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Optimization of Mulching and Plant Spacing on the Improvement of Productivity in Upland Rice *(Oryza sativa L.)* variety INPAGO 13

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***Abstract*—*This study was conducted to evaluate the effect of the combination of plant spacing and mulch application on upland rice (Oryza Sativa L.) variety INPAGO 13. The experiment was carried out using a Split Plot Design (RPT), with the main plots (PU) consisting of M0 (no mulch), M1 (straw mulch), and M2 (Black-Silver Mulch), while the subplots (AP) included T1 (plant spacing 20 cm x 20 cm), T2 (plant spacing 30 cm x 30 cm), and T3 (plant spacing 40 cm x 20 cm x 12.5 cm). The observed parameters included plant height, number of tillers per clump, number of leaves per clump, leaf area per clump, leaf area index (LAI), dry weight per clump, dry weight of rice grains per clump, dry weight of rice grains per m², rice yield per hectare, dry weight of 1000 grains, albedo, soil temperature, and solar energy conversion efficiency. The results showed that both mulch application and plant spacing had a significant effect on growth and yield parameters. The application of black-silver mulch with a plant spacing of 40 cm x 20 cm x 12.5 cm generally improved plant growth. This study indicates that the combination of plant spacing and mulch application can enhance the yield of upland rice (Oryza Sativa L.) variety INPAGO 13.*

***Keywords*— Mulch, Plant Spacing, Upland Rice**

I. INTRODUCTION

Rice is one of the most important staple crops in Indonesia. The increasing population in Indonesia also impacts the demand for food, particularly rice. Therefore, improving rice productivity has become a priority in supporting food security. According to BPS (2021), the national average rice productivity in 2020 was 5.1 tons of milled dry paddy (GKG) per hectare, while in 2021, it increased to 5.3 tons (GKG) per hectare. However, it is important to note that the annual increase in rice productivity is only 1.9% per year, while the national population continues to grow. This means that if this trend continues, the government will face a deficit in food production compared to population growth, as population growth far exceeds the productivity of staple crops, particularly rice. Climate change also significantly affects rice productivity. Climate change, through altered rainfall patterns, increased CO2 concentration in the atmosphere, and rising temperatures, affects rice productivity (Wang, Liu, and Shi, 2023). According to Li (2023), rice production is influenced by several meteorological factors such as temperature, rainfall, wind speed, and solar radiation.

The development of upland rice cultivation on dry land is one strategic alternative to meet national food needs, considering the large potential of unused dry land in Indonesia. According to BPS (2019), the total area of dry land in Indonesia is 63.4 million hectares, accounting for 33.7% of the country's total land area. Of this, 8.8 million hectares are used for dryland farming, while 26.3 million hectares are used for mixed shrubs, and 18 million hectares are used for plantations, leaving 10.3 million hectares that have yet to be fully utilized. Given this, the development of dryland rice farming through the application of technology seems more promising than the productivity of irrigated rice fields, which have long relied on subsidies or other forms of assistance. According to Marwanti (2022), the development of dryland rice based on technology is much more promising compared to the long-standing reliance on aid in various forms since the 1970s. Upland rice (padi gogo) is one variety of rice cultivated on dry land. The underutilization of dryland is due to limited water availability and organic matter in the soil.

Upland rice is an important genetic resource for rice diversity in Indonesia. There are several upland rice varieties available in Indonesia, such as Situbagendit, Inpago 9, Inpago 10, Inpago 11, Inpago 12, and the most recent, Inpago 13. The production potential of Inpago varieties ranges from 6 to 10 tons per hectare, depending on the variety; however, in practice, the average production is only around 3 to 4 tons per hectare (Malik, 2017). It is essential to understand that there are various constraints in upland rice cultivation on dry land that significantly impact productivity, such as the limited water availability and the dominance of weeds, which compete for nutrients and reduce plant growth, ultimately decreasing yield. Additionally, competition for nutrients due to the broadcasting planting system affects soil quality, making proper plant spacing crucial. Improper plant spacing not only increases nutrient competition but also reduces photosynthesis efficiency due to leaf coverage in rice plants.

Mulch is a soil cover material used in crop cultivation. There are two types of mulch: inorganic and organic. Common organic mulches used by farmers include straw, palm oil empty fruit bunches, plant litter, leaves, and plastic mulches, such as black-silver plastic mulch (MPHP). The use of mulch aims to reduce irrigation needs by minimizing water evaporation from the soil, stabilize soil temperature, suppress weed growth (thus reducing weeding costs), prevent water and wind erosion, provide nutrients, protect the soil surface from raindrop impact, reduce surface runoff, and maintain soil moisture (Zhao et al., 2023). In addition, plastic mulches, especially black-silver plastic mulch (MPHP), can reflect light, which is utilized by the plant in the photosynthesis process of the lower leaves. The use of mulch in upland rice farming is unconventional but can have positive effects on photosynthesis due to the light reflection produced by the black-silver plastic mulch. Furthermore, in upland rice cultivation, plant spacing must also be considered as it affects the plant's ability to capture solar energy. Research by Rhauf, Suryanto, and Nurlaili (2022) showed that using three rice seedlings per hole with a 25x25 cm square planting layout resulted in the highest yield of 8.26 tons per hectare compared to other planting distance.

This study is expected to provide useful information for upland rice farmers (Oryza Sativa L.) in improving rice production by managing the combination of plant spacing and mulch application.

II. MATERIALS AND METHODS

2.1 Time and place

This research was conducted from July to December 2023. The experiment was carried out at the Experimental Farm of the Faculty of Agriculture, located in Jatimulyo, Malang, East Java. The elevation of the site is 507 meters above sea level, measured using Google Earth, with an air temperature ranging from 23°C to 25°C, and the soil type is Regosol. The annual rainfall is approximately 1,500 mm.

