing the area of intercropping crops (agroforestry) and providing forest areas for food development is continuously carried out in the forestry sector to support food security (Duffy et al. 2021). Furthermore, Sengon trees can be combined with rice (*Oryza sativa* L.) on the same land, providing an alternative solution to increase community food security. Rice is an agricultural crop that can be developed on dry land; high rice production will increase rice supply, a basic need for the Indonesian people. However, there are several obstacles in developing rice varieties under plant stands, including determining genotypes that effectively adapt and the appropriate age of Sengon stands for intercropping.

This research aimed to determine the response of the morphological and agronomic characters of two rice genotypes planted in open land conditions and under 2-year-old *sengon* stands. The results will be used as input for increasing rice production capacity under agroforestry plantations or forestry plantations.

MATERIALS AND METHODS

Treatment and research design

The research was conducted from October 2017 to March 2018, using community forest land in Cikarang Village, Bogor Regency, West Java, at coordinates 06° 33.061' North Latitude and 106° 43.987' South Latitude. The land was planted with 2-year-old *sengon,* spaced at 2.5 m x 2.5 cm in an open land area. The analysis was arranged using a randomized block design (RBD) with a single-factor treatment of rice genotypes consisting of IR64 (G1) and Situ Patenggang (G2). Each treatment was repeated 5 times in 2 cultivation systems, namely open land cultivation (O) and agroforestry system cultivation under 2-year-old *sengon* plants (A). The linear model and analysis of variance followed the approach by Mattjik and Sumertajaya (2013):

$$Y_{ij} = \mu + \tau_i + \beta_j + \acute{\varepsilon}_{ij}.$$

Where: Y_{ij} -Observational value in the Ist treatment and jth group, μ-average, τ_i-effect of the ith treatment, β_j-jth group effect, $\acute{\varepsilon}_{ij}$-random effect in the Ith treatment and jth group.

Indicators of environmental conditions for the two planting locations are shown in Table 1.

Research implementation

The soil was processed to a depth of 25-30 cm, followed by creating beds with a width of 100 cm and a length of 1,000 cm. Seeds were sown directly at 25 cm x 25 cm spacing, with 2-3 seeds per planting hole. Basic fertilization was carried out when planting Urea 100 kg ha^{-1}, TSP 200 kg ha^{-1}, and KCl 50 kg ha^{-1}. Subsequently, a follow-up fertilization was conducted 4 weeks after planting, using Urea 100 kg ha^{-1} and KCl 50 kg ha^{-1}. Pest and disease control was carried out using pesticides according to plant conditions in the field with recommended doses. Weed control was carried out twice at the age of 3 and 6 weeks after planting (WAT).

The agronomic and morphological characteristics observation includes several aspects: the number of productive tillers, plant height, leaf color index, leaf chlorophyll content, stem diameter, stem strength, grain per panicle, and grain weight per panicle. These observations were carried out per the Guidelines for Characterization and Evaluation of Rice Plants (Silitonga et al. 2014).

The leaf color index was observed using SPAD meters. Observation of chlorophyll content was calculated using the equation: y = 0.113x, where y is the total leaf chlorophyll content, 0.113 = constant, and x = level of the greenness of leaves (from SPAD measurements) (Dulbari: unpublished data).

The observational data were analyzed for diversity using the Bartlett test. When the data met the requirements, further analysis of variance was carried out. Subsequently, the differences between treatments were analyzed using the T-test with $\alpha = 0.05$.

Table 1. Environmental indicators for planting locations

Indicator	Open	Agroforestry	Information
pH KCl	4.29	4.53	
H_2O	4.90	5.20	
N-total	0.26	1.62	%
P-total	131.90	105.34	mg P_2O_5 100g^{-1}
K-total	96.25	112.42	mg K_2O 100g^{-1}
P-tersedia	11.28	14.32	P_2O_5 ppm
C-organik	0.25	1.74	%
KTK	21.43	21.41	Cmol(+) kg^{-1}
Al-dd	0.26	0.78	Cmol(+) kg^{-1}
H-dd	0.33	0.40	Cmol(+) kg^{-1}
Ca-dd	3.04	3.36	Cmol(+) kg^{-1}
Mg-dd	2.82	3.30	Cmol(+) kg^{-1}
K-dd	0.77	1.20	Cmol(+) kg^{-1}
Na-dd	0.15	0.11	Cmol(+) kg^{-1}

RESULTS AND DISCUSSION

Number of productive tillers and plant height

The results of observing the number of tillers and plant height characteristics are shown in Figure 1.

