



Growth and Production of Tall and Short Rice Genotypes in Multicanopy Cultivation

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ABSTRACT

Multi-canopy rice cultivation is a cropping approach that combines tall and short rice genotypes within the same planting system to optimize vertical canopy space and improve land-use efficiency. This study aimed to evaluate the growth, physiological responses, yield components, and land equivalent ratio (LER) of tall and short rice genotypes under monoculture and multi-canopy cultivation systems. This experiment was conducted between December 2024 and May 2025 at the Sawah Baru Experimental Farm, IPB, using a randomised complete block design comprising a single factor: the combination of plant varieties and multi-canopy systems. The treatment combinations comprised short-statured varieties (IPB202-F-1, IPB201-F-1) and tall-statured varieties (IPB197-E-1, IPB200-F-51) and the multi-canopy intercropping systems (Intercropping 1 and Intercropping 2) as well as monoculture. The results of the study indicate that the cropping system and genotype combinations have a significant effect on the number of productive tillers and the number of grains per panicle, but do not have a significant effect on most physiological traits, panicle length, and 1000-grain weight. The highest number of productive tillers was obtained in the IPB201 monoculture, whilst the highest number of grains per panicle was obtained in the IPB202–IPB200 combination in the two-row interplanting system. All multi-canopy combinations produced an NKL value greater than one, indicating higher land-use efficiency compared to the monoculture system. The IPB201–IPB200 combination in the double-row system yielded the highest NKL value of 1.59. The results of this study indicate that the appropriate combination of tall and short rice genotypes, particularly in the double-row system, can improve land-use efficiency and has the potential to support the sustainable intensification of rice cultivation on limited land.

Keywords: Genotype Combination; Land Equivalent Ratio; Multi-Canopy System; Rice Yield.

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INTRODUCTION

Rice is the main source of carbohydrates for the Indonesian people and a source of livelihood for millions of farmers in Asia (Henny *et al.* 2021). The rice harvest area from January to April 2024 is estimated at 3.52 million hectares, representing a decrease of 0.69 million hectares (16.48%) compared to the previous period. Rice production also decreased by 18.59 million tonnes of grain equivalent in January to April 2024, compared to last year's rice production, which decreased by 3.95 million tonnes of grain equivalent (17.54%) (BPS 2024). The ability to produce food is not proportional to the increase in population (Juliyanti and Usman, 2018). With the increase in harvested land area, agricultural production also tends to increase, with land availability and quality greatly determining agricultural productivity (Suryadi and Rusastra 2021).

Land area has a significant influence on rice production levels (Henny *et al.* 2021). Although population pressure has led to increasingly limited agricultural land, rice production can still be increased through the development of modern cultivation techniques, the use of high-yield rice varieties, and the

optimisation of production inputs (Xin *et al.* 2022). Given the rapid population growth and declining quality of agricultural land, intensive efforts to increase rice production are essential to meet food needs (Nakano *et al.* 2023). There is an innovation in rice cultivation to increase production, namely the multi-canopy cropping system. This method is an alternative to the monoculture system. The multi-canopy system involves planting two rice genotypes with different plant heights and close planting distances. The difference between tall and short rice genotypes will form tiered panicles so that vertical harvesting space can be utilised, thereby increasing grain yield per unit area (Widyastuti *et al.* 2020; Hidayah *et al.* 2022). The multi-canopy cultivation system can influence plant characteristics and produce better rice compared to monovarietal cultivation (Lazzaro *et al.* 2018). According to Reiss and Drinkwater (2017), the increase in rice production in the multi-canopy cultivation system reached 2.2% of the harvest yield compared to the monovarietal cultivation system. According to Widyastuti *et al.* (2020), the multi-canopy planting system affects several components of rice yield and

growth characteristics, as well as increasing rice production by 0.54 t ha⁻¹ compared to monoculture. The use of a multi-canopy planting system for rice also has a significant effect on the total number of tillers and productive tillers, as well as the total number of filled grains (Sholehah *et al.* 2024).