2.2 Tools and materials

The tools used in this study included an altimeter, a cultivator for land preparation, a LI-3100 Leaf Area Meter, bamboo, netting, writing materials, a digital scale (SF-400), a Memmert Oven (model 21037 FNR), and a smartphone camera. The materials used in the study included Inpago 13 rice seeds, Urea (46% N), KCl, and Fertipos. Solar radiation intensity data were obtained from the nearest climatology station (±10 km), the Meteorology, Climatology, and Geophysics Agency (BMKG) Karangploso, Malang.

2.3 Research methods

The experiment was conducted using a Split Plot Design (RPT), with three replications. The main plots (PU) consisted of M0 (no mulch), M1 (straw mulch), and M2 (Black-Silver Mulch), while the subplots (AP) included T1 (plant spacing 20 cm x 20 cm), T2 (plant spacing 30 cm x 30 cm), and T3 (plant spacing 40 cm x 20 cm x 12.5 cm). The combination of these treatments resulted in nine treatment combinations, each replicated three times.

The observed parameters included plant height, number of tillers per clump, number of leaves per clump, leaf area per clump, leaf area index (LAI), dry weight per clump, dry weight of rice grains per clump, dry weight of rice grains per m², rice yield per hectare, dry weight of 1000 grains, albedo, soil temperature, and solar energy conversion efficiency.

The efficiency of solar energy conversion (EKE) indicates the percentage of solar energy that can be converted into carbohydrate energy through photosynthesis in plant dry matter. The equation for EKE is as follows (Sinclair and Muchow, 1999; Suryanto, 2018):

$$\mathrm{EKE} = \frac{\Delta \mathrm{W.K}}{\mathrm{I.t.PAR}} \mathrm{x}100\%$$

Where:

ΔW = Difference in plant dry weight (g) per m² over a given time period

K = Heat combustion coefficient (4,000 $cal.g^{-1}$)

I = Daily solar radiation intensity ($cal.m^2.day^{-1}$)

t = A specific time period (days)

PAR = Photosynthetically Active Radiation (0.45)

Weed observation was carried out using a square raffia cord measuring 25 cm x 25 cm in 4 plots. The weeds were then grouped by species, identified, and the following parameters were calculated: species density, relative species density, species frequency, relative species frequency, relative species dominance, species dominance, and the Important Value Index (IVI) using the formulas according to (Aryani, 2023):

a.Density of a type (K)

K = Σ individual type/Area of example tile

b. Relative density of a type (KR)

KR = K of a type/K All types x 100 %

c. Frequency of a type (F)

F = Σ Sub− tile found of type/Σ All sub−example tiles

d. Relative frequency of a type (FR)

FR = F of a type/ F of all types x 100%

The plant frequency classes are:

Class A : 0 -20%

Class B : 21 - 40%

Class C : 41 - 60%

Class D : 61 - 80%

Class E : 81 – 100 %

e. Dominance of a type (D)

D = Base field area of a type/Example tile area

Base Area = π x (rod diameter/2)2

f. Relative dominance of a type (DR)

DR = D of a type/D of all types x 100%

g. Important Value Index (INP)

INP = KR + FR + DR

Information:

FR = Relative Frequency,

KR = Relative Density,

DR = Relative DominationData analysis

From the observation results that have been obtained, then analyzed using ANOVA in the form of a 5% level F test. If there are real results, then continued with the Smallest Real Difference (LSD) test.

III.RESULTS

3.1 The effect of mulch application and plant layout on the growth of rainfed rice variety Inpago 13.

The effect of mulch application and plant spacing on the growth of upland rice (Oryza Sativa) was observed. In the treatments with no mulch and straw mulch, with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm, no significant increase in plant height was observed. However, in the treatment with black-silver mulch, plant heights at plant spacings of 30 cm x 30 cm and 40 cm x 20 cm x 12.5 cm were significantly taller compared to the 20 cm x 20 cm spacing. In the 20 cm x 20 cm plant spacing treatment, no significant increase in plant height was observed across the no mulch, straw mulch, and black-silver mulch treatments.

Table1. Plant length due to treatment of various types of mulch and plant layout at 70 Days after planting (DAP)

Treatment	Plant Length (Cm)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	69.67 a	69.42 a	81.92 a	23.79
	A	A	A	
30cm x 30cm	69.17 a	67.33 a	106.83 b	
	A	A	B	
40 cm x 20 cm x 12.5 cm	80.67 a	80.58 a	108.08 b	
	A	A	B	
BNJ 5%		10.45		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

In the treatments with no mulch and straw mulch at plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm, there was no significant increase in the number of tillers per clump. However, in the treatment with black-silver mulch at a plant spacing of 40 cm x 20 cm x 12.5 cm, the number of tillers per clump was higher compared to the 20 cm x 20 cm plant spacing. In the 20 cm x 20 cm plant spacing treatment, there was no significant increase in the number of tillers per clump across the no mulch, straw mulch, and black-silver mulch treatments. In contrast, at plant spacings of 30 cm x 30 cm and 40 cm x 20 cm x 12.5 cm, the black-silver mulch treatment resulted in a higher number of tillers per clump compared to the no mulch and straw mulch treatments.

Table 2. Number of shoots per clump due to treatment with various types of mulch and plant layout

Treatment	Number of Tillers Per Clump (tan-1)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	30.25 a	31.92 a	30.75 a	7.76
	A	A	A	
30cm x 30cm	26.33 a	27.00 a	38.00 b	
	A	A	AB	
40 cm x 20 cm x 12.5 cm	30.50 a	32.17 a	42.17 b	
	A	A	B	
BNJ 5%	7.76			

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

The treatments with no mulch and straw mulch at plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm did not significantly increase the number of leaves per clump. However, the treatment with black-silver mulch at a plant spacing of 40 cm x 20 cm x 12.5 cm resulted in a higher number of leaves per clump compared to the 20 cm x 20 cm plant spacing. In the 20 cm x 20 cm plant spacing treatment, no significant increase in the number of leaves per clump was observed across the no mulch, straw mulch, and black-silver mulch treatments. In contrast, at plant spacings of 30 cm x 30 cm and 40 cm x 20 cm x 12.5 cm, the black-silver mulch treatment resulted in a higher number of leaves per clump compared to the no mulch and straw mulch treatment.