The two rice genotypes experienced decreased growth and yield responses due to the dominant environmental influences of reduced sunlight. The reduction in response to plant height and the number of productive tillers in the two rice genotypes was due to the low intensity of sunlight, leading to a hindered rate of photosynthesis; it's supposed to be a genetic factor. That showed plants no longer have the energy to distribute assimilates-production to the demanded plant parts. This distribution was done using tools such as proteins and proton pumps driven by ATP (ATP-Ase), which necessitated energy and enzymes. Similarly, Amin et al. (2021) stated that plants maintained an electrochemical balance within the entire biomembrane to ensure survival.

The closing rate of 2-year-old *sengon* stands with a spacing of 2.5 m x 2.5 m prevented light interception by approximately 80%. Therefore, photosynthesis, which served as the main energy source for plants to carry out growth processes, was disrupted.

Leaf color index character and leaf chlorophyll content

The results of leaf color index characteristic observations and leaf chlorophyll content are shown in Figure 2.

The two genotypes' leaf color index characters and leaf chlorophyll content had different tendencies. For genotype 1 (IR 64), these variables showed decreased growing conditions under 2-year-old sengon stands (agroforestry). The leaf color index decreased from 25.02 to 15.34, while the chlorophyll content of the leaves reduced from 2.83 to 1.73. For genotype 2 (Situ Patenggang), the variables showed a tendency to increase in growing conditions under 2-year-old *sengon* stands (agroforestry), where leaf color index increased from 16.10 to 17.96, and chlorophyll content increased from 1.82 to 2.03. That showed the genotypic response to leaf color index characters and chlorophyll content differed due to the adaptability of the IR64 and Situ Patenggang rice genotypes to shade stress.

Each genotype exhibited a different response and ability to adapt to the environment. In this research, the plant growth environment was different, specifically regarding sunlight intensity. Plants responded to the differences in light intensity according to their genetic capacity. Furthermore, plants developed acclimatization and plasticity methods to respond to environmental stress through morphological, anatomical, and physiological adjustments (Yetgin 2023).

Flag leaf size character

The results of observations of flag leaf size characters are shown in Figure 3.

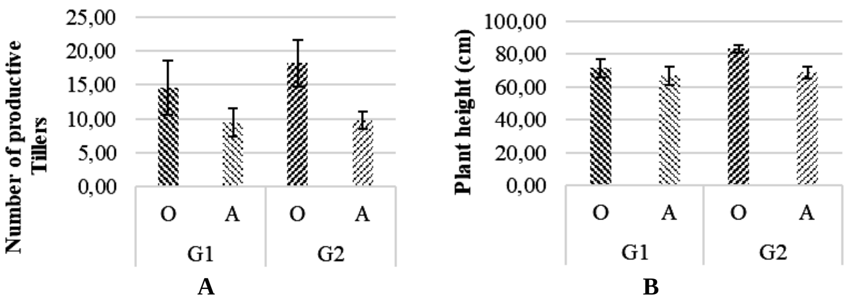

Figure 1. A. Number of productive tiller character, B. Plant height character. G1: Rice genotype 1 (IR64); G2: Rice genotype 2 (Situ Patenggang); O: Open, A: Agroforestry

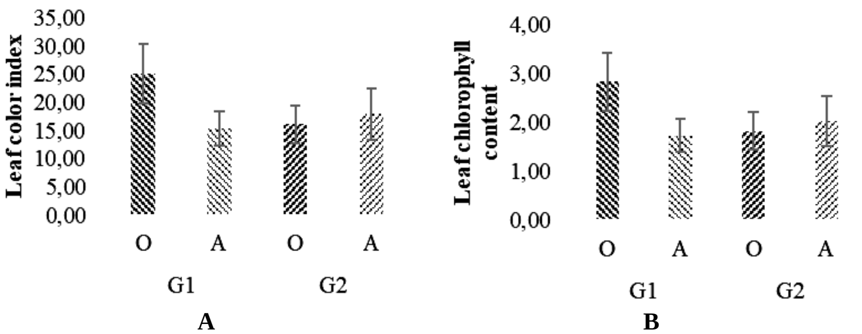

Figure 2. A. Leaf color index (SPAD), B. Leaf chlorophyll content (Chl Leaf), G1: Rice genotype 1 (IR64); G2: Rice genotype 2 (Situ Patenggang), O: Open; A: Agroforestry

