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Application of Various Mulches to Increase Yield of Several Black Rice Genotypes Intercropped with Mungbean under Aerobic Irrigation System

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ABSTRACT

Black rice is widely consumed because of its beneficial effects on human health. However, its productivity is still low, while mulching has been reported to increase crop yield. This study aimed to determine the effects of different mulches on the growth and yield of three promising black rice lines grown on raised beds under an aerobic irrigation system. The experiment was conducted in Dasan Tebu, West Lombok Regency (Indonesia), using a split-plot design with three replications and two treatment factors, namely black rice promising lines (G3, G6, G9) as the main plots and mulch types (M0 = no mulch, M1 = rice straw mulch, M2 = silver–black plastic mulch) as the subplots. The results showed no significant interaction between black rice genotypes and mulch types, indicating that all three genotypes responded similarly to the mulch treatments, and among the two factors, mulch type was more dominant than genotype in affecting the growth and yield of black rice under the aerobic irrigation system. Mulching significantly increased black rice grain yield, with the highest grain yield (31.54 g/clump) obtained under rice straw mulch treatment compared with plastic mulch (29.30 g/clump) and no mulch (26.86 g/clump), while among the three genotypes, G6 (29.92 g/clump) and G3 (29.82 g/clump) produced higher grain yield than G9 (27.97 g/clump).

KEY WORDS: black rice; aerobic irrigation; straw mulch; plastic mulch; mungbean intercropping

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1. INTRODUCTION

Indonesia's population reached 273 million in 2021, prompting the government to increase rice production to meet the growing demand for food due to increasing population. In 2021, rice production was 54.42 million tons of milled dry grain, a decrease of 233.91 thousand tons or 0.43% compared with 2020 (54.65 million tons). Rice production for food consumption in 2021 was 31.3 million tons, which also declined by 140.73 thousand tons or 0.45% compared with 2020 (31.50 million tons). The main cause of this decline was reduced productivity [1].

Black rice is one type of rice in addition to red and white rice. It has recently gained attention and is increasingly consumed as a functional food because it contains one or more physiologically active compounds that are beneficial to human health. Black rice has higher nutritional value than other rice types and is gluten-free, cholesterol-free, and low in sugar, salt, and fat. It is rich in dietary fiber, anthocyanins, antioxidants, B-complex vitamins, vitamin E, iron, thiamine, magnesium, niacin, phosphorus, selenium, copper, zinc, and 18 amino acids. However, the high nutritional value of black rice is not yet matched by sufficient market availability. Black rice productivity is lower than that of white rice, and its crop duration is longer (5–6 months), so it is rarely cultivated by farmers [2].

In irrigated lowland rice cultivation, water is generally supplied continuously. Fields are flooded at a relatively constant water depth from transplanting until a few days before harvest, which can be done when water availability is adequate, usually with a water depth of about 10 cm. Continuous flooding, however, has drawbacks, including inhibiting rice growth and causing inefficient water use [3]. Aerobic irrigation systems are generally applied in rice cultivation on non-flooded or non-saturated soils [4]. According to previous reports, aerobic rice cultivation can reduce water use by up to 40% [5]. Furthermore, water management aimed at maintaining aerobic soil conditions can increase the number of productive tillers, biomass, and leaf area compared with continuous flooding [6]. Simarmata (2008) [7] also reported that the aerobic rice system can produce 1.6–1.9 times more filled grains than conventional flooded rice systems

Despite these advantages, the aerobic rice system carries a greater risk of weed infestation than flooded rice, although this can be managed using herbicides at the beginning and end of the growing season. Another approach to controlling weeds is the use of mulch. The application of organic mulch in soybean has been reported to reduce crop–weed competition and thereby increase soybean growth and yield [8]. Rice straw mulch has also been shown to significantly increase the yield of black rice under aerobic irrigation [9,10]. Inayah et al. (2022) [8] further demonstrated that plastic mulch significantly improved the growth and yield of black rice under an aerobic irrigation system.

This study therefore aimed to determine the effects of different mulch types on the growth and yield of several black rice lines grown on raised beds and intercropped with mungbean under an aerobic irrigation system.

II. MATERIALS AND METHODS

This experiment was conducted in Dasan Tebu Hamlet, Kediri Sub-district, West Lombok Regency (Indonesia), from January to May 2021. The experiment was arranged in a split-plot design with three replications (blocks) and two treatment factors: black rice lines (G3, G6, G9) as the main plots and mulch types (M0 = no mulch, M1 = rice straw mulch, M2 = silver–black plastic mulch) as the subplots.