Placing short and tall characters in one place does provide many benefits, but it also has a negative impact, namely competition for nutrients caused by the same root space. In addition, the multi-canopy cultivation system also affects plants in obtaining sunlight (Widyastuti *et al.* 2020). Optimal light availability will increase plant productivity through increased photosynthesis rates. (Yang *et al.* 2019). Optimisation of planting space use is greatly influenced by rice variety diversity, which includes differences in root morphology, plant height, vegetative structure, and canopy size (Joshi *et al.* 2020). Rice variety differences are a determining factor in optimising cultivation land, particularly in relation to root morphology characteristics and soil pH preferences (Cossani and Sadras 2021).

The use of cultivar mixtures plays a positive role in increasing rice yields. Rice cultivation using a cultivar mixture system also increases the competitiveness of rice and reduces weed biomass production (Jareen *et al.* 2019). However, adding tall plants among short plants will cause the population to increase, thereby limiting the growing space for plants, especially due to intense competition for sunlight absorption between tall and short plants as a result of differences in canopy structure (Hidayah *et al.* 2022). The effect of the multi-canopy cultivation system on plants is very interesting to study, because changes in the characteristics of each variety will also affect rice production. To study this cultivation system, research is needed on the right combination of varieties so that rice production can be increased as expected. This study aims to analyse the growth and productivity responses of tall and short rice genotypes in a multi-canopy cultivation system.

MATERIALS AND METHODS

The research was conducted from December 2024 to May 2025 at the Sawah Baru Experimental Farm, Babakan Dramaga, Bogor Regency, West Java. Observations of the yield components were carried out at the Plantation Laboratory, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University. The equipment used included Li-Cor 6800ct, SPAD, oven and digital scales, while the materials used were rice seeds, chicken manure, urea fertiliser, SP-26 and KCL. This study employed a Randomized Complete Block Design (RCBD). The treatment consisted of a single factor, namely the combination of plant variety and multi-canopy system. The treatment combinations comprised 'short' plant varieties (IPB202-F-1, IPB201-F-1) and 'tall' plant varieties (IPB197-E-1, IPB200-F-51). The cultivation systems consisted of monoculture, single-insertion multi-canopy, and double-insertion multi-canopy systems.

Soil preparation was carried out prior to planting by ploughing and harrowing using tools available at the research site. Rice was planted using a 4:1 spacing (30 cm × 15 cm × 60 cm). In the single-intercropped multi-canopy system, tall plants were intercropped between the second and third rows of the main crop. Meanwhile, in the two-intercropped multi-canopy system, tall plants

are inserted between the first and second rows and between the third and fourth rows of the main crop. The monoculture system uses a single crop as a control. Crop maintenance includes weeding, irrigation, and pest and disease control. Fertiliser is applied at a dose of 200 kg of urea ha⁻¹, 100 kg of SP-26 ha⁻¹, and 100 kg of KCl ha⁻¹. Urea fertiliser was applied three times, namely at planting, 21 days after planting, and 42 days after planting; SP-26 was applied once at planting; while KCl was applied twice, namely at planting and 21 days after planting. Harvesting was carried out when more than 90% of the panicles had turned yellow, then the harvest was collected according to the experimental plots and threshed for further observation.

Observations of rice plant growth include: the number of tillers, the age at flowering calculated from the time of planting, and the measurement of photosynthesis rates using Li -Cor by selecting the flag leaf, bending it and placing it in the measuring device, observed during the heading phase; measurement of leaf greenness using a SPAD device by measuring the top, middle and bottom thirds of the leaf during the heading phase; and the length and width of the flag leaf (cm). Yield observations include: number of productive tillers, panicle length (cm), number of grains per panicle, weight of 1000 grains (g), and the Land Equivalence Ratio calculated using the formula $LER = \frac{Y_a}{M_a} + \frac{Y_b}{M_b}$, Y_a = yield of genotype A in the multi-canopy system M_a = yield of genotype A in the monoculture system Y_b = yield of genotype B in the multi-canopy system M_b = yield of genotype B in the monoculture system, rice yield calculated using the formula, and dry grain yield. Observation data for each variable were tabulated using Microsoft Excel 2019 and then analysed using an F-test at a significance level of α 5%. If any variable showed a significant effect, an LSD test was conducted at a significance level of α 5%. The software used for data analysis was SAS ODA online.

