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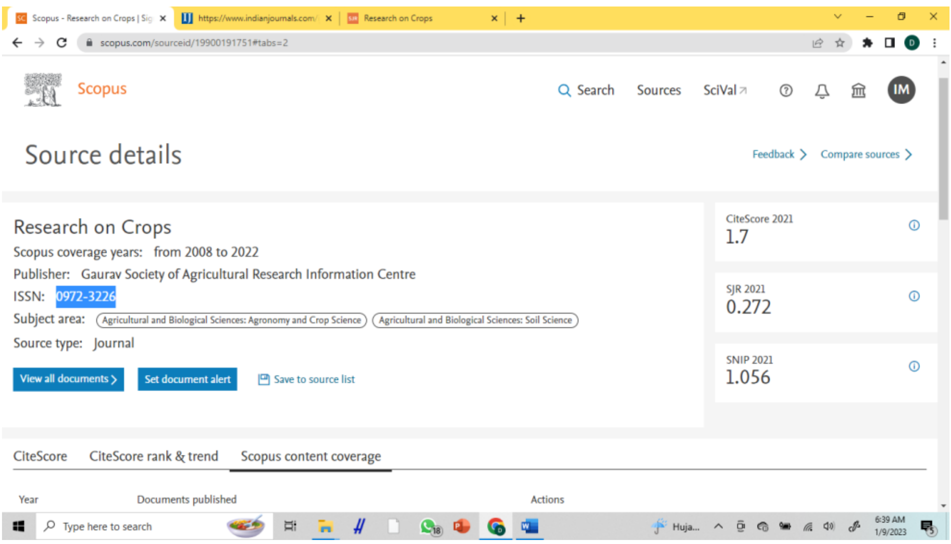

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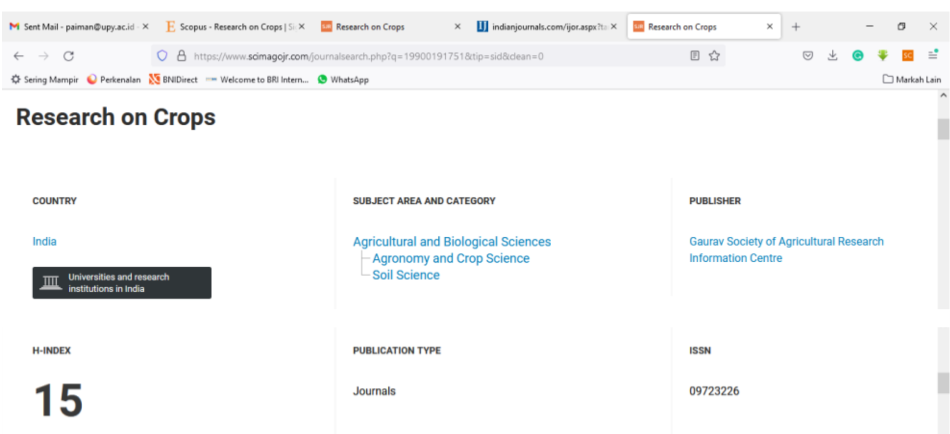

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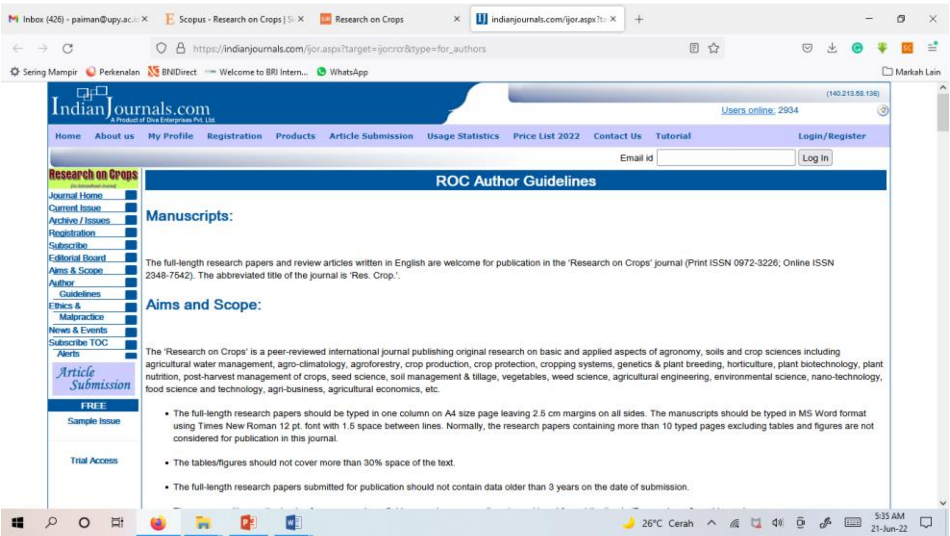

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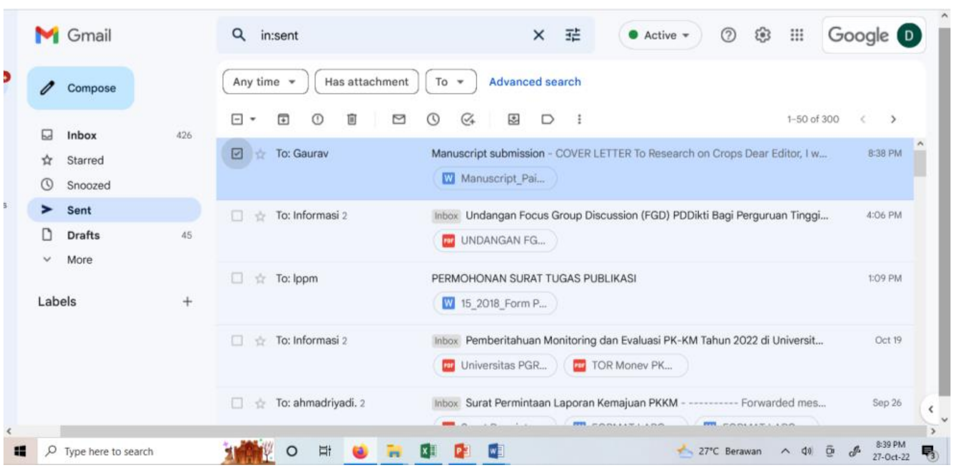

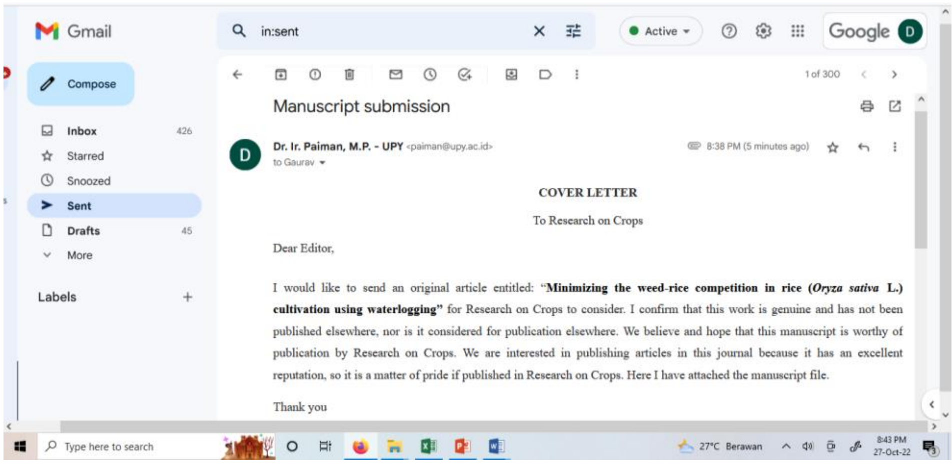

COVER LETTER

To Research on Crops

Dear Editor,

I would like to send an original article entitled: "**Minimizing the weed-rice competition in rice (*Oryza sativa* L.) cultivation using waterlogging"** for Research on Crops to consider. I confirm that this work is genuine and has not been published elsewhere, nor is it considered for publication elsewhere. We believe and hope that this manuscript is worthy of publication by Research on Crops. We are interested in publishing articles in this journal because it has an excellent reputation, so it is a matter of pride if published in Research on Crops. Here I have attached the manuscript file.

Thank you
Best regards,

Paiman
Universitas PGRI Yogyakarta, Indonesia

The manuscript for submission:

Minimizing the weed-rice competition in rice (*Oryza sativa* L.) cultivation using waterlogging

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ABSTRACT

The presence of weeds is a significant constraint in rice cultivation. One of the mechanical weed controls is waterlogging. This method is considered sustainable weed control, environmentally friendly, and reduces the cost of weed management. This study aimed to know the waterlogging period to minimize the weed-rice competition and increase the rice yield. This study was arranged in a completely randomized design (CRD) factorial with three replications. The first factor was waterlogging periods, which consisted of three levels: without waterlogging, 1–15 days after planting (DAP), and 1–30 DAP. The second factor was soil types, which consisted of four kinds: latosol, coastal sandy, volcanic, and regosol soil. The weed growth was observed at 60 DAP, but the growth and yield of rice were conducted at 104 DAP. The results showed that waterlogging could minimize weed-rice competition in rice cultivation. Furthermore, waterlogging period of 1–30 DAP could inhibit the weed dry weight (WDW) and increase the leaf area index (LAI), shoot root ratio (SRR), grain dry weight (GDW), and harvest index (HI) in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 tons/ha), then decreased in volcanic (6.0 tons/ha), regosol (5.9 tons/ha), and the lowest in coastal sandy (4.8 tons/ha). The research findings show that waterlogging period of 1-30 DAP can minimize the weed-rice competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation.

Key words: Competition, rice, soil, waterlogging, weed control

Running headline: Minimizing the weed-rice competition

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food predominantly consumed by more than half of the world's population (Anwar *et al*., 2012; Auškalnienė *et al*., 2018). It is grown on over 161 million hectares worldwide, and over 90% of rice is produced in the Asian region (Shekhawat *et al*., 2020). Rice cultivation is mainly for food and livelihood security. It can be cultivated in different environments, including tropical to temperate climates and aerobic soil in the uplands to anaerobic soil in wet lowlands (Ismail *et al*., 2012).