The cultivation techniques for black rice on raised beds under an aerobic irrigation system with mungbean intercropping followed the bed dimensions, planting method, irrigation, fertilization, and fertilizer rates described in Wangiyana et al. (2019) [12], with red rice replaced by black rice in this study. Harvesting of black rice grains was carried out at 142 days after seeding (DAS).

Observations were made on sample plants (five clumps per treatment bed) for growth variables, grain yield, and yield components, including plant height, number of tillers, number of leaves, rate of plant height increase, rate of tiller number increase, rate of leaf number increase, dry straw weight per clump, panicle length, number of panicles per clump, percentage of unfilled grain number, number of filled grains per clump, 100-grain weight (filled grains), and dry grain yield per clump.

Data were analyzed using analysis of variance (ANOVA), and treatment means were compared using Tukey's HSD test at the 5% significance level, with CoStat for Windows version 6.303.

III. RESULTS AND DISCUSSION

The ANOVA results for all variables (Table 1) showed no significant interaction between the two treatment factors for any observed variable. Between the two factors, mulch type had significant effects on a greater number of variables than black rice genotype. Genotype significantly affected only tiller number, rate of increase in tiller number, and weight of filled grains, whereas mulch type significantly affected plant height, tiller number, rate of tiller number increase, leaf number, rate of leaf number increase, dry straw weight, panicle number, 100-grain weight, and weight of filled grains per clump.

Table 1. Summary of ANOVA p-values for the effects of genotypes and mulch types on black rice growth and yield variables

Measurement variables	Genotypes (G)	Mulch type (M)	G*M Interaction
Plant height at flowering	0.0594	**0.0003**	0.5608
Tiller number per clump at flowering	**0.0180**	**0.0272**	0.2862
Leaf number per clump at flowering	0.0820	**0.0001**	0.1260
Average growth rate (AGR) of plant height	0.1393	**0.0233**	0.4175
Average growth rate (AGR) of tiller number	**0.0748**	0.0825	0.2286
Average growth rate (AGR) of leaf number	0.0820	**0.0001**	0.1260
Dry straw weight per clump	0.4755	**0.0026**	0.4781
Panicle length	0.3724	0.2754	0.8451
Panicle number per clump	0.5419	**0.0002**	0.5857
Filled grain number per panicle	0.0520	0.2964	0.6273
Percentage of unfilled grain number	0.6855	0.8715	0.9421
Weight of 100 dry filled grains	0.0507	**0.0382**	0.7836
Grain yield per clump	**0.0031**	**0.0000**	0.0667

Growth of black rice plants

Table 2 shows that plant height and rate of plant height increase under silver–black plastic mulch (M2) were higher than under no mulch (M0) and rice straw mulch (M1). Leaf number and rate of leaf number increase with rice straw mulch (M1) and plastic mulch (M2) were higher than without mulch (M0). Dry straw weight under plastic mulch (M2) was higher than under no mulch (M0) and straw mulch (M1). Tiller number with straw mulch (M1) was higher than without mulch (M0), but the rate of tiller number increase did not differ significantly among mulch treatments.

For the black rice lines, tiller number (27.15 tillers/clump), and the rate of tiller number increase in G6 were higher than in G3 and G9, whereas plant height, leaf number, rate of height increase, rate of leaf number increase, and dry straw weight did not differ significantly among the promising lines.

The greater tiller number and rate of tiller initiation in line G6 compared with G3 and G9 are presumably due to genetic differences among the lines, which led to different numbers of tillers at flowering and different rates of tiller development, even though some growth variables were similar. This is consistent with Yulina et al. (2021) [13], who reported that each genotype has distinct characteristics determined by its genetic traits.