RESULT AND DISCUSSION

The number of tillers is a component of vegetative growth that determines the potential number of panicles and rice productivity. In Table 1, the number of tillers at 2–4 WAP did not show any significant differences, but at 5–6 WAP, there were significant differences because the plants entered the peak tiller formation phase (active tillering stage). In the early phase (2–4 WAP), plants still focus on primary root and leaf formation and adaptation to the environment. This is in line with Yuan *et al.* (2024), who stated that tillering is most active in the 4th to 6th week after planting. The IPB 201 cultivar showed a higher number of tillers compared to IPB 202, IPB 197, and IPB 200, with the highest number in the monoculture treatment, namely 19 tillers. Shade conditions in mixed systems can inhibit tillering through changes in growth hormone balance, such as increased strigolactone and decreased cytokinin, as well as increased competition between plants, which reduces tillering dynamics due to reduced nitrogen availability for meristem growth (Yuan *et al.*, 2024; Wang *et al.*, 2024).

In Table 2, the leaf greenness values showed no significant differences between treatments. This indicates that the multi-canopy system has not yet caused significant changes to the chlorophyll status of the leaves. SPAD values are closely related to leaf chlorophyll and nitrogen content, but are also influenced

Table 1. Number of tillers in rice plants with different cultivation systems and rice genotypes

Treatment	Number of tillers				
	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
Cultivation System					
Monoculture					
IPB 202	4.11	8.87	10.94	16.23 ab	17.33 ab
IPB 201	4.66	9.87	12.44	19.89 a	19.00 a
IPB 197	5.05	7.89	10.28	12.22 bcdef	12.94 bcde
IPB 200	4.50	7.72	10.33	13.22 bcde	14.33 abcde
Single insertion					
(IPB 202) IPB 197 [#]	3.88	9.66	11.00	13.00 bcdef	14.22 bcde
IPB 202 (IPB 197)	4.78	9.33	9.00	8.88 f	12.89 bcde
(IPB 202) IPB 200 [#]	4.55	9.11	10.33	12.89 bcdef	12.55 cde
IPB 202 (IPB 200)	4.89	8.77	9.55	12.11 bcdef	10.44 e
(IPB 201)IPB 197 [#]	4.78	9.00	9.44	13.33 bcde	15.22 abcd
IPB 201(IPB 197)	5.33	7.99	9.00	11.44 cdef	14.33 abcde
(IPB 201) IPB 200 [#]	4.33	8.66	8.66	12.33 bcdef	14.22 bcde
IPB 201(IPB 200)	4.66	8.89	9.55	11.55 cdef	12.44 cde
Double insertion					
(IPB 202) IPB 197 [#]	4.89	12.44	13.11	15.22 bc	17.00 abc
IPB 202 (IPB 197)	5.55	10.66	10.86	13.00 bcdef	13.11 bcde
(IPB 202)IPB 200 [#]	3.55	7.33	7.89	9.44 ef	11.66 ed
IPB 202 (IPB 200)	5.44	9.78	8.66	10.66 def	11.33 dc
(IPB 201)IPB 197 [#]	3.67	7.22	8.44	11.67 cdef	13.22 bcde
IPB 201(IPB 197)	4.11	6.99	8.66	10.44 def	12.44 cde
(IPB 201)IPB 200 [#]	4.89	8.00	9.77	14.11 bcd	11.47 de
IPB 201(IPB 200)	5.22	7.89	8.22	11.44 cdef	9.78 e
Pr>F	0.5677 ^{ns}	0.3201 ^{ns}	0.1348 ^{ns}	0.0042*	0.0377*
KK (%)	22.02	23.50	19.74	20.31	21.21

Description: Multicanopy 1 consists of tall rice plants (IPB 197/IPB200) planted between short rice plants (IPB202/IPB201); Multicanopy 2 is two rows of tall rice (IPB 197/IPB200) planted between short rice (IPB202/IPB201); Data is considered short when planted with tall varieties (in parentheses) # Data is considered tall when planted with short varieties (in parentheses). Numbers followed by different letters in the same column indicate significant differences based on LSD tests at the 5% level; WAP = Week After Plant.

by leaf thickness, leaf age, and the position of measurement. Thus, the relatively uniform SPAD values indicate that the plants are still able to maintain their physiological status despite differences in planting patterns and canopy structure. These findings are consistent with those of Kim *et al.* (2024), who state that SPAD can be used as an indirect indicator of leaf nitrogen and chlorophyll status.