Table 3. Number of leaves per clump due to various types of mulch treatment and plant layout at 70 Days after planting(DAP)

Treatment	Number of Leaves Per Clump (strands.tan-1)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	89.75 a	95.75 a	92.25 a	15.45
	A	A	A	
30cm x 30cm	79 a	81 a	114 b	
	A	A	AB	
40 cm x 20 cm x 12.5 cm	91.5 a	96.5 a	126.5 b	
	A	A	B	
BNJ 5%	23.53			

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

The treatment with no mulch at plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm did not significantly increase the leaf area index (LAI). However, the straw mulch treatment at a plant spacing of 40 cm x 20 cm x 12.5 cm significantly increased the LAI compared to the 30 cm x 30 cm plant spacing. The black-silver mulch treatment significantly increased the LAI, with the 40 cm x 20 cm x 12.5 cm spacing showing the highest LAI compared to the 20 cm x 20 cm and 30 cm x 30 cm spacings.

At the 20 cm x 20 cm and 30 cm x 30 cm plant spacings, the treatments with no mulch, straw mulch, and black-silver mulch did not significantly increase the LAI. However, at the 40 cm x 20 cm x 12.5 cm plant spacing, the treatments with no mulch, straw mulch, and black-silver mulch all significantly increased the LAI, with the black-silver mulch treatment showing the highest LAI compared to the no mulch and straw mulch treatment.

Table 4. Leaf Area Index (LAI) due to various types of mulch and plant layout treatments

Treatment	Leaf Area Index (m2m-2)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	1.92 a	3.13 a	3.61 a	2.16
	A	AB	B	
30cm x 30cm	0.71 a	1.33 a	1.73 a	
	A	A	A	
40 cm x 20 cm x 12.5 cm	2.3 a	4.31 a	6.92 b	
	A	B	C	
BNJ 5%		1.86		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

The treatment with no mulch showed a significant effect, where plant spacings of 40 cm x 20 cm x 12.5 cm and 30 cm x 30 cm resulted in the highest dry weight per clump compared to the 20 cm x 20 cm plant spacing. The straw mulch and black-silver mulch treatments also showed significant effects on the dry weight per clump, with the 40 cm x 20 cm x 12.5 cm plant spacing resulting in the highest dry weight per clump compared to the 20 cm x 20 cm and 30 cm x 30 cm plant spacings.

For the 20 cm x 20 cm and 30 cm x 30 cm plant spacings, the treatments with no mulch, straw mulch, and black-silver mulch did not show significant differences in the dry weight per clump. However, at the 40 cm x 20 cm x 12.5 cm plant spacing, the black-silver mulch treatment showed a significant difference in dry weight per clump compared to the no mulch and straw mulch treatments.

Table 5.Plant Dry Weight Per Clumpdue to the treatment of various types of mulch and plant layout

Treatment	Dry Weight of Plants Per Clump (g.tan-1)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	91.08 a	107.83 a	118.33 a	44.37
	A	A	A	
30cm x 30cm	112.58 a	106.83 a	134.75 a	
	B	A	A	
40 cm x 20 cm x 12.5 cm	116.58 a	128.92 ab	169.33 b	
	B	B	B	
BNJ 5%		20.82		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

3.2 The Effect of Mulch Application and Plant Layout on the Yield of Rainfed Rice Variety Inpalgo 13

In the treatment with no mulch, plant spacings of 40 cm x 20 cm x 12.5 cm and 30 cm x 30 cm had significantly higher milling dry grain weight per clump compared to the 20 cm x 20 cm spacing. For the black-silver mulch and straw mulch treatments, the 30 cm x 30 cm plant spacing resulted in significantly higher milling dry grain weight per clump compared to the 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm spacings.

For the 20 cm x 20 cm plant spacing, treatments with no mulch, straw mulch, and black-silver mulch did not significantly increase the milling dry grain weight per clump. At the 30 cm x 30 cm spacing, the application of straw mulch and black-silver mulch resulted in a significantly higher milling dry grain weight per clump compared to the no mulch treatment. At the 40 cm x 20 cm x 12.5 cm spacing, the application of no mulch, straw mulch, and black-silver mulch increased the milling dry grain weight per clump, with the no mulch and black-silver mulch treatments resulting in the heaviest milling dry grain weight compared to the straw mulch treatment.

In the treatment with no mulch, no significant increase in milling dry grain weight per m² was observed for plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm. However, the straw mulch treatment at the 40 cm x 20 cm x 12.5 cm spacing resulted in a higher milling dry grain weight per m² compared to the 20 cm x 20 cm spacing. The black-silver mulch treatment significantly increased milling dry grain weight per m², with the 40 cm x 20 cm x 12.5 cm spacing producing the heaviest milling dry grain weight per m² compared to the 20 cm x 20 cm and 30 cm x 30 cm spacings.

For the 20 cm x 20 cm plant spacing, the application of no mulch, straw mulch, and black-silver mulch did not significantly increase milling dry grain weight per m². At the 30 cm x 30 cm spacing, the black-silver mulch treatment showed a significant result, where black-silver mulch was heavier compared to no mulch and straw mulch treatments for milling dry grain weight per m². At the 40 cm x 20 cm x 12.5 cm spacing, the black-silver mulch treatment significantly increased milling dry grain weight per m², with black-silver mulch resulting in the heaviest milling dry grain weight per m² compared to the no mulch and straw mulch treatments.