Weed competition is a major problem in all rice-cultivation systems around the world. This problem worsened when the rice farmer shifted from the transplanted to the direct seeding method due to labor and water shortage (Kumar *et al*., 2017). The presence of weeds in paddy fields can increase control costs, decrease grain quality, and yield losses (Scavo and Mauromicale, 2020). Weeds are recognized as the most critical biotic factor that limits crop production. Previous studies reported rice grown in an aerobic system competed with 90 weed species, causing a 23–100% decrease in grain yield (Jabran and Chauhan, 2015). Some weed species caused crop yield loss of up to 45% (Korav *et al*., 2018). Therefore, weed control to minimize weed-rice competition is important for increasing the rice yield. Flooding in the rice fields is called waterlogging. Waterlogging can suppress weed seed germination and growth. This method can be a safer, environmentally friendly, low-cost weed control alternative.

A single weed species can produce a large number of weed seeds. The weed seeds can disperse in different ways to extend their migration and population, such as by the wind, water, ants, gravity, and anthropogenic activities (Gao *et al*., 2018). Dry and flooded rice fields may have different weed flora. The identified significant weed floras in flooded rice ecosystems were *Echinochloa colona* and *Echinochloa crus-galli* (Bhatt *et al*., 2021). The dominant weed species in the system of rice intensification (SRI) was *Echinocloa crus-galli*, while in the conventional system was *Ludwigia hyssopifolia* (Mustakim *et al*., 2022).

The soil seed bank is the principal source of new infestations of annual weeds, which contains most of the weed species composition. According to Auškalnienė *et al*. (2018), the weed seed bank in the soil significantly decreased over five years by soil tillage. In recent years, chemical weed control has been regarded as the most efficient and cost-effective approach. Weed management strategies based on herbicides are no longer environmentally friendly, economically practical, and efficient against different weed species. However, this method can lead to the emergence of herbicide-resistant weed biotypes (Kumar *et al*., 2017). Challenges arise in weed management because cultivated rice and weedy rice share similar morphological and physiological characteristics. Therefore, they competed for growing space, nutrients, water, and sunlight in the same field plot. Under these circumstances, any plant that emerges in the cropping field will compete with these limited resources and diminish the quality and quantity of crop production. In addition, some weed species produced phytotoxins that were harmful to rice growth (Bastiaans and Kropff, 2017). The weed–rice competition can be measured from their growth rate.

Flooding the soil may alter the rice plant density, vigor, and uniformity, as well as the intensity of weed competition and herbicide efficiency (Ismail *et al*., 2012). The survival and development of weed species are also influenced by the depth and length of flooding (Kumalasari, 2014). Farmers can flood their rice fields up to 1 cm to support the rice growth (Khairi *et al*., 2015). However, flooding can create low oxygen (O_2) and anaerobic conditions and induce secondary weed dormancy (Fennimore, 2017). The decreased O_2 levels in the soil can cause excessive water content, compaction, compression, and hard surfaces, thus reducing the success and speed of the weed seed dispersal (Yasin and Andreasen, 2016).

Most of the weeds have tolerant and adaptive traits that can germinate and elongate under hypoxia more quickly with the mobilization of starch reserves, allowing weeds and rice to grow in flooded areas. Tolerant rice genotypes can adapt well to flooding. At the same time can suppress weeds that grow (Ismail *et al*., 2012). The water defense in the paddy fields can increase rice growth and reduce weed growth (Kaya-Altop *et al*., 2019). At this critical period, rice plants are sensitive to weeds around them.

Waterlogging can inhibit weed growth during this period. Therefore, weed control at a critical period can increase rice yield. According to Anwar *et al*. (2012), the rice should be weed-free during 2–43 DAP for better yield. In addition, Rahman *et al*. (2014) found that a critical period of rice weed competition occurred up to 30 DAP.

Rice cultivation can be carried out in different soil types. However, each soil type had an additional carrying capacity for the growth and yield of rice. The soil types had different physical and chemical properties. The amount of water needed for waterlogging depends on soil types. Sandy soils require more water because macro-pores are more dominant. Ideally, the soil needed to include around 50% clay content. Also, the soil was underlain with an impervious claypan to help to hold the water. The sandy soil has many aerations and water holding capacity. At the same time, clay is generally more fertile due to less aeration and high water-holding capacity.

The sandy loam texture soil is the best for maximum seed germination (Gulshan and Dasti, 2012). The excellent soil's physical condition can store and conduct water, air, and nutrients promoting both maximum crop yield and minimum environmental degradation (Valle *et al*., 2018). The sandy soil is often considered physical properties that quickly define the weak structure, reduced water retention, and high permeability.

To date, most researchers were only focused on the effect of waterlogging on O_2 levels in soil (aerobic system) and weed seed germination. This research will use waterlogging to suppress weed growth in rice cultivation. Previous researchers have investigated mechanical weed control in rice cultivation, but the period of waterlogging has never been carried out. However, until now, there has been no research on the effect of waterlogging on weed suppression in lowland rice. Therefore, weed control in rice cultivation by waterlogging needs to be done. Waterlogging significantly contributes to weed suppression and can improve the rice yield. Therefore, this study aimed to know the waterlogging period for minimizing the weed-rice competition to increase the rice yield.

MATERIALS AND METHODS

Study Site

The research area was conducted from July to November 2019 in the greenhouse, Faculty of Agriculture, Universitas PGRI Yogyakarta, Bantul, Yogyakarta, Indonesia, having an elevation of 118 m above sea level (ASL). Bantul Regency is located between 14º04'50"- 27º50'50" South Latitude and 110º10'41"-110º34'40" East Longitude. The average temperature and humidity of the air during the study were 34 °C and 60%, respectively.

Soil Sampling

The soil used in this research was the former paddy fields from 0-20 cm soil depth. The sampling of soil types was taken from three districts, namely, Kulonprogo, Sleman, and Bantul, in a special territory of Yogyakarta.

Experimental Design

The research was arranged in a complete randomized design (CRD) factorial with three replications. The first factor was waterlogging, which consisted of three levels: without waterlogging, 1–15, and 1–30 DAP. The second factor was soil types, which consisted of four types: latosol, coastal sandy, volcanic, and regosol. Therefore, the experiment needed as many as 36 wooden boxes as sample plots.

Research Procedures

The rice nurseries were carried out in plastic boxes of 25 cm (width) × 30 cm (length) × 10 cm (high) for germination. The soil media used a mixture of soil and cow manure (1:1). The Ciherang variety was used in this study. First, the rice seeds were spread and covered with 0.2-0.4 cm soil. The seeds would germinate for four days after spreading (DAS) in the media. Then, the rice seedlings were planted 14 DAS in wooden boxes.

The wooden boxes were 50 cm (width) × 80 cm (length) × 25 cm (height). It was placed on the table in a greenhouse coated with waterproof plastic. Before putting it in wooden boxes, the soil was crushed into small granules and dry soil conditions. Each soil type was put into a wooden box as high as 20 cm. Each soil type was without the manure addition. The soil types were put into wooden boxes based on the treatment randomization. It was done on all of the soil types.

The soil in wooden boxes was watered until field capacity. Then, the seedlings were planted a day after watering in eight holes with a plant spacing of 20 cm × 25 cm in two-row planting. Next, each row was planted with four clumps of rice crops. So, 16 rice seedlings were needed. The soil surface area in a wooden box was 0.4 m^2.

The treatment of waterlogging was done since seedlings were planted. However, water application was only carried out at field capacity until 1–30 HST for the treatment without waterlogging. Then, the waterlogging height was as high as 3 cm from the soil surface. For the waterlogging period of 1–15 DAP, the soil only was flooded for 1–15 DAP, and next in the field capacity until 30 DAP. Therefore, waterlogging of 1–30 DAP, the soil was saturated at a period of 1–30 DAP. After the waterlogging treatment ended, all were treated equally suitable for their needs.

Weed seeds germination in the soil surface was after 5 DAP from the first water application. After that, the weeds were allowed to grow in around rice crops. Fertilizing rice crops using NPK Mutiara was done in three stages, namely, 15, 30, and 45 DAP. The dosage for each application was 25 g/0.4 m^2 of the soil areas.

Parameters

The weed observation was carried out on the weed species that grew on the soil surface around rice clumps at 60 DAP. The variable of weed was observed by WDW (kg). The observation of rice was done by collecting the variable, including LAI, SRR, GDW, and HI, in sample plots at 104 DAP.

The WDW, shoots dry weight (SDW), roots dry weight (RDW), and GDW were dried in Binder FED 53–UL Forced Convection Drying Oven for 48 hours at a temperature of 80 °C or until a constant weight was achieved. The Ohaus PA214 Pioneer Analytical Balance was used to measure the WDW, SDW, RDW, and GDW. The Portable Laser Leaf Area Meter CI–202 was used for measuring the leaf areas (cm^2). The SDW was total from the dry weight of the stem, leaf, and panicle. The WDW, SDW, RDW, and GDW from sample plots of 0.4 m^2 were converted to m^2, except for the parameter of leaf areas.

The SRR is between SDW (kg/m^2) and RDW (kg/m^2) ratio. The formula for calculating the SRR is represented in Eq. 1.

$$SRR = \frac{SDW}{RDW} \qquad \text{(Eq. 1)}$$

The economic yield (EY) was in the form of GDW (kg/m^2). The biological yield (BY) of rice is total from GDW, SDW, and RDW (kg/m^2). The harvest index (HI) is the EY and BY ratio. The formula to calculate the HI is used in Eq. 2.

$$HI = \frac{EY}{BY} \qquad \text{(Eq. 2)}$$

Statistical Analysis

Observational data were analyzed by analysis of variance (ANOVA) at P = 0.05 level of probability, with IBM SPSS Statistic 23. In addition, the difference between the treatment averages was compared using Duncan's new multiple range tests (DMRT) at P = 0.05 level of probability.

RESULTS AND DISCUSSION

Effect of Waterlogging on the Growth of Weed and Rice

The treatment combination of waterlogging and soil types significantly interacted in WDW, LAI, SRR, GDW, and HI parameters. Then, the DMRT at P = 0.05 level of probability on the WDW, LAI, SRR, GDW, and HI can be seen in **Error! Reference source not found.**.

Table 1. Effect of waterlogging on the WDW, LAI, SRR, GDW, and HI in different soil types.