Flowering time showed significant differences between treatments, but the range of variation was relatively narrow. These differences are thought to be influenced more by genetic factors than by the multi-canopy cropping system. In rice, flowering time is controlled by the interaction between flowering-regulating genes and the environment, particularly photoperiod and temperature. However, as the differences in flowering time were relatively small, their effect on grain yield is not expected to be significant. Yield differences are more strongly influenced by the number of productive tillers, the number of grains per panicle, and grain-filling efficiency. This is supported by Song *et al.* (2024) and Wang *et al.* (2024), who explain

that the flowering age of rice is strongly influenced by genetic regulation and environmental adaptation.

The length of the flag leaf does not show any significant differences, as the length of rice leaves is more strongly controlled by genetic factors than environmental influences. Leaf length is determined in the early stages of leaf primordium, before the leaf enters the full expansion stage. Because its control is more genetic and less plastic, treatment changes such as multi-canopy, tall-short variety differences, or light variations are not strong enough to modify leaf length (Singh *et al.* 2024).

The photosynthetic rate did not show any significant differences. This is due to the ability of rice to maintain photosynthetic stability through physiological acclimation mechanisms. Rice leaves undergo photosynthetic acclimation by adjusting nitrogen use efficiency, mesophyll conductance, and electron transport so that CO₂ assimilation values remain within a similar range even when light or environmental conditions differ (Yao *et al.* 2025).

Table 2. Physiological characteristics of rice plants with cultivation system treatments and rice genotypes

Treatment	Harvest				
	Leaf Greenness	Flower Age (DAT)	Flag Length (cm)	Flag Width (cm)	Rate of Photosynthesis
Cultivation System					
Monoculture					
IPB 202	38.14	62.00 abc	27.35	1.62 fg	11.58
IPB 201	34.80	61.44 cde	33.75	1.87 bcdef	13.34
IPB 197	34.79	62.00 abc	32.00	1.98 abcd	8.46
IPB 200	39.60	61.44 de	33.46	2.15 a	9.81
Single insertion					
(IPB 202) IPB 197 [#]	35.91	62.00 abc	29.76	1.67 efg	11.33
IPB 202 (IPB 197)	33.95	61.11 e	30.83	1.97 abcd	10.56
(IPB 202) IPB 200 [#]	33.52	62.11 ab	28.33	1.72 defg	8.36
IPB 202 (IPB 200)	32.94	62.44 a	30.73	1.78 defg	7.54
(IPB 201)IPB 197 [#]	33.43	62.00 abc	28.52	1.53 g	10.41
IPB 201(IPB 197)	33.07	62.00 abc	32.05	2.12 ab	12.44
(IPB 201) IPB 200 [#]	35.88	62.33 a	30.12	1.77 defg	12.68
IPB 201(IPB 200)	33.98	62.00 abc	32.17	1.95 abcd	8.82
Double insertion					
(IPB 202) IPB 197 [#]	34.36	62.11 ab	28.66	1.76 defg	8.03
IPB 202 (IPB 197)	35.42	62.22 ab	36.74	2.09 abc	9.68
(IPB 202)IPB 200 [#]	34.85	62.00 abc	30.16	1.83 cdef	10.44
IPB 202 (IPB 200)	32.40	62.00 abc	26.22	1.74 defg	8.69
(IPB 201)IPB 197 [#]	33.12	62.00 abc	31.34	1.81 def	9.97
IPB 201(IPB 197)	35.88	62.00 abc	28.89	1.80 def	9.66
(IPB 201)IPB 200 [#]	33.42	61.55 cde	33.50	1.75 defg	7.47
IPB 201(IPB 200)	28.21	61.78 bcd	31.03	1.89 bcde	7.61
Pr>F	0.9073 ^{ns}	0.0043*	0.3588 ^{ns}	0.0012*	0.4831 ^{ns}
KK (%)	15.53	0.52	13.15	8.62	31.08