In the treatment with no mulch, plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm did not significantly increase milling dry grain weight per hectare. For the straw mulch treatment at the 40 cm x 20 cm x 12.5 cm spacing, the milling dry grain weight per hectare was higher compared to the 20 cm x 20 cm spacing. Similarly, the black-silver mulch treatment at the 40 cm x 20 cm x 12.5 cm spacing showed significant results, where this spacing produced the heaviest milling dry grain weight per hectare compared to the 20 cm x 20 cm and 30 cm x 30 cm spacings.

For the 20 cm x 20 cm plant spacing, the application of no mulch, straw mulch, and black-silver mulch did not significantly increase milling dry grain weight per hectare. At the 30 cm x 30 cm spacing, the application of black-silver mulch resulted in a significantly heavier milling dry grain weight per hectare compared to the no mulch and straw mulch treatments. At the 40 cm x 20 cm x 12.5 cm spacing, the black-silver mulch treatment significantly increased milling dry grain weight per hectare, with black-silver mulch resulting in the heaviest milling dry grain weight per hectare compared to no mulch and straw mulch treatments.

In the treatment with no mulch, plant spacings of 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm had significantly heavier 1000-grain weight compared to the 30 cm x 30 cm spacing. For the straw mulch treatment, plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm had no significant effect on 1000-grain weight. However, in the black-silver mulch treatment, the 40 cm x 20 cm x 12.5 cm spacing significantly increased the 1000-grain weight, with this spacing having the heaviest 1000-grain weight compared to the 20 cm x 20 cm spacing.

For the 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm plant spacings, the application of no mulch, straw mulch, and black-silver mulch did not result in significant differences in 1000-grain weight. However, at the 30 cm x 30 cm spacing, the application of black-silver mulch showed a significant result, where black-silver mulch produced a significantly heavier 1000-grain weight compared to the no mulch and straw mulch treaments.

In the no mulch treatment with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm, there was no significant effect on the albedo value at 110 days after planting (DAP). The straw mulch treatment at the 40 cm x 20 cm x 12.5 cm plant spacing significantly increased the albedo value at 110 DAP compared to the 20 cm x 20 cm plant spacing, while the black-silver mulch treatment at both the 40 cm x 20 cm x 12.5 cm and 30 cm x 30 cm plant spacings significantly increased the albedo value. The 40 cm x 20 cm x 12.5 cm and 30 cm x 30 cm spacings resulted in the highest albedo values at 110 DAP compared to the 20 cm x 20 cm spacing.

For the plant spacings of 20 cm x 20 cm, 40 cm x 20 cm x 12.5 cm, and 30 cm x 30 cm, the application of no mulch, straw mulch, and black-silver mulch had a significant effect. The black-silver mulch treatment at the plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm showed the highest albedo values at 110 DAP compared to both the straw mulch and no mulch treatments.

Table 6. Dry Milled Grain Per Clump, Per M2, Per Ha and Weight of 1000 Grains of Graindue to the treatment of various types of mulch and plant layout

Treatment	Milled Dry Grain Per Clump (g.tan-1)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	23.6 a A	25.67 a A	30.26 a A	15.67
30cm x 30cm	64.95 a B	82.03 b C	90.31 b C	
40 cm x 20 cm x 12.5 cm	68.59 b B	47.58 a B	60.31 b B	
BNJ 5%	11.00			
Treatment	**Dry Milled Paddy Per M2 (g.m2)**			**BNJ 5%**
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	589.92 a A	641.83 a A	756.42 a A	203.65
30cm x 30cm	584.58 a A	738.25 ab AB	812.75 b A	
40 cm x 20 cm x 12.5 cm	640.00 a A	761.33 a B	965 c B	
BNJ 5%	98.79			
Treatment	**Milled Dry Grain Per ha (ton.ha-1)**			**BNJ 5%**
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	5.90 a A	6.42 a A	7.56 a A	2.04
30cm x 30cm	5.85 a A	7.38 ab AB	8.13 b A	
40 cm x 20 cm x 12.5 cm	6.40 a A	7.61 a B	9.65 c B	
BNJ 5%	0.99			
Treatment	**Weight of 1000 Grains of Paddy (g)**			**BNJ 5%**
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	23.82 a B	24.7 a A	24.64 a A	5.01
30cm x 30cm	21.11 a A	23.5 ab A	26.23 b AB	
40 cm x 20 cm x 12.5 cm	23.43 a B	24.12 a A	27.43 a B	
BNJ 5%	2.28			

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

Table 7.Albedo 110 Days after planting (DAP) due to the treatment of various types of mulch and plant layout

Treatment	Albedo 110 Hst			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	2.44 a	3.16 b	10.03 c	0.50
	A	A	A	
30cm x 30cm	2.6 a	3.41 b	11.56 c	
	A	AB	B	
40 cm x 20 cm x 12.5 cm	2.66 a	3.55 b	11.4 c	
	A	B	B	
BNJ 5%		0.30		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

In the no mulch treatment with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm, significant effects on temperature changes were observed at 60 days after planting (DAP) at 13:00 WIB, where the no mulch treatment at the 30 cm x 30 cm spacing showed higher temperatures compared to the 20 cm x 20 cm spacing. The straw mulch treatment at the 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm plant spacings did not significantly affect the temperature change at 60 DAP at 13:00 WIB. The black-silver mulch treatment at the 30 cm x 30 cm spacing significantly resulted in higher temperatures compared to the 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm spacings.

For the plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm, the application of no mulch, straw mulch, and black-silver mulch showed significant effects, with the black-silver mulch treatment at the 20 cm x 20 cm spacing resulting in the lowest temperature compared to the no mulch treatment. At the 30 cm x 30 cm plant spacing, the application of straw mulch and black-silver mulch significantly resulted in lower temperatures compared to the no mulch treatment. At the 40 cm x 20 cm x 12.5 cm plant spacing, the black-silver mulch treatment significantly resulted in lower soil temperatures compared to the no mulch and straw mulch treatments.