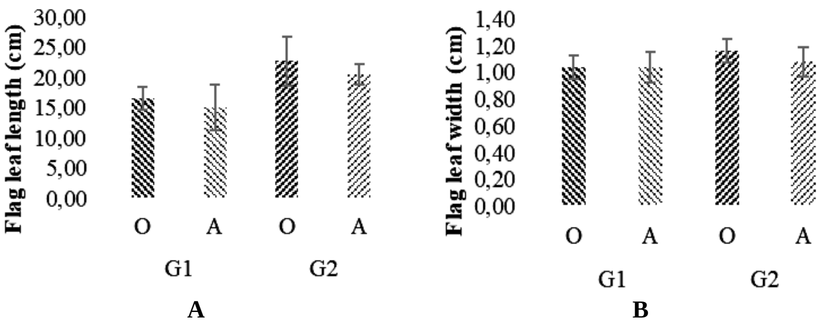

Figure 3. A. Flag leaf length character, B. Flag leaf width character. G1: Rice genotype 1 (IR64); G2: Rice genotype 2 (Situ Patenggang); O: Open; A: Agroforestry

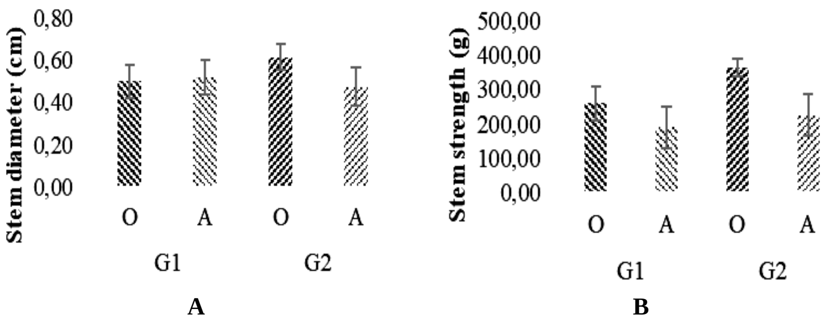

Figure 4. A. Stem diameter character, B. Stem strength character, G1-rice genotype 1 (IR64), G2-rice genotype 2 (Situ Patenggang), O-open, A-agroforestry

The two rice genotypes' responses to flag leaf size characters (length and width) showed no significant differences under open location and 2-year-old *sengon* (agroforestry) planting. However, significant variations were observed between the genotypes, indicating that the genotypes had different adaptation abilities to the stresses. The IR64 genotype showed a relatively stable response to flag leaf length and width, namely 16.58 and 15.04, as well as 1.04 and 1.04. Meanwhile, the Situ Patenggang genotype showed an insignificant decreasing trend for length measurements from 22.76 to 20.54 and width sizes from 1.16 to 1.08.

The morphology of rice plants' flag leaf (Sink) was important in filling the plant's grains. The large sink characteristic in superior rice varieties had a higher photosynthetic rate. Furthermore, the upright morphology of the leaves allowed greater penetration and distribution of light to the bottom, causing an increase in plant photosynthesis. According to previous research, the photosynthesis of plants in upright leaf canopies is about 20% higher than in drooping leaf canopies under high leaf area index conditions (Pan et al. 2023). The flag leaf, as a light-harvesting organ, can allocate its assimilates to panicle formation, thereby influencing the length of the panicle and the number of seeds per panicle. The less ideal flag leaf morphology also affected tiller and grain growth (Liu et al. 2014). Furthermore, the flag leaf size affected the number of stomata pores, influencing the ability to exchange H_2O and CO_2 (Franks and Beerling 2009).

Diameter and stem strength character

The results of observations of stem diameter and strength characters are shown in Figure 4.