Waterlogging (DAP)	Soil types	Weed	Rice			
		WDW (kg/m^2)	LAI	SRR	GDW (kg/m^2)	HI
Without	Latosol	0.673 c	3.15 e	1.74 bcd	0.25 g	0.17 g
	Coastal sandy	0.779 bc	1.76 f	1.31 d	0.20 g	0.25 ef
	Volcanic	1.060 a	3.08 e	2.20 abc	0.37 f	0.30 de
	Regosol	0.820 b	1.65 f	1.19 d	0.18 g	0.22 pq
1-15	Latosol	0.116 de	4.34 abcd	2.38 a	0.65 b	0.36 ab
	Coastal sandy	0.070 de	3.25 e	2.62 a	0.42 ef	0.30 cd

	Volcanic	0.088 de	3.55 de	2.03 abc	0.51 cd	0.31 bcd
	Regosol	0.186 d	4.48 ab	1.67 cd	0.47 de	0.28 de
1-30	Latosol	0.087 de	4.54 abc	2.33 ab	0.75 a	0.37 a
	Coastal sandy	0.004 e	3.76 cde	2.57 a	0.48 de	0.29 cd
	Volcanic	0.029 e	3.67 de	1.69 cd	0.59 bc	0.34 abc
	Regosol	0.029 e	4.75 a	2.25 abc	0.60 b	0.28 de
Treatments interaction		(+)	(+)	(+)	(+)	(+)

Remarks: The number in the same column followed by the same characters is not significantly different based on DMRT at P = 0.05 level of probability and (+) = significant interaction.

Table 1 shows that waterlogging can significantly suppress WDW and increase LAI, SRR, GDW, and HI. Waterlogging period of 1-30 DAP was appropriate to suppress weed growth and increase the growth and yield of rice. The WDW was higher in soil without waterlogging but lower in the 1-30 DAP period. In soil types of latosol, coastal sandy, volcanic, and regosol with a waterlogging of 1–30 DAP can inhibit the weed growth by 87.7, 99.5, 97.3, and 96.5% than without waterlogging.

The highest LAI occurred in regosol soil with waterlogging of 1-30 DAP. Next, the highest SRR happened in latosol and coastal sandy with waterlogging of 1-15 DAP and in latosol soil with waterlogging of 1-30 DAP. Waterlogging of 1-30 DAP in latosol soil produced higher GDW and HI. Waterlogging of 1-30 DAP could increase GDW by 66.7, 58.3, 37.3, and 70.0% than without waterlogging.

The weed growth in the volcanic soil was higher than in other soil types, especially without waterlogging. Each soil type had a different weed seed bank. In this study, waterlogging was effective in inhibiting weed growth. Waterlogging can reduce the O_2 level in the soil. Then, the weed seeds can not germinate maximally at the low O_2 level. This anaerobic condition can cause weed growth to decrease due to inhibited respiration. The weed growth decreased at the waterlogging periods of 1–15 and 1-30 DAP in regosol, latosol, volcanic, and coastal sandy soil.

The weed growth was lower in a waterlogging period of 1–30 DAP in coastal sandy, volcanic, and regosol soil. The extended period of waterlogging caused a reduction in weed growth. The water availability on the soil surface at early rice growth potentially inhibited weed seed germination. Therefore, waterlogging of 1–30 DAP could significantly inhibit weed growth.

Also, the controlling of weed intolerant effectively used waterlogging. The results of this study follow the opinion of Matloob *et al*. (2015) that the weed species could be grouped into three conditions: intolerant, tolerant, and stimulant with waterlogging treatment. The weed competition, even during 20 DAP reduced grain yield in dry–seeded rice.

Waterlogging periods of 1–15 and 1–30 DAP could decrease weed growth, giving the rice crops a chance to grow better. But, on the other hand, Waterlogging period of 1–30 DAP could increase the LAI and SRR more maximal. Because weed growth was most robust on soil without waterlogging, it then caused a decrease in rice LAI on all of the soil types, especially in coastal sandy and regosol. However, waterlogging periods of 1–15 and 1–30 DAP in the latosol soil caused higher SRR. Therefore, the waterlogging treatment could increase the SRR.

In certain conditions, if it did not occur the weed–rice competition, then the rice crops were more concentrated in improving the growth of the shoot than the root. Therefore, it caused the SRR to be higher. On the contrary, weeds experienced rapid growth without waterlogging, so the rice crops were depressed in their development. The rice could not compete in getting nutrients, water, sunlight, and growing space, and then root growth was more robust, so the SRR was lower. It occurred in the coastal sandy and regosol soil without waterlogging. Waterlogging period of 1–30 DAP increased the LAI of rice. Wider leaves allow the process of capturing sunlight more optimally so that the production of carbohydrates is higher. Carbohydrates were used for tissue growth and seed filling. Waterlogging period of 1–30 DAP caused the highest LAI in the regosol soil, then a decrease in the latosol soil. Although, the highest GDW was not produced in the regosol soil. It showed that the LAI higher occurred in the latosol soil, and then GDW higher too. According to Olajumoke *et al*. (2016), the potential of weed-rice competition was at all stages of plant development. This potential caused yield loss of rice yield.

The LAI and SRR could provide strong support for grain filling during generative growth. The results of carbohydrates for the grains filling (stored capacity) could be maximally processed. Generally, GDW higher was obtained at waterlogging period of 1–30 DAP in different soil types, especially in the latosol soil (0.75 kg/m^2 or 7.5 tons/ha). The results of this study were higher than the average potential of Ciherang rice yields, as high as 5–7 tons/ha (Sastro *et al*., 2021). The latosol soil had a maximal carrying capacity on the GDW production in without waterlogging conditions. The GDW began to decline at the waterlogging period of 1–15 DAP. After all, the treatment showed that the weed growth started to get stronger than the waterlogging period of 1–

30 DAP. The lowest GDW occurred in without waterlogging because the weed-rice competition was inevitable.

Without waterlogging, the LAI and SRR were lower, so it caused the GDW and HI to be low too. Therefore, weed control using the waterlogging of 1–30 DAP was the appropriate period to get rice's maximal growth and yield. On the other hand, waterlogging could increase the GDW in latosol, coastal sandy, volcanic, and regosol soil.

During a long weed-rice competition, relative rice grain yield loss was between 68% and 80% (Matloob *et al*., 2015). The weeds contributed to a 40% rice yield loss (Ramesh *et al*., 2016). The impact of weed on the rice can be seen directly in the change of leaf area. The higher WDW caused lower LAI. The weed growth that gets more vigorous causes growing space competition in the sunlight. The rice crops with lower LAI, consequently absorption of sunlight was low too. The low consumption of light by rice crops will cause low photosynthetic yields. If the seed filling period were not optimal, it would cause a low GDW.

The weed impact on SRR can be seen directly in the change in the dry weight of shoots and roots. The weeds were greedy for nutrients and water in the soil. The rice responded by strengthening its roots. In high weed–rice competition, the rice showed that the SRR was getting smaller. Conversely, the roots grew to produce a higher SRR. According to Olajumoke *et al*. (2016), the interactions of weed and rice crops often reflected early vigor, more tillering, and nutrient utilization ability for the shoot development of rice crops. Even though the latter also showed an improvement in shoot development under competition.

Solar radiation is highly correlated with LAI and dry matter (Garcés-varon and Restrepo-díaz, 2015). The process of sunlight absorption was affected by the leaf areas. More sunlight being held captive in the photosynthetic process caused the rice seed filling to increase. The optimal crop planting density is generally based on a weed-free environment (Dass *et al*., 2017).

The effect of waterlogging on the WDW and GDW of rice in different soil types can be seen in Fig. 1.

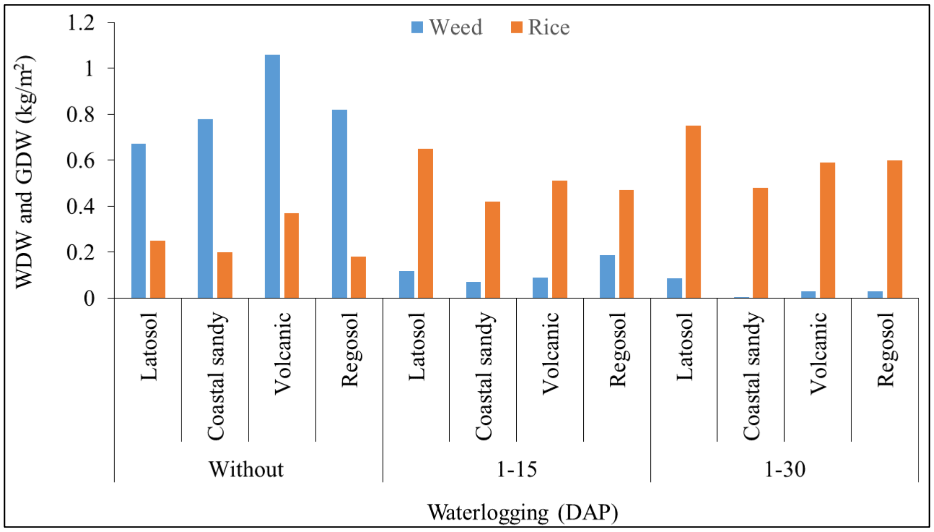

Fig. 1. Effect of waterlogging on WDW and GDW in different soil types.

Weed and Rice Correlation

The correlation analysis was done on the relationship between WDW, LAI, SRR, GDW, and HI. The results of the correlation analysis can be seen in Table 2.

Table 2. The correlation analysis between weed growth and rice growth and yield.

Variable		LAI	SRR	GDW	HI
WDW	Pearson Correlation	$-.736^{**}$	$-.548^{ns}$	$-.776^{**}$	$-.576^{ns}$
	Sig. (2-tailed)	.006	.065	.003	.050
	N	12	12	12	12

Remarks: ** = Correlation is significant at P = 0.01 level of probability (2-tailed), and ^{ns} = correlation is not significantly at P = 0.05 level of probability.

Table 2 shows that GDW was significantly negatively correlated with LAI (-0.736**) and GDW (-0.776**), respectively, but not significantly with SRR (-0.548^{ns}) and HI (-0.576^{ns}). Growing weeds is followed by a decrease in LAI and GDW.

The correlations between rice yield under weed-free and weedy conditions could strongly affect weed pressure levels. The weeds were greedy for environmental factors, namely, nutrients, water, sunlight, space growing, and more robust growth than crops. Without waterlogging, weed growth was most robust. The stronger weed was followed by lower growth and yield of rice crops. The effect of waterlogging on GDW was different and depended on the soil types. The lower WDW occurred in coastal sandy soils, but higher GDW in regosol soil. It showed that soil fertility level also determined WDW and GDW. Regosol soil resulted in a higher GDW.