Table 8. Soil Temperature 60 Days after planting (DAP) at 13:00 WIB due to various types of mulch and plant layout

Treatment	Temperature 60 Hst 13:00(o C)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	28.25b	28.01ab	27.2a	0.87
	A	A	B	
30cm x 30cm	29.57b	28.16a	28.42a	
	B	A	C	
40 cm x 20 cm x 12.5 cm	28.8c	27.79b	26.05a	
	AB	A	A	
BNJ 5%		0.91		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

In the no mulch and straw mulch treatments with plant spacings of 30 cm x 30 cm and 40 cm x 20 cm x 12.5 cm, significant increases in solar energy conversion efficiency (ECE) were observed, with the no mulch and straw mulch treatments at the 30 cm x 30 cm plant spacing showing lower ECE values compared to the 20 cm x 20 cm plant spacing. In contrast, the black-silver mulch treatment at the 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm plant spacings exhibited higher solar energy conversion efficiency (ECE) compared to the black-silver mulch treatment at the 30 cm x 30 cm spacing.

At the 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm plant spacings, the application of no mulch, straw mulch, and black-silver mulch showed significant differences in solar energy conversion efficiency (ECE), with the black-silver mulch treatment at both plant spacings resulting in the highest ECE values compared to the no mulch and straw mulch treatments. However, at the 30 cm x 30 cm plant spacing, no significant differences in ECE were observed between the no mulch, straw mulch, and black-silver mulch treatments.

Table 9.Energy Conversion Efficiency (ECE) due to the treatment of various types of mulch and plant layout

Treatment	Energy Conversion Efficiency (ECE)			BNJ 5%
	Without Mulch	Straw Mulch	Black Silver Mulch	
20cm x 20cm	3.56 a	4.22 ab	4.63 b	1.04
	C	C	B	
30cm x 30cm	1.59 a	1.5 a	1.9 a	
	A	A	A	
40 cm x 20 cm x 12.5 cm	2.92 a	3.23 ab	4.24 b	
	B	B	B	
BNJ 5%		0.56		

Description: Numbers followed by different capital letters in the same column and different non-capital letters in the same row indicate significant differences in the 5% HSD test.

Based on Table 10, the Summed Domination Ratio (SDR) percentage of weeds at 14 days after sowing (DAS), the highest Summed Domination Ratio (SDR) percentage was observed in the species (Ipomoea purpurea) under the no mulch and straw mulch treatments with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm. The lowest percentage was observed in the species (Asclepias incarnata L).

Table 10.Summed Dominance Ratio (SDR)on 14 DAP due to the treatment of various types of mulch and plant layout

Species	*Summed Dominance Ratio* (SDR)			
	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	SDR (%)
Euphorbia hirta	6.86	16.67	17.53	13.69
Annual Bluegrass	3.92	16.67	13.25	11.28
Cyperus Esculentus	25.49	50.00	6.25	27.25
Hairy Crabgrass	13.73	50.00	5.23	22.99
Ipomoea Purpurea	23.53	83.33	11.18	39.35
Panicum Dichotomiflorum	12.75	33.33	12.6	19.56
Asclepias Incarnata L.	2.94	16.67	8.25	9.29
Diplocyclos Palmatus	10.78	66.67	5.54	27.66

Based on Table 11, the Summed Domination Ratio (SDR) percentage of weeds at 28 days after sowing (DAS), the highest SDR percentage was observed in the species (Ipomoea purpurea) under the no mulch and straw mulch treatments with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm. The lowest percentage was observed in the species (Asclepias incarnata L.).

Based on Table 12, the Summed Domination Ratio (SDR) percentage of weeds at 42 days after sowing (DAS), the highest SDR percentage was observed in the species (Ipomoea purpurea) under the no mulch and straw mulch treatments with plant spacings of 20 cm x 20 cm, 30 cm x 30 cm, and 40 cm x 20 cm x 12.5 cm. The lowest percentage was observed in the species (Asclepias incarnata).

Table 11. Summed Domination Ratio (SDR) on 28 DAP due to the treatment of various types of mulch and plant layout

Summed Dominance Ratio(SDR)				
Species	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	SDR (%)
Euphorbia hirta	6.71	16.67	13.69	12.35
Annual Bluegrass	4.03	16.67	11.28	10.66
Cyperus Esculentus	25.50	50.00	27.25	34.25
Hairy Crabgrass	13.42	50.00	22.99	28.80
Ipomoea Purpurea	25.50	83.33	39.35	49.39
Panicum Dichotomiflorum	12.08	33.33	19.56	21.66
Asclepias Incarnata L.	2.68	16.67	9.29	9.55
Diplocyclos Palmatus	10.07	66.67	27.66	34.80

Table 12. Summed Domination Ratio (SDR) on 42 DAP due to the treatment of various types of mulch and plant layout

Summed Dominance Ratio(SDR)				
Species	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	SDR (%)
Euphorbia hirta	5.67	16.67	13.69	12.01
Annual Bluegrass	4.53	16.67	11.28	10.83
Cyperus Esculentus	24.08	50.00	27.25	33.78
Hairy Crabgrass	14.45	50.00	22.99	29.14
Ipomoea Purpurea	25.21	83.33	39.35	49.30
Panicum Dichotomiflorum	11.33	33.33	19.56	21.41
Asclepias Incarnata L.	2.83	16.67	9.29	9.60
Diplocyclos Palmatus	11.90	66.67	27.66	35.41

IV. DISCUSSION

4.1 Application of Mulch and Plant Spacing on the Growth of INPAGO 13 Rainfed Rice

The growth of rice plants, particularly the INPAGO 13 rainfed rice variety, can be observed during the vegetative phase by monitoring the increase in cell number, which results in changes in plant size. During the vegetative phase, rice plants require several factors to grow optimally. Optimizing rice growth can be achieved through mulch application and proper plant spacing arrangements. Rainfed rice plants often face challenges in suppressing weed growth, as weeds tend to thrive in areas with physical and chemical conditions similar to those required by rice plants. Weeds generally grow well in moist soil, warm temperatures, and adequate sunlight, which are also ideal conditions for rice growth. Therefore, effective weed control strategies are essential for improving rainfed rice productivity.