The responses of the two rice genotypes, cultivated under open conditions and 2-year-old *sengon* trees, did not show significant differences in the stem diameter character. However, there was a significant variation in the stem strength characteristics. The IR64 tended not to experience a change in stem diameter, compared to Situ Patenggang, which decreased stem diameter from 0.61 cm to 0.47 cm. On underexposed conditions and a 2-year-old *sengon* tree to stem strength characters, both genotypes experienced a significant decrease. The IR 64 genotype decreased from 260.00 g to 191.00 g, and Situ Patenggang reduced from 364.00 g to 226.00 g.

The characteristic of stem strength is crucial for plants to withstand lodging, which can significantly affect crop production due to potential yield losses (Dulbari et al. 2018). Larger stem diameter plants also exhibit better strength and the characteristic of stem strength is significantly correlated with stem diameter, at a correlation coefficient value (0.77) (Dulbari; data has not been published). That indicated rice plant genotypes with a larger lower stem diameter (± 10 cm above the soil surface) had a better stem strength, thereby following the research of (Zhang et al. 2014) and (Dreccer et al. 2020).

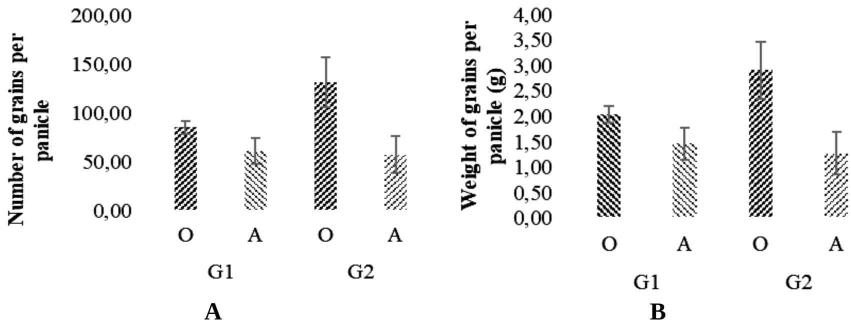

Figure 5. A. The number of grains per panicle character; B. The weight of grains per panicle; G1: Rice genotype 1 (IR64); G2: Rice genotype 2 (Situ Patenggang); O: Open; A: Agroforestry

The number of grain and grain weight characteristics per panicle

The results of observing the character of the number of grains and the weight of grain per panicle are shown in Figure 5.

The response of the rice genotypes cultivated in open land conditions and under 2-year-old *sengon* trees experienced a significant decrease in the number of grains per panicle and grain weight per panicle, which were the yield component characteristics. The IR 64 genotype exhibited a smaller reduction in the number of grains per panicle (85.00 to 61.40) compared to the Situ Patenggang (132.00 to 57.60). Similarly, the grain weight per panicle also had the same tendency, with IR 64 genotypes ranging from 2.40 to 1.46 (40.65%) and Situ Patenggang from 2.90 g to 1.27 g (56.21%). This showed that genotype significantly influenced planting plans under agroforestry crop stands.

The characteristics of grain number and weight were the results of plant metabolism processes, which were closely related to the process of photosynthetic ability (source) and the distribution of the assimilates to the sink. Environmental conditions, such as light, temperature, and humidity, significantly influenced plants' ability to produce the grain amount and weight per panicle. Furthermore, light intensity was closely related to temperature, with lower values resulting in reduced rice products and quality (Dutta et al. 2017).

Light is crucial in regulating the opening and closing of stomata. Lower light intensity will make stomata tend to close, thereby hindering CO_2 entry. Limited CO_2 and sunlight also caused a decrease in the rate of photosynthesis, impacting the assimilation of carbohydrates and biomass formation (Liu et al. 2014). Moreover, the regulation of stomatal opening is a dynamic and reversible process; water loss and CO_2 inflow rapidly adjust in response to several environmental and intrinsic signals, such as light, CO_2, and the plant stress hormone abscisic acid (Bhattacharya 2021). The ability of plants to produce and distribute photosynthate to their storage organs is an important part of increasing crop production (Fischer et al. 2012).

Agronomic and morphological characteristics of two rice genotypes under open conditions and agroforestry

The results of the observations of the agronomic and morphological characters of the two rice genotypes planted in open land conditions and under 2-year-old *sengon* stands are shown in Table 2.