Performance of the weed-rice competition

The effect of waterlogging on the performance of the weed-rice competition can be seen in Fig. 2.

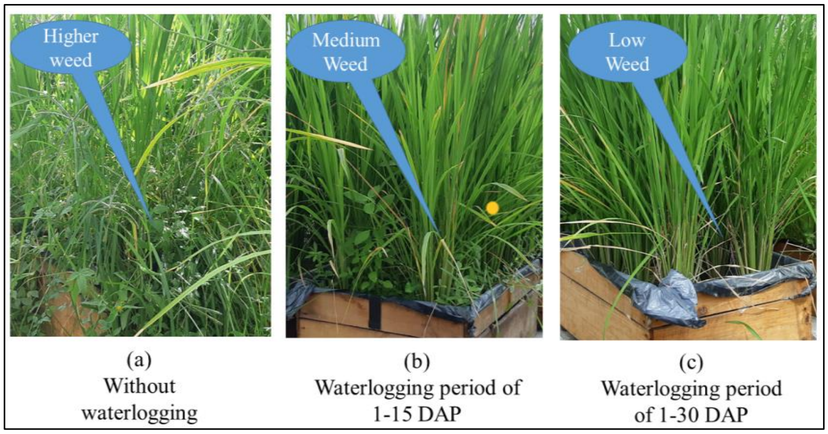

Fig. 2. The effect of waterlogging on the weed-rice competition.

Fig. 2 shows that weed and rice performances were very different. Without waterlogging showed that weed growth was very strong (a). Treatment of 1-15 DAP waterlogging indicated medium weed growth (b). Finally, low weed growth occurred in waterlogging of 1-30 DAP (c).

CONCLUSIONS

In conclusion, waterlogging could minimize weed-rice competition in rice cultivation. Furthermore, waterlogging of 1–30 DAP could inhibit the WDW and increase the LAI, SRR, GDW, and HI in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 tons/ha), then decreased in volcanic (6.0 tons/ha), regosol (5.9 tons/ha), and the lowest in coastal sandy (4.8 tons/ha). The research findings indicate that waterlogging period of 1-30 DAP can minimize the weed-rice competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation.

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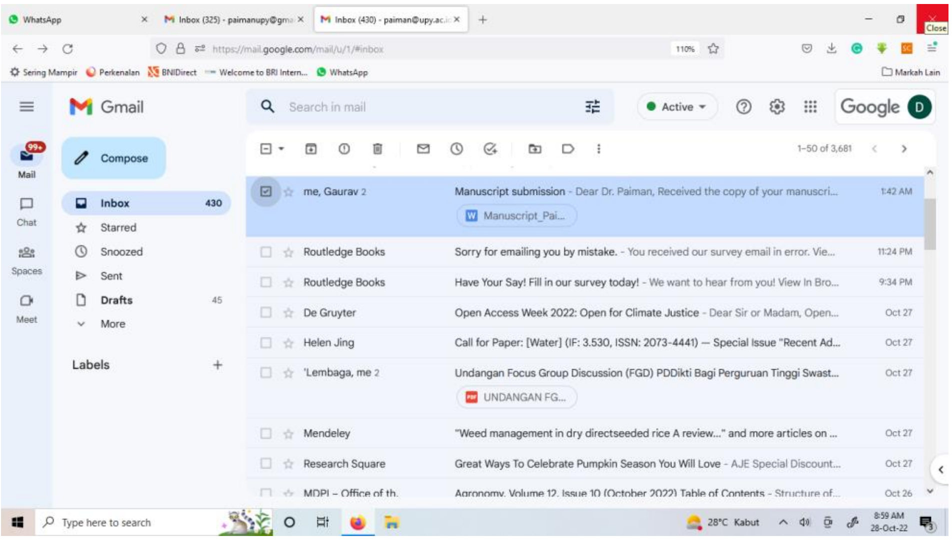

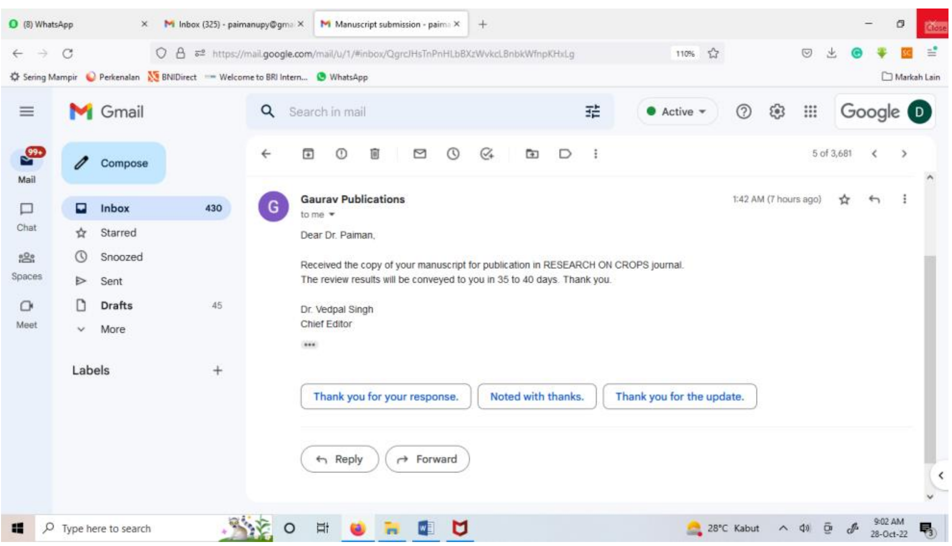

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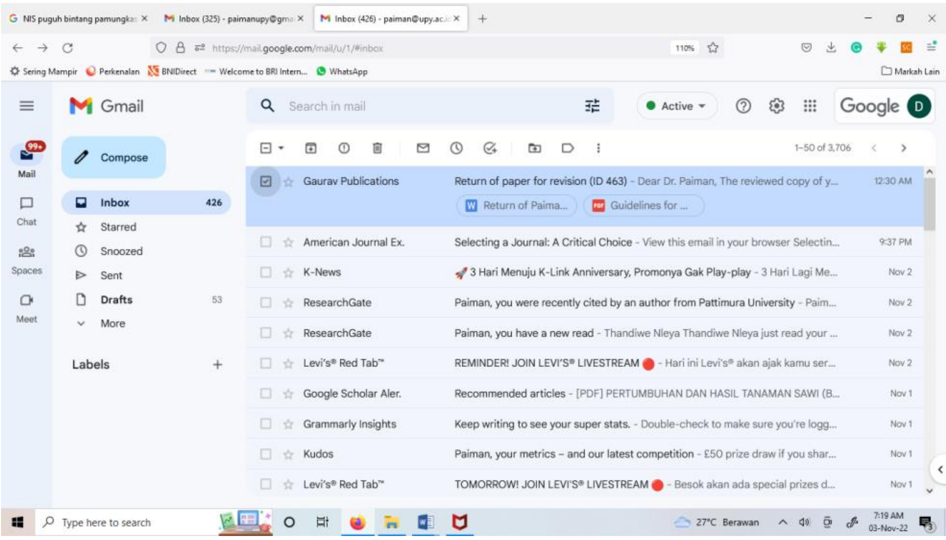

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<u>*Minimizing the weed-rice competition*</u>

Evaluating waterlogging in rice (*Oryza sativa*) to minimize weed competition in various soil types of Indonesia

(or)

Minimizing weed competition through waterlogging in rice (*Oryza sativa*) under various soil types

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ABSTRACT

The presence of weeds is a significant constraint in rice cultivation. One of the mechanical weed controls is waterlogging. This method is considered sustainable weed control, environmentally friendly, and reduces the cost of weed management. This study was conducted during __ at __ aimed to know the waterlogging period to minimize the weed-rice competition and increase the rice yield. This study was arranged in a completely randomized design (CRD) factorial with three replications under greenhouse conditions. The first factor was waterlogging periods, which consisted of three levels: without waterlogging, 1–15 days after planting (DAP), and 1–30 DAP. The second factor was soil types, which consisted of four kinds: latosol, coastal sandy, volcanic, and regosol soil. The weed growth was observed at 60 DAP, but the growth and yield of rice were conducted at 104 DAP. The results showed that waterlogging could minimize weed-rice competition in rice cultivation. Furthermore, waterlogging period of 1–30 DAP could inhibit the weed dry weight (WDW) and increase the leaf area index (LAI), shoot root ratio (SRR), grain dry weight (GDW), and harvest index (HI) in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 tons/ha), then decreased in volcanic (6.0 tons/ha), regosol (5.9 tons/ha), and the lowest in coastal sandy (4.8 tons/ha). The research findings show that waterlogging period of 1-30 DAP can minimize the weed-rice competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation.

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Key words: Rice, soil type, waterlogging, weed control, competition.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food predominantly consumed by more than half of the world's population (Anwar *et al*., 2012; Auškalnienė *et al*., 2018). It is grown on over 161 million hectares worldwide, and over 90% of rice is produced in the Asian region (Shekhawat *et al*., 2020). Rice can be cultivated in different environments, including tropical to temperate climates and aerobic soil in the uplands to anaerobic soil in wet lowlands (Ismail *et al*., 2012).

Weed competition is a major problem in all rice-cultivation systems around the world. This problem worsened when rice farmers shifted from the transplanted to the direct seeding method due to labor and water shortage (Kumar *et al*., 2017). The presence of weeds in paddy fields can increase control costs, decrease grain quality, and yield losses (Scavo and Mauromicale, 2020). Weeds are recognized as the most critical biotic factor that limits crop production. Previous studies reported rice grown in an aerobic system competed with 90 weed species, causing a 23–100% decrease in grain yield (Jabran and Chauhan, 2015). Some weed species caused crop yield loss of up to 45% (Korav *et al*., 2018). Therefore, weed control to minimize weed-rice competition is important for increasing the rice yield. Flooding in the rice fields is called waterlogging. Waterlogging can suppress weed seed germination and growth. This method can be a safer, environmentally friendly, low-cost weed control alternative.

A single weed species can produce many weed seeds. The weed seeds can disperse in different ways to extend their migration and population, such as by the wind, water, ants, gravity, and anthropogenic activities (Gao *et al*., 2018). Dry and flooded rice fields may have different weed flora. The identified significant weed floras in flooded rice ecosystems were *Echinochloa colona* and *Echinochloa crus-galli* (Bhatt *et al*., 2021). The dominant weed species in the system of rice intensification (SRI) was *Echinocloa crus-galli*, while in the conventional system was *Ludwigia hyssopifolia* (Mustakim *et al*., 2022).