Weed observations shown in Tables 10 to 12 indicate that the application of silver-black mulch did not result in significant weed growth, unlike straw mulch and no mulch treatments. Overall, it can be concluded that the use of mulch helps suppress weed growth. Weeds in straw mulch treatments were caused by the relatively thin straw layer and the influence of strong winds, which created gaps where weeds could grow. The application of straw mulch and silver-black mulch, on the other hand, differs in terms of the light wavelengths reflected. Observations of weeds at 14, 28, and 42 days after sowing (DAS) showed dominance of species *Cyperus esculentus* and *Ipomoea purpurea*. Mulch also plays a role in controlling weeds and improving nutrient availability, both of which contribute to an increase in the number of tillers and leaves (Osman et al., 2020). The increase in the number of tillers and leaves in INPAGO 13 rice plants with silver-black mulch can also be explained through physiological mechanisms. Studies have shown that mulch can enhance photosynthesis and light-use efficiency, which are important for biomass production (Doni et al., 2014). Thus, the use of silver-black mulch not only increases plant height but also improves the plant's ability to produce tillers and leaves, which are key indicators of potential rice yield (Afrin et al., 2017). Overall, this study suggests that applying silver-black mulch in the cultivation of INPAGO 13 rainfed rice can be an effective strategy to enhance plant growth and yield.

Rainfed rice is typically planted with relatively tight spacing to minimize the space available for weeds to grow between plants, thus requiring optimization of plant spacing, which also impacts productivity. However, overly dense planting can negatively affect rice plant growth, as competition for light, water, and nutrients intensifies. Therefore, it is crucial to optimize plant spacing to not only reduce weed growth but also improve rainfed rice productivity. Additionally, the use of superior varieties resistant to biotic and abiotic stresses can also contribute to weed control and increased yield.

In general, weed control in rainfed rice cultivation requires a holistic approach, which includes selecting the appropriate variety, optimizing plant spacing, and applying good land management practices. By doing so, the productivity of rainfed rice can be significantly improved, which in turn will support food security in areas dependent on rice as a primary carbohydrate source.

The results of this study show that the plant height of INPAGO 13 rice (Table 1) with the silver-black mulch treatment was higher than the no mulch and straw mulch treatments. As for the number of tillers (Table 2) and leaves (Table 3), the silver-black mulch treatment significantly increased both the number of tillers and leaves in the INPAGO 13 rice plants. The effect of mulch on the growth of INPAGO 13 rice plants indicates that the use of silver-black mulch can significantly enhance plant height, the number of tillers, and the number of leaves compared to no mulch and straw mulch treatments. This aligns with findings that show mulch can improve microclimate conditions, thereby meeting the light requirements of plants and supporting better vegetative growth (Hidayat et al., 2019; Regmi et al., 2021).

In the context of plant growth, silver-black mulch helps regulate soil moisture and temperature, as shown in Table 8, which is crucial for early plant growth. Research indicates that mulch can reduce irrigation needs and improve microclimate conditions, which contribute to enhanced plant growth (Karki et al., 2020). The use of mulch not only reduces irrigation requirements but also improves the microclimate around the plants, contributing to better plant growth (Lin et al., 2023). By reducing excessive soil temperature, silver-black mulch creates a better environment for root growth and the absorption of water and nutrients, which in turn supports optimal plant growth (Ryan et al., 2021).

At noon, 13:00 WIB, when sunlight intensity is at its peak, the effect of mulch, especially silver-black mulch that reflects light, on soil temperature becomes more evident, as soil exposed to direct sunlight heats up more quickly. At 60 DAS, the plants are larger and more developed with more leaves, which can increase shade and interaction with sunlight. At this stage, the plants can block most of the sunlight, particularly during the peak sunlight hours of 13:00 WIB. This may accentuate the temperature differences more than at younger stages (30 DAS) or older stages (90 DAS), when plants might begin to reduce photosynthetic activity as they approach the reproductive phase.

Overall, the application of silver-black mulch and optimal plant spacing is an important strategy for enhancing the growth of rainfed rice. Further research is needed to explore the interactions between mulch usage and plant spacing in a broader context, as well as to understand the mechanisms underlying the impact of mulch on microclimate conditions and plant growth.

Plant height and the number of tillers are crucial factors in determining rice yield. Optimal plant height and an adequate number of tillers can increase the productivity of rainfed rice (Sinaga et al., 2021). This study shows that rainfed rice varieties grown with proper plant spacing result in better plant height and a higher number of tillers, contributing to better panicle length and higher grain yield. In this context, proper plant spacing not only affects plant height and the number of tillers but also the length of the panicles (Krismiratsih et al., 2022). Therefore, correct plant spacing, alongside other factors such as fertilization and water management, is crucial for enhancing rainfed rice yield.

The application of mulch with plant spacing shown in Table 1 indicates that silver-black mulch with a plant spacing of 30 cm x 30 cm (M2T2) and silver-black mulch with a plant spacing of 40 cm x 20 cm x 12.5 cm (M2T3) significantly increased plant height, resulting in taller plants compared to other treatments. For the number of tillers (Table 2) and the number of leaves (Table 3), the silver-black mulch with a plant spacing of 40 cm x 20 cm x 12.5 cm (M2T3) was higher compared to other treatments. This can be explained by the role of mulch and proper plant spacing, which affect soil temperature and moisture. Silver-black mulch enhances plant growth by regulating soil temperature and moisture, which are critical for vegetative growth (Silmi & Chozin, 2015). Mulch functions to retain soil moisture and reduce temperature fluctuations, ultimately supporting root growth and improving nutrient absorption (Bakri, 2023).