Table 2. Mean plant height (PH), tiller number (TN), leaf number (LN), average growth rate (AGR) of plant height (AGR PH), AGR of tiller number (AGR TN), AGR of leaf number (AGR LN), and dry straw weight (DSW) of black rice as affected by genotypes and mulch types

Treatments	Plant height (cm)		Tiller number per clump		Leaf number per clump		AGR PH (cm/day)		AGR TN (tillers/day)		AGR LN (leaves/day)		DSW (g/clump)	
G3	114.39	a	24.00	b	74.73	a	1.13	a	0,22	a	0,77	a	67,27	a
G6	113.09	a	27.15	a	76.43	a	1.11	a	0,24	a	0,67	a	68,79	a
G9	107.45	a	23.67	b	74.64	a	1.07	a	0,19	a	0,73	a	64,32	a
Tukey's HSD	ns		**2.69**		ns		ns		**0.05**		ns		ns	
M0: no mulch	106.91	b	21.50	b	63.39	b	1.05	b	0,17	a	0,56	b	60,44	b
M1: rice straw	108.25	b	28.25	a	82.18	a	1.04	b	0,25	a	0,79	a	61,80	b
M2: plastic	119.77	a	25.07	ab	80.23	a	1.22	a	0,23	a	0,82	a	78,14	a
Tukey's HSD	**6.44**		**5.73**		**6.58**		**66**		s		**0.11**		**11.63**	

Remarks: - M0= No mulch, M1= Rice straw mulch, M2= Plastic mulch; Genotypes (G3, G6, G9); ns = non-significant ANOVA
- Mean values followed by the same letters are not significantly different between levels of a treatment factor

The generally positive effects of mulching on most growth variables compared with no mulch (Table 2) are likely due to the coverage of the bed surface with plastic mulch, which reduces direct solar radiation reaching the soil surface, thereby preventing excessive soil surface temperature and reducing evaporation. This helps maintain soil moisture and available water, allowing roots to absorb water more optimally than in unmulched plots or those with straw mulch. Rice straw mulch still leaves open spaces for evaporation. Adequate water availability in the root zone enhances nutrient solubility and thus increases nutrient availability for root absorption.

According to Kurniawan et al. (2014) [14], water is a key physical component that is required in large amounts for plant growth and development and acts as a solvent for nutrients supplied or present in the soil, which are then used in photosynthesis. Water deficits disrupt plant metabolic processes and ultimately affect plant growth and development. In addition to reducing soil evaporation, plastic mulch can also reflect solar radiation. Muslim and Soelistyono (2017) [15] also stated that silver–black plastic mulch can reflect solar radiation back to the plant canopy, especially for the leaves in the lower position of the canopy, thereby improving light availability for photosynthesis, as also reported by Prayoga et al. (2016) [16].

Light plays a crucial role in photosynthesis in the leaves. Leaves positioned in the lower canopy are usually shaded by upper leaves. Light reflected by the silver surface of plastic mulch can be utilized by these shaded leaves for photosynthesis, which ultimately increases total photosynthesis per clump. Increased photosynthate production then promotes plant growth. Noorhadi and Supriyadi (2003) [17] also reported that silver–black plastic mulch reflects a substantial portion of incident sunlight. The more light intercepted by the canopy, the higher the photosynthetic rate and the greater the photosynthate amount produced.

Similar effects of plastic mulch on plant height were reported for soybean by Nurbaiti et al. (2017) [18], who found that silver–black plastic mulch increased plant height in the variety Grobogan. Muslim and Soelistyono (2017) [15] also reported that silver–black plastic mulch on flat beds significantly increased cabbage plant height compared with no mulch. In this study, dry straw weight of black rice was consistent with plant height and rate of height increase, indicating a positive correlation between plant height and dry straw weight per clump (Table 2). According to Andita et al. (2016) [19], plant development is a combination of complex processes of growth and differentiation leading to dry matter accumulation.

Tiller number per clump, leaf number, and rate of leaf number increase in black rice under mulched treatments, both plastic and rice straw, were significantly higher than under no mulch. This is presumably because mulching reduces weed presence and growth, thereby decreasing competition with rice plants for growth factors. When competition from weeds is reduced, rice plants can access more water, nutrients, and light. Mokoginta et al. (2017) [20] also reported that plastic mulch was the most effective mulch treatment for suppressing weed growth compared with other mulches. According to Limonu et al. (2021) [21], rice straw mulch reduces water loss and lowers soil temperature, helping maintain a more stable soil moisture regime around the plants. Incorporation and decomposition of straw mulch improve soil physical properties, increase soil water infiltration, enhance soil organic matter, and suppress weed growth, thereby reducing competition for nutrients.