The soil seed bank is the principal source of new infestations of annual weeds, which contains most of the weed species composition. According to Auškalnienė *et al*. (2018), the weed seed bank in the soil significantly decreased over five years by soil tillage. In recent years, chemical weed control has been regarded as the most efficient and cost-effective approach. Weed management strategies based on herbicides are no longer environmentally friendly, economically practical, and efficient against different weed species. However, this method can lead to the emergence of herbicide-resistant weed biotypes (Kumar *et al*., 2017). Challenges arise in weed management because cultivated rice and weedy rice share similar morphological and physiological characteristics. Therefore, they competed for growing space, nutrients, water, and sunlight in the same field plot. Under these circumstances, any plant that emerges in the cropping field will compete with these limited resources and diminish the quality and quantity of crop production. In addition, some weed species produced phytotoxins that were harmful to rice growth (Bastiaans and Kropff, 2017). The weed–rice competition can be measured from their growth rate.

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Flooding the soil may alter the rice plant density, vigor, and uniformity, as well as the intensity of weed competition and herbicide efficiency (Ismail *et al*., 2012). The survival and development of weed species are also influenced by the depth and length of flooding (Kumalasari, 2014). Farmers can flood their rice fields up to 1 cm to support the rice growth (Khairi *et al*., 2015). However, flooding can create low oxygen (O_2) and anaerobic conditions and induce secondary weed dormancy (Fennimore, 2017). The decreased O_2 levels in the soil can cause excessive water content, compaction, compression, and hard surfaces, thus reducing the success and speed of the weed seed dispersal (Yasin and Andreasen, 2016).

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Most of the weeds have tolerant and adaptive traits that can germinate and elongate under hypoxia more quickly with the mobilization of starch reserves, allowing weeds and rice to grow in flooded areas. Tolerant rice genotypes can adapt well to flooding. At the same time can suppress weeds that grow (Ismail *et al*., 2012). The water defense in the paddy fields can increase rice growth and reduce weed growth (Kaya-Altop *et al*., 2019). At this critical period, rice plants are sensitive to weeds around them.

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Waterlogging can inhibit weed growth during this period. Therefore, weed control at a critical period can increase rice yield. According to Anwar *et al*. (2012), the rice should be weed-free during 2–43 DAP for better yield. In addition, Rahman *et al*. (2014) found that a critical period of rice weed competition occurred up to 30 DAP.

Rice cultivation can be carried out in different soil types. However, each soil type had an additional carrying capacity for the growth and yield of rice. The soil types had different physical and chemical properties. The amount of water needed for waterlogging depends on soil types. Sandy soils require more water because macro-pores are more dominant. Ideally, the soil needed to include around 50% clay content. Also, the soil was underlain with an impervious claypan to help to hold the water. The sandy soil has many aerations and water holding capacity. At the same time, clay is generally more fertile due to less aeration and high water-holding capacity.

The sandy loam texture soil is the best for maximum seed germination (Gulshan and Dasti, 2012). The excellent soil's physical condition can store and conduct water, air, and nutrients promoting both maximum crop yield and minimum environmental degradation (Valle *et al*., 2018). The sandy soil is often considered physical properties that quickly define the weak structure, reduced water retention, and high permeability.

To date, most researchers have only focused on the effect of waterlogging on O_2 levels in soil (aerobic system) and weed seed germination. This research will study on waterlogging and its effect on suppressing weed growth in rice fields. Previous researchers have investigated mechanical weed control in rice cultivation, but the period of waterlogging has never been carried out. However, until now, there has been no research on the effect of waterlogging on weed suppression in lowland rice. Therefore, weed control in rice cultivation by waterlogging needs to be done. Waterlogging significantly contributes to weed suppression and can improve the rice yield. Therefore, this study aimed to know the waterlogging period for minimizing the weed-rice competition to increase the rice yield.

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MATERIALS AND METHODS

Study Site

The research area was conducted from July to November 2019 in the greenhouse, Faculty of Agriculture, Universitas PGRI Yogyakarta, Bantul, Yogyakarta, Indonesia, having an elevation of 118 m above sea level (ASL). Bantul Regency is located between 14º04'50" - 27º50'50" S and 110º10'41"-110º34'40" E. The average temperature and humidity of the air during the study were 34 °C and 60%, respectively.

Soil Sampling

The soil used in this research was the former paddy fields from 0-20 cm soil depth. The sampling of soil types was taken from three districts, namely, Kulonprogo, Sleman, and Bantul, in a special territory of Yogyakarta.

Experimental Design

The research was arranged in a complete randomized design (CRD) factorial with three replications. The first factor was waterlogging, which consisted of three levels: without waterlogging, 1–15, and 1–30 DAP. The second factor was soil types, which consisted of four types: latosol, coastal sandy, volcanic, and regosol. Therefore, the experiment needed as many as 36 wooden boxes as sample plots.

Research Procedures

The rice nurseries were carried out in plastic boxes of 25 cm (width) × 30 cm (length) × 10 cm (high) for germination. The soil media used a mixture of soil and cow manure (1:1). The Ciherang variety was used in this study. First, the rice seeds were spread and covered with 0.2-0.4 cm soil. The seeds would germinate for four days after spreading (DAS) in the media. Then, the rice seedlings were planted 14 DAS in wooden boxes.

The wooden boxes were 50 cm (width) × 80 cm (length) × 25 cm (height). It was placed on the table in a greenhouse coated with waterproof plastic. Before putting it in wooden boxes, the soil was crushed into small granules and dry soil conditions. Each soil type was put into a wooden box as high as 20 cm. Each soil type was without the manure addition. The soil types were put into wooden boxes based on the treatment randomization. It was done on all the soil types.

The soil in wooden boxes was watered until field capacity. Then, the seedlings were planted a day after watering in eight holes with a plant spacing of 20 cm × 25 cm in two-row planting. Next, each row was planted with four clumps of rice crops. So, 16 rice seedlings were needed. The soil surface area in a wooden box was 0.4 m^2.

The treatment of waterlogging was done since seedlings were planted. However, water application was only carried out at field capacity until 1–30 HST for the treatment without waterlogging. Then, the waterlogging height was as high as 3 cm from the soil surface. For the waterlogging period of 1–15 DAP, the soil only was flooded for 1–15 DAP, and next in the field capacity until 30 DAP. Therefore, waterlogging of 1–30 DAP, the soil was saturated at a period of 1–30 DAP. After the waterlogging treatment ended, all were treated equally suitable for their needs.

Weed seeds germination in the soil surface was after 5 DAP from the first water application. After that, the weeds were allowed to grow in around rice crops. Fertilizing rice crops using NPK Mutiara was done in three stages, namely, 15, 30, and 45 DAP. The dosage for each application was 25 g/0.4 m^2 of the soil areas.

Parameters

The weed observation was carried out on the weed species that grew on the soil surface around rice clumps at 60 DAP. The variable of weed was observed by WDW (kg). The observation of rice was done by collecting the variable, including LAI, SRR, GDW, and HI, in sample plots at 104 DAP.

The WDW, shoots dry weight (SDW), roots dry weight (RDW), and GDW were dried in Binder FED 53–UL Forced Convection Drying Oven for 48 hours at a temperature of 80 °C or until a constant weight was achieved. The Ohaus PA214 Pioneer Analytical Balance was used to measure the WDW, SDW, RDW, and GDW. The Portable Laser Leaf Area Meter CI–202 was used for measuring the leaf areas (cm^2). The SDW was total from the dry weight of the stem, leaf, and panicle. The WDW, SDW, RDW, and GDW from sample plots of 0.4 m^2 were converted to m^2, except for the parameter of leaf areas.

The SRR is between SDW (kg/m^2) and RDW (kg/m^2) ratio. The formula for calculating the SRR is represented in Eq. 1.

$$\text{SRR} = \frac{\text{SDW}}{\text{RDW}} \quad \text{(Eq. 1)}$$

The economic yield (EY) was in the form of GDW (kg/m^2). The biological yield (BY) of rice is total from GDW, SDW, and RDW (kg/m^2). The harvest index (HI) is the EY and BY ratio. The formula to calculate the HI is used in Eq. 2.

$$\text{HI} = \frac{\text{EY}}{\text{BY}} \quad \text{(Eq. 2)}$$

Statistical Analysis

Observational data were analyzed by analysis of variance (ANOVA) at $P = 0.05$ level of probability, with IBM SPSS Statistic 23. In addition, the difference between the treatment averages was compared using Duncan's new multiple range tests (DMRT) at $P = 0.05$ level of probability.

RESULTS AND DISCUSSION

Effect of Waterlogging on the Growth of Weed and Rice

The treatment combination of waterlogging and soil types significantly interacted in WDW, LAI, SRR, GDW, and HI parameters. Then, the DMRT at $P = 0.05$ level of probability on the WDW, LAI, SRR, GDW, and HI can be seen in **Error! Reference source not found.**.

Table 1 shows that waterlogging can significantly suppress WDW and increase LAI, SRR, GDW, and HI. Waterlogging period of 1-30 DAP was appropriate to suppress weed growth and increase the growth and yield of rice. The WDW was higher in soil without waterlogging but lower in the 1-30 DAP period. In soil types of latosol, coastal sandy, volcanic, and regosol with a waterlogging of 1–30 DAP can inhibit the weed growth by 87.7, 99.5, 97.3, and 96.5% than without waterlogging.

The highest LAI occurred in regosol soil with waterlogging of 1-30 DAP. Next, the highest SRR happened in latosol and coastal sandy with waterlogging of 1-15 DAP and in latosol soil with waterlogging of 1-30 DAP. Waterlogging of 1-30 DAP in latosol soil produced higher GDW and HI. Waterlogging of 1-30 DAP could increase GDW by 66.7, 58.3, 37.3, and 70.0% than without waterlogging.

The weed growth in the volcanic soil was higher than in other soil types, especially without waterlogging. Each soil type had a different weed seed bank. In this study, waterlogging was effective in inhibiting weed growth. Waterlogging can reduce the O_2 level in the soil. Then, the weed seeds cannot germinate maximally at the low O_2 level. This anaerobic condition can cause weed growth to decrease due to inhibited respiration. The weed growth decreased at the waterlogging periods of 1–15 and 1-30 DAP in regosol, latosol, volcanic, and coastal sandy soil.