Description: Multicanopy 1 consists of tall rice plants (IPB 197/IPB200) planted between short rice plants (IPB202/IPB201); Multicanopy 2 is two rows of tall rice (IPB 197/IPB200) planted between short rice (IPB202/IPB201); Data is considered short when planted with tall varieties (in parentheses) #) Data is considered tall when planted with short varieties (in parentheses). Numbers followed by different letters in the same column indicate significant differences based on LSD tests at the 5% level ; DAT = Days After Transplanting.

The number of productive tillers showed a significant difference, with IPB 202 in a monoculture system having the highest value of 10.50 grains compared to other varieties. Each productive tiller develops into one panicle, so an increase in the number of tillers will increase the potential number of grains formed and ultimately contribute to grain yield. Productive tiller number has a positive and significant correlation with grain yield and other yield components such as panicle length and number of filled grains (Kalaitzidis *et al.* 2025). In addition, analysis of the relationship between agronomic traits shows that the number of productive tillers is often a key determinant trait in yield variation between genotypes (Carsono *et al.* 2025).

The panicle length in Table 3 does not show any significant differences. This is because panicle length is a reproductive architectural trait that is strongly controlled by genetic regulation rather than cultivation management factors. Panicle length components such as panicle rachis length and primary branch length are regulated by specific developmental genes, so their expression is relatively stable unless there is direct genetic modification (Agata. 2025).

The number of grains per panicle showed a significant difference, ranging from 75 to 171. Treatment

2 with the IPB 202 and IPB 200 lines produced the highest number of grains per panicle, namely 171.17. This difference was influenced by the interaction between genetic and environmental factors. Genetically, the number of grains per panicle is a quantitative trait with moderate to high heritability, so that variation between lines can occur, mainly due to variation in the gene that regulates the number of grains per panicle, which determines the number of spikelets and grains on the panicle (Ma *et al.*, 2025). In addition, environmental factors such as nitrogen availability and photosynthetic efficiency also affect the number of spikelets per panicle, as varieties with different panicle types show different responses to nitrogen fertilisation, while nitrogen restriction can reduce the number of spikelets that develop into grains (Zhou *et al.*, 2025; Kim *et al.*, 2025).

The weight of 1000 grains in Table 3 does not show any significant differences. This is because, physiologically, the weight of 1000 grains is greatly influenced by genetic factors that determine grain size, starch accumulation capacity, and the expression of seed growth regulatory genes, so that treatment variations often only have a minor impact on the final grain size without triggering significant statistical changes. In evaluating rice genotypes in various

Table 3. Rice crop yield components with cultivation system treatments and rice genotypes