The agronomic and morphological characters of the two rice genotypes grown in different environmental conditions (open and under a 2-year-old *sengon* stand) showed different responses. These included the number of tillers, plant height, stem strength, number of grains per panicle, and grain weight per panicle. The response of the agronomic and morphological characteristics of cultivated plants under 2-year-old *sengon* trees significantly decreased. There was no significant difference in the leaf color index characters, leaf chlorophyll content, stem diameter, as well as the length and width of the flag leaf. This showed that the character was more determined by genetic factors. However, the overall character was still influenced by pressure due to environmental factors, with light being the dominant. Measurements showed that the intensity of sunlight on open land was 52,800 lux, which decreased to 10,468 lux on agroforestry land (shade 80%). The limitation of light availability was the main contributing factor to the genotypic response experiencing a decreased ability to express morphological and agronomic characters optimally.

Sunlight is a source of energy for photosynthesis. The absorption of sunlight by the plant canopy is an important factor that determines photosynthesis and plant yield. Previous research reported that plants use the light spectrum in the 400-700 nm wavelength range, commonly called Photosynthetically Active Radiation (PAR) (Prakash et al. 2023). Generally, shade affects the intensity of sunlight plants receive, influencing energy availability or growth and yield processed (Raffo et al. 2020). Therefore, to avoid the harmful effects of low light, tolerant varieties can be used to maintain the ability to produce carbohydrates, improve photosynthetic efficiency, and enhance the ability to produce antioxidants as a form of plant adaptation to stress in low-light conditions (Kowalczewski et al. 2020).

Table 2. Character number of tillers, plant height, leaf color index, leaf chlorophyll content, stem diameter of 2 rice genotypes in an open environment, and agroforestry

Replication	Number of tillers				Plant height				Leaf color index				Leaf chlorophyll content				Stem diameter			
	O		A		O		A		O		A		O		A		O		A	
	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
1	10.00	23.00	11.00	9.00	70.00	84.00	60.00	66.00	26.10	20.90	13.30	18.30	2.95	2.36	1.50	2.07	0.56	0.69	0.43	0.41
2	14.00	18.00	8.00	10.00	72.00	80.00	70.00	74.00	32.90	18.40	13.10	24.20	3.72	2.08	1.48	2.73	0.51	0.65	0.61	0.36
3	21.00	20.00	9.00	8.00	80.00	86.00	72.00	68.00	24.90	14.20	15.20	19.50	2.81	1.60	1.72	2.20	0.41	0.58	0.60	0.49
4	15.00	15.00	12.00	11.00	65.00	84.00	62.00	70.00	18.50	14.10	14.70	15.90	2.09	1.59	1.66	1.80	0.43	0.62	0.47	0.59
5	13.00	15.00	7.00	11.00	70.00	82.00	70.00	66.00	22.70	12.90	20.40	11.90	2.57	1.46	2.31	1.34	0.59	0.53	0.48	0.52
Mean	14.60	18.20	9.40	9.80	71.40	83.20	66.80	68.80	25.02	16.10	15.34	17.96	2.83	1.82	1.73	2.03	0.50	0.61	0.52	0.47
Combine	16.40		9.60		77.30		67.80		20.56		16.65		2.32		1.88		0.56		0.50	
Stdev	3.73		1.65		3.87		4.38		4.33		3.75		0.49		0.43		0.07		0.09	
Notation	**				**				ns				ns				ns			
P-Value	0.001				0.002				0.161				0.161				0.240			

Note: O: Open; A: Agroforestry; G1: Rice genotype (IR64); G2: Rice genotype (Situ Patenggang); ns: not significant; **: significantly different in the α 1% t-test level

Table 3. Characteristics of stem strength, length of flag leaf, the width of flag leaf, number of grains per panicle, and grain weight per panicle of 2 rice genotypes in an open environment and agroforestry