Yield and yield components of black rice

Based on the mean comparison of yield and yield components among treatments (Table 3), grain yield among black rice genotypes was higher in G3 and G6 than in G9, while other yield components did not differ significantly among lines. In contrast, among mulch treatments, grain yield per clump, panicle number, and 100-grain weight differed significantly, with the highest means under rice straw mulch (M1), followed by plastic mulch (M2), and the lowest values under no mulch (M0). Panicle number per clump with straw mulch (M1) and plastic mulch (M2) did not differ, but both were higher than under no mulch (M0). The 100-grain weight in straw mulch (M1) was higher than under no mulch (M0), but not significantly different from plastic mulch (M2). The highest weight of filled grains per clump was obtained with straw mulch (M1), followed by plastic mulch (M2), and the lowest under no mulch (M0). Other variables did not differ significantly among mulch treatments.

Table 3. Mean panicle length, panicle number (PN), number of filled grains (NFG), percentage of unfilled grains (%UFG), 100-grain weight, and dry grain yield per clump of black rice as affected by genotypes and mulch types

Treatments	Panicle length (cm)		PN (panicles/clump)		NFG (grains/clump)		%UFG (%)		100-grain weight (g)		Grain yield (g/clump)	
G3	22,03	a	19,97	a	94,85	a	11,60	a	2,72	a	29,82	a
G6	22,45	a	20,36	a	102,39	a	11,56	a	2,70	a	29,92	a
G9	22,04	a	19,52	a	96,58	a	12,11	a	2,84	a	27,97	b
Tukey's HSD	ns		ns		ns		ns		ns		**,95**	
M0: no mulch	21,64	a	16,72	b	99,14	a	11,97	a	2,67	b	26,86	c
M1: rice straw	22,37	a	22,22	a	95,00	a	11,76	a	2,86	a	31,54	a
M2: plastic	22,51	a	20,91	a	99,68	a	11,54	a	2.73	ab	29,30	b
Tukey's HSD	ns		**,53**		ns		s		**.7**		**,75**	

Remarks: - M0= No mulch, M1= Rice straw mulch, M2= Plastic mulch; Genotypes (G3, G6, G9); ns = non-significant ANOVA
- Mean values followed by the same letters are not significantly different between levels of a treatment factor

The higher panicle number per clump, 100-grain weight, and weight of filled grains per clump with straw mulch (M1) compared with plastic mulch (M2) and no mulch (M0), as shown in Table 3, are presumably due to weed suppression and improved soil conditions resulting from straw decomposition during the reproductive phase. According to Fadhly and Fahdiana (2011) [22], weeds are the most serious competitors in crop production because they compete for water, nutrients, and light. Rice straw mulch can also supply nutrients to the plants as it decomposes, which can be used to increase yield [23]. Raihana and William (2006) [24] also reported that rice straw mulch not only suppresses weed growth but also improves soil fertility, maintains soil moisture, increases nutrient uptake, and optimizes soil temperature. Straw mulching has also been shown to increase mungbean grain yield [24] and fresh bulb weight of shallot [25].

In terms of 100-grain weight of filled grains, straw mulch application resulted in the highest mean (2.86 g), followed by plastic mulch (2.73 g) and no mulch (2.67 g). Jannah et al. (2011) [25] stated that the 100-grain weight of filled grains reflects grain plumpness and the amount of biomass stored in the grain, which is strongly determined by nutrient availability and the continuity of physiological processes. This appears to be supported by the higher leaf number per clump at flowering under straw mulch (Table 2), and since leaves are the main photosynthetic organs, a greater leaf number likely increases the rate of photosynthesis and, consequently, the rate of grain filling under straw mulch compared with other treatments.

IV. CONCLUSION

Based on the results and discussion, it can be concluded that both silver–black plastic mulch (M2) and rice straw mulch (M1) increased the mean values of several growth and yield variables compared with no mulch (M0), including plant height, tiller number, leaf number, rate of plant height increase, rate of leaf number increase, dry straw weight, panicle number, 100-grain weight, and grain yield per clump. The highest mean grain yield (31.54 g/clump) was obtained with rice straw mulch, followed by plastic mulch (29.30 g/clump) and no mulch (26.86 g/clump). Among the black rice lines, G6 (29.92 g/clump) and G3 (29.82 g/clump) produced higher grain yields than G9 (27.97 g/clump). However, there was no interaction between genotype and mulch type.

V. DISCLOSURE

We do not have any conflicts of interest in this work.

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