Treatment	Harvest			
	Number of Productive Tillers	Panicle Length (cm)	Number of Grains Per Panicle	Weight of 1000 Grains (g)
Cultivation System				
Monoculture				
IPB 202	10.50 a	22.25	95.33 defg	13.33
IPB 201	9.57 ab	24.95	92.83 efg	15.67
IPB 197	7.11 bcd	25.50	102.33 cdefg	16.67
IPB 200	8.72 abc	29.08	152.67 ab	18.00
Single insertion				
(IPB 202) IPB 197 [#]	7.78 bcd	23.51	145.83 abc	13.00
IPB 202 (IPB 197)	6.67 cd	26.51	111.83 bcdefg	17.00
(IPB 202) IPB 200 [#]	8.55 abc	23.66	111.25 bcdefg	14.00
IPB 202 (IPB 200)	7.67 bcd	23.91	101.83 cdefg	15.00
(IPB 201)IPB 197 [#]	6.78 cd	25.83	140.67 abcd	17.00
IPB 201(IPB 197)	6.55 cd	25.08	104.00 cdefg	14.67
(IPB 201) IPB 200 [#]	6.77 cd	25.26	105.00 cdefg	17.00
IPB 201(IPB 200)	7.22 bcd	27.41	158.00 ab	15.00
Double insertion				
(IPB 202) IPB 197 [#]	8.55 abc	26.23	135.67 abcde	13.67
IPB 202 (IPB 197)	8.57 abc	25.93	117.33 bcdefg	17.33
(IPB 202)IPB 200 [#]	8.55 abc	25.06	122.33 bcdef	13.00
IPB 202 (IPB 200)	7.33 bcd	26.65	171.17 a	16.33
(IPB 201)IPB 197 [#]	6.67 cd	26.21	102.33 cdefg	16.33
IPB 201(IPB 197)	5.53 d	29.33	129.17 abcde	15.67
(IPB 201)IPB 200 [#]	6.22 cd	23.91	81.50 fg	15.00
IPB 201(IPB 200)	6.22 cd	25.78	75.50 g	14.33
Pr>F	0.0374*	0.0768 ^{ns}	0.0073*	0.6315 ^{ns}
KK (%)	20.40	9.60	24.03	18.60

Description: Multicanopy 1 consists of tall rice plants (IPB 197/IPB200) planted between short rice plants (IPB202/IPB201); Multicanopy 2 is two rows of tall rice (IPB 197/IPB200) planted between short rice (IPB202/IPB201); Data is considered short when planted with tall varieties (in parentheses) #) Data is considered tall when planted with short varieties (in parentheses). Numbers followed by different letters in the same column indicate significant differences based on LSD tests at the 5% level.

Table 4. LER values in rice plants with cultivation system treatments and rice genotypes

Genotypes	LER	Percentage (%)
IPB202 Mono	1.00	100.00
IPB201 Mono	1.00	100.00
IPB197 Mono	1.00	100.00
IPB200 Mono	1.00	100.00
IPB202 (IPB197)1	1.33	133.23
IPB202 (IPB200)1	1.24	123.87
IPB201 (IPB197)1	1.42	141.55
IPB201 (IPB200)1	1.47	146.95
IPB202 (IPB197)2	1.56	155.70
IPB202 (IPB200)2	1.44	143.75
IPB201 (IPB197)2	1.54	153.89
IPB201 (IPB200)2	1.59	159.23

Description: Monoculture (Mono); Single insertion (1); Double insertion (2) ; LER = Land Equivalence Ratio

environments, grain quality components such as grain weight tend to be stable despite environmental variations and other genotypes that are more responsive to growing conditions (Aswidinoor *et al.* 2023).

Treatment IPB201 and IPB200 with interplanting 2 yielded the highest LER value of 1.59. An LER (Land Equivalence Ratio) value greater than 1 in a multi-canopy system indicates that the combination of rice varieties can increase land use efficiency compared to

monoculture. Conceptually, an LER (Land Equivalence Ratio) > 1 indicates that one unit of land area in a mixed system can produce higher yields than a single system on the same area. Intercropping consistently increases LER significantly and maintains an LER value > 1 in various environmental conditions (Song *et al.* 2025). Intercropping plays an important role in improving the efficiency of resource use, such as light, water, and

nutrients, and supports sustainable agricultural intensification (Shahidullah *et al.* 2024).

CONCLUSION

The multi-canopy planting system influenced several components of rice growth and yield, particularly the number of productive tillers and the number of grains per panicle. In contrast, most physiological traits, panicle length, and 1000-grain weight showed no significant differences among treatments. The monoculture system produced higher grain yield per plot compared to the multi-canopy system, with the IPB197 genotype yielding the highest grain and dry grain yields. However, all genotype combinations in the multi-canopy system had an LER (Land Equivalence Ratio) value greater than one, indicating better land use efficiency compared to the monoculture system. The combination of genotypes IPB201 and IPB200 in the two-row interplanting pattern yielded the highest LER value of 1.59. These findings indicate that the appropriate combination of tall and short-statured rice genotypes in a multi-canopy system can enhance land-use efficiency and has the potential to support sustainable rice intensification on limited land.

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