The weed growth was lower in a waterlogging period of 1–30 DAP in coastal sandy, volcanic, and regosol soil. The extended period of waterlogging caused a reduction in weed growth. The water availability on the soil surface at early rice growth potentially inhibited weed seed germination. Therefore, waterlogging of 1–30 DAP could significantly inhibit weed growth. Also, the controlling of weed intolerant effectively used waterlogging. The results of this study follow the opinion of Matloob *et al*. (2015) that the weed species could be grouped into three conditions: intolerant, tolerant, and stimulant with waterlogging treatment. The weed competition, even during 20 DAP reduced grain yield in dry–seeded rice.

Waterlogging periods of 1–15 and 1–30 DAP could decrease weed growth, giving the rice crops a chance to grow better. But, on the other hand, Waterlogging period of 1–30 DAP could increase the LAI and SRR more maximal. Because weed growth was most robust on soil without waterlogging, it then caused a decrease in rice LAI on all the soil types, especially in coastal sandy and regosol. However, waterlogging periods of 1–15 and 1–30 DAP in the latosol soil caused higher SRR. Therefore, the waterlogging treatment could increase the SRR.

In certain conditions, if it did not occur the weed–rice competition, then the rice crops were more concentrated in improving the growth of the shoot than the root. Therefore, it caused the SRR to be higher. On the contrary, weeds experienced rapid growth without waterlogging, so the rice crops were depressed in their development. The rice could not compete in getting nutrients, water, sunlight, and growing space, and then root growth was more robust, so the SRR was lower. It occurred in the coastal sandy and regosol soil without waterlogging. Waterlogging period of 1–30 DAP increased the LAI of rice. Wider leaves allow the process of capturing sunlight more optimally so that the production of carbohydrates is higher. Carbohydrates were used for tissue growth and seed filling. Waterlogging period of 1–30 DAP caused the highest LAI in the regosol soil, then a decrease in the latosol soil. Although, the highest GDW was not produced in the regosol soil. It showed that the LAI higher occurred in the latosol soil, and then GDW higher too. According to Olajumoke *et al*. (2016), the potential of weed-rice competition was at all stages of plant development. This potential caused yield loss of rice yield.

The LAI and SRR could provide strong support for grain filling during generative growth. The results of carbohydrates for the grains filling (stored capacity) could be maximally processed. Generally, GDW higher was obtained at waterlogging period of 1–30 DAP in different soil types, especially in the latosol soil (0.75 kg/m^2 or 7.5 tons/ha). The results of this study were higher than the average potential of Ciherang rice yields, as high as 5–7 tons/ha (Sastro *et al*., 2021). The latosol soil had a maximal carrying capacity on the GDW production in without waterlogging conditions. The GDW began to decline at the waterlogging period of 1–15 DAP. After all, the treatment showed that the weed growth started to get stronger than the waterlogging period of 1–30 DAP. The lowest GDW occurred in without waterlogging because the weed-rice competition was inevitable.

Without waterlogging, the LAI and SRR were lower, so it caused the GDW and HI to be low too. Therefore, weed control using the waterlogging of 1–30 DAP was the appropriate period to get rice's maximal growth and yield. On the other hand, waterlogging could increase the GDW in latosol, coastal sandy, volcanic, and regosol soil.

During a long weed-rice competition, relative rice grain yield loss was between 68% and 80% (Matloob *et al*., 2015). The weeds contributed to a 40% rice yield loss (Ramesh *et al*., 2016). The impact of weed on the rice can be seen directly in the change of leaf area. The higher WDW caused lower LAI. The weed growth that gets more vigorous causes growing space competition in the sunlight. The rice crops with lower LAI, consequently absorption of sunlight was low too. The low consumption of light by rice crops will cause low photosynthetic yields. If the seed filling period were not optimal, it would cause a low GDW.

The weed impact on SRR can be seen directly in the change in the dry weight of shoots and roots. The weeds were greedy for nutrients and water in the soil. The rice responded by strengthening its roots. In high weed–rice competition, the rice showed that the SRR was getting smaller. Conversely, the roots grew to produce a higher SRR. According to Olajumoke *et al*. (2016), the interactions of weed and rice crops often reflected early vigor, more tillering, and nutrient utilization ability for the shoot development of rice crops. Even though the latter also showed an improvement in shoot development under competition.

Solar radiation is highly correlated with LAI and dry matter (Garcés-varon and Restrepo-díaz, 2015). The process of sunlight absorption was affected by the leaf areas. More sunlight being held captive in the photosynthetic process caused the rice seed filling to increase. The optimal crop planting density is generally based on a weed-free environment (Dass *et al*., 2017).

The effect of waterlogging on the WDW and GDW of rice in different soil types can be seen in Fig. 1.

Weed and Rice Correlation

The correlation analysis was done on the relationship between WDW, LAI, SRR, GDW, and HI. The results of the correlation analysis can be seen in Table 2.

Table 2 shows that GDW was significantly negatively correlated with LAI (-0.736**) and GDW (-0.776**), respectively, but not significantly with SRR (-0.548^{ns}) and HI (-0.576^{ns}). Growing weeds is followed by a decrease in LAI and GDW.

The correlations between rice yield under weed-free and weedy conditions could strongly affect weed pressure levels. The weeds were greedy for environmental factors, namely, nutrients, water, sunlight, space growing, and more robust growth than crops. Without waterlogging, weed growth was most robust. The stronger weed was followed by lower growth and yield of rice crops. The effect of waterlogging on GDW was different and depended on the soil types. The lower WDW occurred in coastal sandy soils, but higher GDW in regosol soil. It showed that soil fertility level also determined WDW and GDW. Regosol soil resulted in a higher GDW.

Performance of the weed-rice competition

The effect of waterlogging on the performance of the weed-rice competition shows that weed and rice performances were very different (Fig. 2). Without waterlogging showed that weed growth was very strong (a). Treatment of 1-15 DAP waterlogging indicated medium weed growth (b). Finally, low weed growth occurred in waterlogging of 1-30 DAP (c).

CONCLUSION

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In conclusion, waterlogging could minimize weed-rice competition in rice cultivation. Furthermore, waterlogging of 1–30 DAP could inhibit the WDW and increase the LAI, SRR, GDW, and HI in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 tons/ha), then decreased in volcanic (6.0 tons/ha), regosol (5.9 tons/ha), and the lowest in coastal sandy (4.8 tons/ha). The research findings indicate that waterlogging period of 1-30 DAP can minimize the weed-rice competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation.

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Table 1. Effect of waterlogging on the WDW, LAI, SRR, GDW, and HI in different soil types.

Waterlogging (DAP)	Soil types	Weed	Rice			
		WDW (kg/m^2)	LAI	SRR	GDW (kg/m^2)	HI
Without	Latosol	0.673 c	3.15 e	1.74 bcd	0.25 g	0.17 g
	Coastal sandy	0.779 bc	1.76 f	1.31 d	0.20 g	0.25 ef
	Volcanic	1.060 a	3.08 e	2.20 abc	0.37 f	0.30 de
	Regosol	0.820 b	1.65 f	1.19 d	0.18 g	0.22 pq
1-15	Latosol	0.116 de	4.34 abcd	2.38 a	0.65 b	0.36 ab
	Coastal sandy	0.070 de	3.25 e	2.62 a	0.42 ef	0.30 cd
	Volcanic	0.088 de	3.55 de	2.03 abc	0.51 cd	0.31 bcd
	Regosol	0.186 d	4.48 ab	1.67 cd	0.47 de	0.28 de
1-30	Latosol	0.087 de	4.54 abc	2.33 ab	0.75 a	0.37 a
	Coastal sandy	0.004 e	3.76 cde	2.57 a	0.48 de	0.29 cd
	Volcanic	0.029 e	3.67 de	1.69 cd	0.59 bc	0.34 abc
	Regosol	0.029 e	4.75 a	2.25 abc	0.60 b	0.28 de
Treatments interaction		(+)	(+)	(+)	(+)	(+)

Figures in the same column followed by the same letters are not significantly different based on DMRT at P = 0.05 level of probability; (+) = Significant interaction.

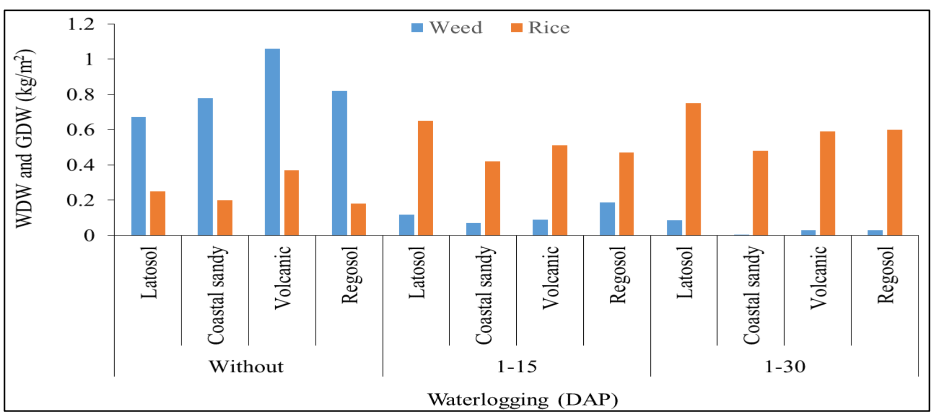

Fig. 1. Effect of waterlogging on WDW and GDW in different soil types.

Table 2. The correlation analysis between weed growth and rice growth and yield.

Variable		LAI	SRR	GDW	HI
WDW	Pearson Correlation	$-.736^{**}$	$-.548^{ns}$	$-.776^{**}$	$-.576^{ns}$
	Sig. (2-tailed)	.006	.065	.003	.050
	N	12	12	12	12

** = Correlation is significant at P = 0.01 level of probability (2-tailed); ^{ns} = Correlation is not significantly at P = 0.05 level of probability.