The treatment with silver-black mulch and a plant spacing of 40 cm x 20 cm x 12.5 cm (M2T3) showed higher increases in the number of tillers and leaves compared to other treatments. This can be explained by the fact that denser plant spacing increases competition among plants for light, contributing to enhanced photosynthesis and biomass production (Sumekar et al., 2018). Previous studies have also shown that the use of mulch increases light-use efficiency in plants, which is important for tiller and leaf growth (Juniati, 2023). Additionally, mulch helps suppress weed growth, minimizing competition for nutrients. The positive effects of silver-black mulch can also reduce weed growth, which often competes with plants for resources such as light, water, and nutrients (Slamet, 2023). By reducing weed competition, INPAGO 13 rainfed rice plants can focus more on the growth and development of tillers and leaves, ultimately improving harvest yield (Ismadi et al., 2021). Overall, the application of silver-black mulch with proper plant spacing not only increases plant height but also the number of tillers and leaves, which are essential indicators of productivity in INPAGO 13 rainfed rice.

Leaf Area Index (LAI) is an important parameter for evaluating how effectively plants absorb sunlight for photosynthesis. The LAI results shown in Table 5 demonstrate significant differences based on mulch type. The application of silver-black mulch resulted in a higher leaf area index compared to no mulch and straw mulch treatments. This is influenced by the high albedo value of silver-black mulch, as shown in Tables 8 and 9. The high albedo value maximizes photosynthesis by reflecting sunlight onto parts of the leaves not directly exposed to sunlight. The application of different plant spacings also affects the leaf area index. The plant spacing of 40 cm x 20 cm x 12.5 cm showed a higher leaf area index compared to 20 cm x 20 cm and 30 cm x 30 cm spacings. The use of silver-black mulch enhances this efficiency due to its high albedo value. Albedo refers to the surface's ability to reflect light, and in the case of silver-black mulch, reflected light helps areas of the plant not directly exposed to sunlight to still receive light, enhancing photosynthesis.

Denser plant spacing can cause leaf shading, reducing photosynthesis efficiency. In this context, research by Arogundade indicated that the appropriate use of mulch can mitigate the negative effects of shading by improving light penetration to the leaf surface (Arogundade et al., 2019). Additionally, mulch functions to maintain soil moisture and reduce soil temperature, contributing to better plant growth (Indarwati, 2024).

With denser plant spacing, such as 40 cm x 20 cm x 12.5 cm, plants compete more intensely for light. Overcrowded spacing can cause leaves to be obstructed by neighboring plants, reducing the number of leaves capable of photosynthesizing effectively. Therefore, optimal plant spacing is crucial to ensure all leaves receive maximum light. The close spacing also results in leaf shading, where shaded leaves do not engage in photosynthesis and instead use photosynthates for respiration. Proper plant spacing can enhance plant growth by minimizing shading between leaves, thus improving photosynthesis efficiency (Singh et al., 2020).

4.2 Application of Mulch and Plant Spacing on the Yield of INPAGO 13 Rainfed Rice

The application of silver-black mulch in the cultivation of INPAGO 13 rainfed rice has shown significant results in increasing the dry weight of plants per hill. As shown in Table 6, plants treated with silver-black mulch have higher dry weight compared to those without mulch and those treated with straw mulch. Previous studies have indicated that the use of mulch, especially reflective types like silver-black mulch, can influence plant growth by regulating soil temperature and moisture, as well as reducing competition with weeds (Machanoff et al., 2022; Regmi et al., 2021; Iqbal et al., 2020). Furthermore, plant spacing also plays an important role in plant growth. In this study, the 40 cm x 20 cm x 12.5 cm spacing resulted in higher dry weight compared to 20 cm x 20 cm and 30 cm x 30 cm spacings. This may be due to the increased space for root growth and better access to resources such as water and nutrients (Kusdiana et al., 2018; Nyochembeng & Mankolo, 2021). Research by Nyochembeng and Mankolo also suggests that proper plant spacing can enhance plant performance by maximizing light reception and reducing plant competition (Nyochembeng & Mankolo, 2021).

The combination of silver-black mulch and optimal plant spacing can create a better microclimate, which supports photosynthesis and vegetative growth. Thakur et al. (2019) found that mulch can enhance essential oil composition and crop yields, contributing to higher dry weight. Additionally, silver-black mulch can assist in pest and disease control, further improving harvest outcomes (Agus et al., 2020). Overall, the application of silver-black mulch with a 40 cm x 20 cm x 12.5 cm plant spacing proved to be more effective in increasing the dry weight of plants compared to other treatments. This highlights the importance of selecting the right mulch type and spacing configuration to optimize crop yields.

The application of mulch with a 30 cm x 30 cm plant spacing was found to be more effective in increasing the milling dry grain weight per hill compared to other treatments. This can be explained through several factors that contribute to increased harvest yield. First, the use of mulch, especially silver-black mulch, improves soil moisture retention and reduces evaporation, which is crucial in supporting rice plant growth (Nurhafsah, 2021). Mulch usage can also reduce competition with weeds, allowing rice plants to grow more optimally and produce higher grain weights (Gunaeni et al., 2022). Second, the proper plant spacing, such as the 30 cm x 30 cm layout, provides sufficient space for plant development. A wider spacing allows the plant roots to access more resources, including water and nutrients, contributing to better growth and higher grain yield. Optimal spacing can increase the number of tillers and grain weight per hill, as aligned with findings in this study (Haq, 2024). Additionally, the combination of mulch and proper plant spacing can create a better microclimate, which enhances photosynthesis and vegetative growth. Research by Zuliati et al. (2020) demonstrated that mulch can improve the availability of water and nutrients, which is essential during the rice growth phase. This contributes to the increase in milling dry grain weight per hill, as healthy and strong plants tend to produce more grains.