Replication	Stem strength				Flag leaf length				Flag leaf width				Number of grains per panicle				Grain weight per panicle			
	O		A		O		A		O		A		O		A		O		A	
	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2	G1	G2
1	310.00	360.00	180.00	190.00	14.30	27.00	11.00	20.00	1.00	1.20	1.00	1.00	86.00	165.00	66.00	50.00	2.05	3.64	1.57	1.10
2	220.00	380.00	150.00	240.00	16.20	16.00	20.00	23.20	1.00	1.10	1.20	1.00	75.00	98.00	48.00	52.00	1.79	2.16	1.14	1.15
3	220.00	340.00	130.00	140.00	16.60	23.50	12.30	20.00	1.00	1.30	1.10	1.20	86.00	130.00	61.00	87.00	2.05	2.87	1.45	1.92
4	230.00	340.00	285.00	290.00	16.30	22.80	17.50	21.00	1.00	1.10	0.90	1.20	88.00	147.00	81.00	63.00	2.10	3.24	1.93	1.39
5	320.00	400.00	210.00	270.00	19.50	24.50	14.40	18.50	1.20	1.10	1.00	1.00	93.00	120.00	51.00	36.00	2.22	2.65	1.22	0.79
Mean	260.00	364.00	191.00	226.00	16.58	22.76	15.04	20.54	1.04	1.16	1.04	1.08	85.60	132.00	61.40	57.60	2.04	2.91	1.46	1.27
Combine	312.00		208.50		19.67		17.79		1.10		1.06		108.80		59.50		2.48		1.37	
Stdev	66.63		60.28		4.43		3.98		0.11		0.11		30.14		15.56		0.60		0.36	
Notation	**				ns				ns				**				**			
P-Value	0.001				0.226				0.373				0.001				0.001			

Note: O: Open; A: Agroforestry; G1: Rice genotype (IR64): G2: Rice genotype (Situ Patenggang); ns: not significant; **: significantly different in the α 1% t-test level

In conclusion, the rice genotypes planted under 2-year-old *sengon* stands experienced decreased productive tillers, plant height, stem strength, number of grains, and grain weight per panicle characteristics. The IR 64 genotype decreased grain weight per panicle by 40.65%, and the Situ Patenggang genotype by 56.21%. The growth limitations imposed by the 2-year-old *sengon* trees suppressed the expression of character indices of leaf color, leaf chlorophyll content, stem diameter, length, and width of flag leaves of two genotypes of rice plants. However, these results showed no statistically significant. There is a need to evaluate the use of rice agroforestry systems under 2-year-old Sengon stands with a spacing of 2.5 m × 2.5 m. Moreover, when the conditions require more development, thinning should be carried out beforehand to provide sufficient space for the intensity of sunlight to support plant growth and production.

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REFERENCES

Amin I, Rasool S, Mir MA, Wani W, Masoodi KZ, Ahmad P. 2021. Ion homeostasis for salinity tolerance in plants: A molecular approach. Physiol Plant 171 (4): 578-594. DOI: 10.1111/ppl.13185.

Bhattacharya A. 2021. Effect of soil water deficit on growth and development of plants: A review. Soil Water Deficit Physiol Issues Plants: 393-488. DOI: 10.1007/978-981-33-6276-5_5.

Binkley D, Fisher RF. 2019. Ecology and management of forest soils. John Wiley & Sons, Hoboken, New Jersey. DOI: 10.1002/9781119455745.

BPS (Badan Pusat Statistik). 2022. Statistik Indonesia 2022. https://www.bps.go.id/.

Danarto SA, Budiharta S, Fauziah F. 2019. Tree species preference and rehabilitation perspective by local community: Case study in Bondowoso, East Java, Indonesia. Asian J For 3 (2): 5 DOI: 10.13057/asianjfor/r030202.

de Mendonça GC, Costa RCA, Parras R, de Oliveira LCM, Abdo MTVN, Pacheco FAL, Pissarra TCT. 2022. Spatial indicator of priority areas for the implementation of agroforestry systems: An optimization strategy for agricultural landscapes restoration. Sci Total Environ 839: 156185. DOI: 10.1016/j.scitotenv.2022.156185.

Dreccer MF, Condon AG, Macdonald B, Rebetzke GJ, Awasi MA, Borgognone MG, Peake A, Piñera-Chavez FJ, Hundt A, Jackway P. 2020. Genotypic variation for lodging tolerance in spring wheat: wider and deeper root plates, a feature of low lodging, high yielding germplasm. Field Crops Res 258: 107942. DOI: 10.1016/j.fcr.2020.107942.

Duffy C, Toth GG, Hagan RPO, McKeown PC, Rahman SA, Widyaningsih Y, Sunderland TCH, Spillane C. 2021. Agroforestry contributions to smallholder farmer food security in Indonesia. Agrofor Syst 95 (6): 1109-1124. DOI: 10.1007/s10457-021-00632-8.