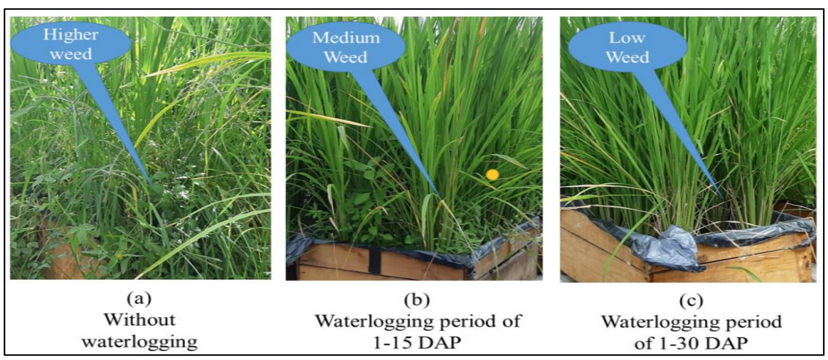

Fig. 2. The effect of waterlogging on the weed-rice competition.

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Minimizing weed competition through waterlogging in rice (*Oryza sativa*) under various soil types

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ABSTRACT

National rice production continues to be increased to meet the needs of food security in Indonesia. But in reality, every rice cultivation always raises the problem of weed disturbances. One way to control weeds can be through waterlogging. Waterlogging can suppress weed growth and increase rice yields. This study was conducted from August 2019 – January 2020 at greenhouse conditions, Faulty of Agriculture, Universitas PGRI Yogyakarta. The study aimed to know the waterlogging period to minimize weed competition and increase the rice yield. This study was arranged in a completely randomized design (CRD) factorial with three replications. The first factor was the waterlogging period, which consisted of three levels: without waterlogging, 1–15 days after planting (DAP), and 1–30 DAP. The second factor was soil types, which consisted of four kinds: latosol, coastal sandy, volcanic, and regosol soil. The weed observation was carried out at 60 DAP, and the rice was done at 104 DAP. The results showed that waterlogging could minimize weed-rice competition in rice cultivation. Furthermore, waterlogging period of 1–30 DAP could inhibit the weed dry weight (WDW) and increase the leaf area index (LAI), shoot root ratio (SRR), grain dry weight (GDW), and harvest index (HI) in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 t/ha), then decreased in volcanic (6.0 t/ha), regosol (5.9 t/ha), and the lowest in coastal sandy (4.8 t/ha). The research findings show that waterlogging period of 1-30 DAP can minimize the weed competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation. In future research, weed types that are tolerant to waterlogging treatment need to be combined with weeding treatment.

Key words: Rice, soil type, waterlogging, weed control, competition.

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food predominantly consumed by more than half of the world's population (Anwar *et al*., 2012; Auškalnienė *et al*., 2018). It is grown on over 161 million

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hectares worldwide, and over 90% of rice is produced in the Asian region (Shekhawat *et al*., 2020). Rice can be cultivated in different environments, including tropical to temperate climates and aerobic soil in the uplands to anaerobic soil in wet lowlands (Ismail *et al*., 2012).

Weed competition is a major problem in all rice-cultivation systems around the world. (Kumar *et al*., 2017). The presence of weeds in paddy fields can increase control costs, decrease grain quality, and yield losses (Scavo and Mauromicale, 2020). Weeds are recognized as the most critical biotic factor that limits crop production. Previous studies reported rice grown in an aerobic system competed with 90 weed species, causing a 23–100% decrease in grain yield (Jabran and Chauhan, 2015). Some weed species caused crop yield loss of up to 45% (Korav *et al*., 2018). Therefore, weed control to minimize weed-rice competition is important for increasing the rice yield. Flooding in the rice fields is called waterlogging. Waterlogging can suppress weed seed germination and growth. This method can be a safer, environmentally friendly, low-cost weed control alternative.

Dry and flooded rice fields may have different weed flora. The identified significant weed floras in flooded rice ecosystems were *Echinochloa colona* and *Echinochloa crus-galli* (Bhatt *et al*., 2021). The dominant weed species in the system of rice intensification (SRI) was *Echinocloa crus-galli*, while in the conventional system was *Ludwigia hyssopifolia* (Mustakim *et al*., 2022).

In recent years, chemical weed control has been regarded as the most efficient and cost-effective approach. Weed management strategies based on herbicides are no longer environmentally friendly, economically practical, and efficient against different weed species. However, this method can lead to the emergence of herbicide-resistant weed biotypes (5). Challenges arise in weed management because cultivated rice and weedy rice share similar morphological and physiological characteristics. Therefore, they competed for growing space, nutrients, water, and sunlight in the same field plot. Under these circumstances, any plant that emerges in the cropping field will compete with these limited resources and diminish the quality and quantity of crop production. In addition, some weed species produced phytotoxins that were harmful to rice growth (Bastiaans and Kropff, 2017). The weed–rice competition can be measured from their growth rate.

Flooding the soil may alter the rice plant density, vigor, and uniformity, as well as the intensity of weed competition and herbicide efficiency (4). The survival and development of weed species are also influenced by the depth and length of flooding (12). Farmers can flood their rice fields up to 1 cm to support the rice growth (Khairi *et al*., 2015). However, flooding can create low oxygen (O_2) and anaerobic conditions and induce secondary weed dormancy (14). The decrease in O_2 levels results from excessive water content, compaction, compression, and hard surfaces, thus reducing the success and speed of the weed seed dispersal (Yasin and Andreasen, 2016).

Most of the weeds have tolerant and adaptive traits that can germinate and elongate under hypoxia more quickly with the mobilization of starch reserves, allowing weeds and rice to grow in flooded areas. Tolerant rice genotypes can adapt well to flooding. At the same time can suppress weeds that grow (4). The water availability in the paddy fields can increase rice growth and reduce weed growth (16). At this critical period, rice plants are sensitive to weeds around them.

Waterlogging can inhibit weed growth during this period. Therefore, weed control at a critical period can increase rice yield. According to Anwar *et al*. (2012), the rice should be weed-free during 2–43 DAP for better yield. In addition, Rahman *et al*. (2014) found that a critical period of rice weed competition occurred up to 30 DAP.

Rice cultivation can be carried out in different soil types. However, each soil type had an additional carrying capacity for the growth and yield of rice. The soil types had different physical

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and chemical properties. The amount of water needed for waterlogging depends on soil types. Sandy soils require more water because macro-pores are more dominant. Ideally, the soil needed to include around 50% clay content. Also, the soil was underlain with an impervious claypan to help to hold the water. The sandy soil has many aerations and water holding capacity. At the same time, clay is generally more fertile due to less aeration and high water-holding capacity.

The sandy loam texture soil is the best for maximum seed germination (Gulshan and Dasti, 2012). The excellent soil's physical condition can store and conduct water, air, and nutrients promoting both maximum crop yield and minimum environmental degradation (Valle *et al*., 2018). The sandy soil is often considered to have physical properties that quickly define the weak structure, reduced water retention, and high permeability.

To date, most researchers have only focused on the effect of waterlogging on O_2 levels in soil (aerobic system) and weed seed germination. This research will study waterlogging and its impact on suppressing weed growth in rice fields. Previous researchers have investigated mechanical weed control in rice cultivation, but the period of waterlogging has never been carried out. However, until now, there has been no research on the effect of waterlogging on weed suppression in lowland rice. Therefore, weed control in rice cultivation by waterlogging needs to be done, especially for irrigated rice fields. Waterlogging significantly contributes to weed suppression and can improve the rice yield. Therefore, this study aimed to know the waterlogging period to minimize weed competition and increase the rice yield.

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MATERIALS AND METHODS

Study Site

The research area was conducted from July to November 2019 in the greenhouse, Faculty of Agriculture, Universitas PGRI Yogyakarta, Bantul, Yogyakarta, Indonesia, having an elevation of 118 m above sea level (ASL). Bantul Regency is located between 14º04'50" - 27º50'50" S and 110º10'41"-110º34'40" E. The average temperature and humidity of the air during the study were 34 °C and 60%, respectively.

Soil Sampling

The soil used in this research was the former paddy fields from 0-20 cm soil depth. The sampling of soil types was taken from three districts, namely, Kulonprogo, Sleman, and Bantul, in a special territory of Yogyakarta.

Experimental Design

The research was arranged in a complete randomized design (CRD) factorial with three replications. The first factor was waterlogging, which consisted of three levels: without waterlogging, 1–15, and 1–30 DAP. The second factor was soil types, which consisted of four types: latosol, coastal sandy, volcanic, and regosol. Therefore, the experiment needed as many as 36 wooden boxes as sample plots.

Research Procedures

The rice nurseries were carried out in plastic boxes of 25 cm (width) × 30 cm (length) × 10 cm (high) for germination. The soil media used a mixture of soil and cow manure (1:1). The Ciherang variety was used in this study. First, the rice seeds were spread and covered with 0.2-0.4 cm soil. The seeds would germinate for four days after spreading (DAS) in the media. Then, the rice seedlings were planted 14 DAS in wooden boxes.

The wooden boxes were 50 cm (width) × 80 cm (length) × 25 cm (height). It was placed on the table in a greenhouse coated with waterproof plastic. Before putting it in wooden boxes, the soil was crushed into small granules and dry soil conditions. Each soil type was put into a wooden box as high as 20 cm. Each soil type was without the manure addition. The soil types were put into wooden boxes based on the treatment randomization. It was done on all the soil types.

The soil in wooden boxes was watered until field capacity. Then, the seedlings were planted a day after watering in eight holes with a plant spacing of 20 cm × 25 cm in two-row planting. Next, each row was planted with four clumps of rice crops. So, 16 rice seedlings were needed. The soil surface area in a wooden box was 0.4 m^2.

The treatment of waterlogging was done since seedlings were planted. However, water application was only carried out at field capacity until 1–30 HST for the treatment without waterlogging. Then, the waterlogging height was as high as 3 cm from the soil surface. For the waterlogging period of 1–15 DAP, the soil only was flooded for 1–15 DAP, and next in the field capacity until 30 DAP. Therefore, waterlogging of 1–30 DAP, the soil was saturated at a period of 1–30 DAP. After the waterlogging treatment ended, all were treated equally suitable for their needs.

Weed seeds germination in the soil surface was after 5 DAP from the first water application. After that, the weeds were allowed to grow in around rice crops. Fertilizing rice crops using NPK Mutiara was done in three stages, namely, 15, 30, and 45 DAP. The dosage for each application was 25 g/0.4 m^2 of the soil areas.

Parameters

The weed observation was carried out on the weed species that grew on the soil surface around rice clumps at 60 DAP. The variable of weed was observed by WDW (kg). The observation of rice was done by collecting the variable, including LAI, SRR, GDW, and HI, in sample plots at 104 DAP.