The parameters for milling dry grain weight per m², milling dry grain weight per hectare, and 1000-grain dry weight, shown in Table 7, indicate that the application of silver-black mulch with a 40 cm x 20 cm x 12.5 cm plant spacing significantly improves milling dry grain weight per m², milling dry grain weight per hectare, and 1000-grain dry weight. The use of silver-black mulch helps regulate soil temperature and moisture, which are vital during the rice growth phase. The use of mulch improves soil moisture retention, allowing rice plants to access water more effectively, contributing to increased grain yields (Paiman, 2022).

The application of optimal plant spacing, such as in the 40 cm x 20 cm x 12.5 cm treatment, provides ample space for plant development. Wider spacing allows the plant roots to access more resources, including water and nutrients, thus enhancing growth and grain yield. Proper plant spacing can increase the number of tillers and grain weight per m² (Yuniansyah et al., 2022). Furthermore, silver-black mulch also reduces competition with weeds, which is a key factor that can hinder rice plant growth. Effective weed control can significantly improve plant growth and yield (Sumekar & Widayat, 2022). By reducing weed competition, rice plants can maximize resource use, leading to higher grain weights.

The application of silver-black mulch with a 40 cm x 20 cm x 12.5 cm plant spacing also shows a positive correlation between yield components, such as panicle length and grain weight per panicle, with the appropriate treatments in rice cultivation (Afa et al., 2021). This indicates that good agronomic management, including the use of mulch and proper plant spacing, can contribute to increased productivity of INPAGO 13 rainfed rice overall. The application of silver-black mulch with a 40 cm x 20 cm x 12.5 cm plant spacing has proven to be more effective in improving milling dry grain weight per m², milling dry grain weight per hectare, and 1000-grain dry weight. This underscores the importance of selecting the right mulch type and plant spacing configuration to achieve optimal yields in rice cultivation.

4.3 Application of Mulch and Plant Spacing on Solar Energy Conversion Efficiency (EKE) in INPAGO 13 Rainfed Rice

The results on Solar Energy Conversion Efficiency (EKE) in INPAGO 13 rainfed rice, presented in Table 14, indicate that the application of silver-black mulch with plant spacing of 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm exhibited higher EKE values compared to other treatments. The use of silver-black mulch enhances the efficiency of solar energy utilization by reflecting light back onto the plants, thereby increasing the light intensity received by the leaves. Studies have shown that mulch can improve soil physical properties, such as water retention and porosity, which contribute to better plant growth and higher crop yields (Haryati & Erfandi, 2019; Nurdin et al., 2019). Additionally, mulch helps reduce water evaporation from the soil surface, which is crucial in dryland conditions, enabling plants to use water more efficiently (Arifin & Saeri, 2020). Mulch serves as a soil conditioner that improves crop yields, suggesting that the combination of these treatments can produce a synergistic effect (Haryati & Erfandi, 2019). In the context of INPAGO 13 rainfed rice, the optimal planting distances of 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm also contribute to energy conversion efficiency, as proper spacing allows each plant adequate access to light and nutrients.

The application of silver-black mulch with plant spacing of 20 cm x 20 cm and 40 cm x 20 cm x 12.5 cm effectively converts solar energy into dry plant matter. According to Suryanto (2018), a plant's ability to produce dry matter is influenced by the solar energy absorbed by the leaves. The application of mulch significantly affects plant growth, as evidenced by increases in plant height and leaf number (Nurdin et al., 2019). This suggests that mulch not only acts as a soil protector but also as a factor that supports better vegetative growth, which in turn improves EKE. According to Burke (2017), while high EKE values do not directly increase crop production, they are typically associated with higher rates of photosynthesis. Overall, the application of silver-black mulch in INPAGO 13 rainfed rice not only enhances the efficiency of solar energy conversion but also supports better plant growth through moisture management and optimization of the photosynthesis process.

V. CONCLUSION ALND SUGGESTIONS

5.1 Conclusion

1. The application of mulch on INPAGO 13 rainfed rice can significantly improve albedo values, as confirmed in this study. Mulch, particularly reflective types such as silver-black mulch, can reflect sunlight back onto the plants, thereby increasing the amount of light received by the leaf surface, especially the parts not directly exposed to sunlight. This increase in albedo helps improve photosynthetic efficiency by reflecting more light to the areas of the plant that need it.

2. The application of mulch can also effectively reduce weed populations and maintain soil moisture, which has been proven in this study. Mulch, especially organic or plastic types, serves as a barrier that reduces the intensity of sunlight reaching the soil surface, thereby inhibiting weed germination and growth. Thus, the use of mulch can effectively reduce competition between the main crop and weeds for light, water, and nutrients. Additionally, mulch plays an important role in maintaining soil moisture by reducing evaporation from the soil surface. This helps retain the moisture necessary for plant growth, especially during dry seasons or in soils that tend to dry out.

3. The application of plant spacing can enhance plant populations and maximize rainfed rice productivity, as evidenced by the findings. Optimal plant spacing provides sufficient space for each plant to grow well, allowing the plants to access adequate light, water, and nutrients without excessive competition. Proper spacing also allows for better root spread and minimizes the possibility of shading between plants, which can reduce photosynthetic efficiency. Therefore, proper plant arrangement can increase plant density without sacrificing growth, ultimately supporting increased productivity and maximizing rainfed rice yields.

5.2 Suggestions

Further research For the plastic mulch treatment, it is recommended to plant more rice seeds in each planting hole, about 7 to 10 seeds per hole. After planting the rice seeds, rice husk ash should be applied to stabilize soil temperature and moisture, ensuring optimal plant growth. Although the results of this study demonstrate significant benefits from mulch and plant spacing, further research is needed to explore the long-term effects of these factors, such as the potential increase in microplastics in the soil, which could hinder plant growth.

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