Dulbari D, Santosa E, Koesmaryono Y, Sulistyono E. 2018. Pendugaan kehilangan hasil pada tanaman padi rebah akibat terpaan angin kencang dan curah hujan tinggi. Indones J Agron 46 (1): 17-23. DOI: 10.24831/jai.v46i1.14376. [Indonesian]

Dutta SS, Tyagi W, Rai M. 2017. Physiological and molecular response to low light intensity in rice: A review. Agric Rev 38 (3): 209-215. DOI: 10.0.73.117/ag.v38i03.8980.

Fischer G, Almanza-Merchán PJ, Ramírez F. 2012. Source-sink relationships in fruit species: A review. Rev Colomb Cienc Hortic 6 (2): 238-253. DOI: 10.17584/rcch.2012v6i2.1980.

Franks PJ, Beerling DJ. 2009. CO_2-forced evolution of plant gas exchange capacity and water-use efficiency over the Phanerozoic. Geobiology 7 (2): 227-236. DOI: 10.1111/j.1472-4669.2009.00193.x.

Korneeva EA. 2022. Economic assessment and management of agroforestry productivity from the perspective of sustainable land use in the south of the Russian plain. Forests 13 (2): 172. DOI: 10.3390/f13020172.

Kowalczewski PŁ, Radzikowska D, Ivanišová E, Szwengiel A, Kačániová M, Sawinska Z. 2020. Influence of abiotic stress factors on the antioxidant properties and polyphenols profile composition of green barley (*Hordeum vulgare* L.). Intl J Mol Sci 21 (2): 397. DOI: 10.3390/ijms21020397.

Liu Q, Wu X, Chen B, Ma J, Gao J. 2014. Effects of Low light on agronomic and physiological characteristics of rice including grain yield and quality. Rice Sci 21 (5): 243-251. DOI: 10.1016/S1672-6308(13)60192-4.

Mattjik AA, Sumertajaya IM. 2013. Design Experiment with SAS and Minitab Software. IPB Press, Bogor. [Indonesian]

Nair PKR, Kumar BM, Nair VD, Nair PKR, Kumar BM, Nair VD. 2021. An Introduction to Agroforestry: Four Decades of Scientific Developments. Springer, Cham. DOI: 10.1007/978-3-030-75358-0.

Octavia D, Suharti S, Murniati, Dharmawan IWS, Nugroho HYSH, Supriyanto B, Rohadi D, Njurumana GN, Yeny I, Hani A. 2022. Mainstreaming smart agroforestry for social forestry implementation to support sustainable development goals in Indonesia: A review. Sustainability 14 (15): 9313. DOI: 10.3390/su14159313.

Pan Y, Cao Y, Chai Y, Meng X, Wang M, Wang G, Guo S. 2023. Identification of photosynthetic parameters for superior yield of two super hybrid rice varieties: A cross-scale study from leaf to canopy. Front Plant Sci 14: 1110257. DOI: 10.3389/fpls.2023.1110257.

Prakash V, Lunagaria MM, Trivedi AP, Upadhyaya A, Kumar R, Das A, Kumar GA, Kumar Y. 2023. Shading and PAR under different density agrivoltaic systems, their simulation and effect on wheat productivity. Eur J Agron 149: 126922. DOI: 10.1016/j.eja.2023.126922.

Raffo A, Mozzanini E, Nicoli FS, Lupotto E, Cervelli C. 2020. Effect of light intensity and water availability on plant growth, essential oil production and composition in *Rosmarinus officinalis* L. Eur Food Res Technol 246 (1): 167-177. DOI: 10.1007/s00217-019-03396-9.

Silitonga TS, Somantri IH, Daradjat AA, Kurniawan H. 2014. Guidelines for Characterization and Evaluation of Rice Plants. Center for Research and Development of Biotechnology and Agricultural Genetic Resources. Agricultural Research and Development Center. Ministry of Agriculture. [Indonesian]

Yetgin A. 2023. Exploring the dynamic nature of root plasticity and morphology in the face of changing environments. Acta Ecol Sin. DOI: 10.1016/j.chnaes.2023.07.008.

Zhang J, Li G, Song Y, Liu Z, Yang C, Tang S, Zheng C, Wang S, Ding Y. 2014. Lodging resistance characteristics of high-yielding rice populations. Field Crops Res 161: 64-74. DOI: 10.1016/j.fcr.2014.01.012.