The WDW, shoots dry weight (SDW), roots dry weight (RDW), and GDW were dried in Binder FED 53–UL Forced Convection Drying Oven for 48 hours at a temperature of 80 °C or until a constant weight was achieved. The Ohaus PA214 Pioneer Analytical Balance was used to measure the WDW, SDW, RDW, and GDW. The Portable Laser Leaf Area Meter CI–202 was used for measuring the leaf areas (cm^2). The SDW was total from the dry weight of the stem, leaf, and panicle. The WDW, SDW, RDW, and GDW from sample plots of 0.4 m^2 were converted to m^2, except for the parameter of leaf areas.

The SRR is between SDW (kg/m^2) and RDW (kg/m^2) ratio. The formula for calculating the SRR is represented in Eq. 1.

$$SRR = \frac{SDW}{RDW} \qquad \text{(Eq. 1)}$$

The economic yield (EY) was in the form of GDW (kg/m^2). The biological yield (BY) of rice is total from GDW, SDW, and RDW (kg/m^2). The harvest index (HI) is the EY and BY ratio. The formula to calculate the HI is used in Eq. 2.

$$HI = \frac{EY}{BY} \qquad \text{(Eq. 2)}$$

Statistical Analysis

Observational data were analyzed by analysis of variance (ANOVA) at P = 0.05 level of probability, with IBM SPSS Statistic 23. In addition, the difference between the treatment averages was compared using Duncan’s new multiple range tests (DMRT) at P = 0.05 level of probability.

RESULTS AND DISCUSSION

Effect of Waterlogging on the Growth of Weed and Rice

The treatment combination of waterlogging and soil types significantly interacted in WDW, LAI, SRR, GDW, and HI parameters. Then, the DMRT at P = 0.05 level of probability on the WDW, LAI, SRR, GDW, and HI can be seen in **Error! Reference source not found.**.

Table 1 shows that waterlogging can significantly suppress WDW and increase LAI, SRR, GDW, and HI. Waterlogging period of 1-30 DAP was appropriate to suppress weed growth and increase the growth and yield of rice. The WDW was higher in soil without waterlogging but lower in the 1-30 DAP period. In soil types of latosol, coastal sandy, volcanic, and regosol with a waterlogging of 1–30 DAP can inhibit the weed growth by 87.7, 99.5, 97.3, and 96.5% than without waterlogging.

The highest LAI occurred in regosol soil with waterlogging of 1-30 DAP. Next, the highest SRR happened in latosol and coastal sandy with waterlogging of 1-15 DAP and in latosol soil with waterlogging of 1-30 DAP. Waterlogging of 1-30 DAP in latosol soil produced higher GDW and HI. Waterlogging of 1-30 DAP could increase GDW by 66.7, 58.3, 37.3, and 70.0% than without waterlogging.

The weed growth in the volcanic soil was higher than in other soil types, especially without waterlogging. Each soil type had a different weed seed bank. In this study, waterlogging was effective in inhibiting weed growth. Waterlogging can reduce the O_2 level in the soil. Then, the weed seeds cannot germinate maximally at the low O_2 level. This anaerobic condition can cause weed growth to decrease due to inhibited respiration. The weed growth decreased at the waterlogging periods of 1–15 and 1-30 DAP in regosol, latosol, volcanic, and coastal sandy soil.

The weed growth was lower in a waterlogging period of 1–30 DAP in coastal sandy, volcanic, and regosol soil. The extended period of waterlogging caused a reduction in weed growth. The water availability on the soil surface at early rice growth potentially inhibited weed seed germination. Therefore, waterlogging of 1–30 DAP could significantly inhibit weed growth. Also, the controlling of weed intolerant effectively used waterlogging. The results of this study follow the opinion of Matloob *et al*. (2015) that the weed species could be grouped into three conditions: intolerant, tolerant, and stimulant with waterlogging treatment. The weed competition, even during 20 DAP reduced grain yield in dry–seeded rice.

Waterlogging periods of 1–15 and 1–30 DAP could decrease weed growth, giving the rice crops a chance to grow better. But, on the other hand, Waterlogging period of 1–30 DAP could increase the LAI and SRR more maximal. Because weed growth was most robust on soil without waterlogging, it then caused a decrease in rice LAI on all the soil types, especially in coastal sandy and regosol. However, waterlogging periods of 1–15 and 1–30 DAP in the latosol soil caused higher SRR. Therefore, the waterlogging treatment could increase the SRR.

In certain conditions, if it did not occur the weed–rice competition, then the rice crops were more concentrated in improving the growth of the shoot than the root. Therefore, it caused the SRR to be higher. On the contrary, weeds experienced rapid growth without waterlogging, so the rice crops were depressed in their development. The rice could not compete in getting nutrients, water, sunlight, and growing space, and then root growth was more robust, so the SRR was lower. It occurred in the coastal sandy and regosol soil without waterlogging. Waterlogging period of 1–30 DAP increased the LAI of rice. Wider leaves allow the process of capturing sunlight more optimally so that the production of carbohydrates is higher. Carbohydrates were used for tissue growth and seed filling. Waterlogging period of 1–30 DAP caused the highest LAI in the regosol soil, then a decrease in the latosol soil. Although, the highest GDW was not produced in the regosol soil. It showed that the LAI higher occurred in the latosol soil, and then GDW higher too. According to Olajumoke *et al*. (2016), the potential of weed-rice competition was at all stages of plant development. This potential caused yield loss of rice yield.

The LAI and SRR could support grain filling during generative growth. The results of carbohydrates for the grains filling (stored capacity) could be maximally processed. Generally, GDW higher was obtained at waterlogging period of 1–30 DAP in different soil types, especially in the latosol soil (0.75 kg/m^2 or 7.5 t/ha). The results of this study were higher than the average potential of Ciherang rice yields, as high as 5–7 t/ha (22). The latosol soil had a maximal carrying capacity on the GDW production in without waterlogging conditions. The GDW began to decline at the waterlogging period of 1–15 DAP. After all, the treatment showed that the weed growth started to get stronger than the waterlogging period of 1–30 DAP. The lowest GDW occurred in without waterlogging because the weed-rice competition was inevitable.

Without waterlogging, the LAI and SRR were lower, so it caused the GDW and HI to be low too. Therefore, weed control using the waterlogging of 1–30 DAP was the appropriate period to get rice's maximal growth and yield. On the other hand, waterlogging could increase the GDW in latosol, coastal sandy, volcanic, and regosol soil.

During a long weed-rice competition, relative rice grain yield loss was between 68% and 80% (20). The weeds contributed to a 40% rice yield loss (Ramesh *et al*., 2016). The impact of weed on the rice can be seen directly in the change of leaf area. The higher WDW caused lower LAI. The weed growth that gets more vigorous causes growing space competition in the sunlight. The rice crops with lower LAI, consequently absorption of sunlight was low too. The low consumption of light by rice crops will cause low photosynthetic yields. If the seed filling period were not optimal, it would cause a low GDW.

The weed impact on SRR can be seen directly in the change in the dry weight of shoots and roots. The weeds were greedy for nutrients and water in the soil. The rice responded by strengthening its roots. In high weed–rice competition, the rice showed that the SRR was getting smaller. Conversely, the roots grew to produce a higher SRR. According to Olajumoke *et al*. (2016), the interactions of weed and rice crops often reflected early vigor, more tillering, and nutrient utilization ability for the shoot development of rice crops. Even though the latter also showed an improvement in shoot development under competition.

Solar radiation is highly correlated with LAI and dry matter (Garcés-varon and Restrepo-díaz, 2015). The process of sunlight absorption was affected by the leaf areas. More sunlight being held captive in the photosynthetic process caused the rice seed filling to increase. The optimal crop planting density is generally based on a weed-free environment (25).

The effect of waterlogging on the WDW and GDW of rice in different soil types can be seen in Fig. 1.

Weed and Rice Correlation

The correlation analysis was done on the relationship between WDW, LAI, SRR, GDW, and HI. The results of the correlation analysis can be seen in Table 2.

Table 2 shows that GDW was significantly negatively correlated with LAI (-0.736**) and GDW (-0.776**), respectively, but not significantly with SRR (-0.548^{ns}) and HI (-0.576^{ns}). The growing weed was followed by a decrease in LAI and GDW.

The correlations between rice yield under weed-free and weedy conditions could strongly affect weed pressure levels. The weeds were greedy for environmental factors, namely, nutrients, water, sunlight, space growing, and more robust growth than crops. Without waterlogging, weed growth was most robust. The stronger weed was followed by lower growth and yield of rice crops. The effect of waterlogging on GDW was different and depended on the soil types. The lower WDW occurred in coastal sandy soils, but higher GDW in regosol soil. It showed that soil fertility level also determined WDW and GDW. Regosol soil resulted in a higher GDW.

Performance of the weed-rice competition

The effect of waterlogging on the performance of the weed-rice competition shows that weed and rice performances were very different (Fig. 2). Without waterlogging showed that weed growth was very strong (a). Treatment of 1-15 DAP waterlogging indicated medium weed growth (b). Finally, low weed growth occurred in waterlogging of 1-30 DAP (c).

CONCLUSION

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In conclusion, waterlogging could minimize weed competition in rice cultivation. Furthermore, waterlogging of 1–30 DAP could inhibit the WDW and increase the LAI, SRR, GDW, and HI in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 t/ha), then decreased in volcanic (6.0 t/ha), regosol (5.9 t/ha), and the lowest in coastal sandy (4.8 t/ha). The research findings indicate that waterlogging period of 1-30 DAP can minimize the weed competition and increase the rice yield. Thus, it is highly recommended to be practiced as cultural weed control in rice cultivation. In future research, weed types that are tolerant to waterlogging treatment need to be combined with weeding treatment.

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Table 1. Effect of waterlogging on the WDW, LAI, SRR, GDW, and HI in different soil types.

Waterlogging (DAP)	Soil types	Weed	Rice			
		WDW (kg/m^2)	LAI	SRR	GDW (kg/m^2)	HI
Without	Latosol	0.673 c	3.15 e	1.74 bcd	0.25 g	0.17 g
	Coastal sandy	0.779 bc	1.76 f	1.31 d	0.20 g	0.25 ef
	Volcanic	1.060 a	3.08 e	2.20 abc	0.37 f	0.30 de
	Regosol	0.820 b	1.65 f	1.19 d	0.18 g	0.22 pq
1-15	Latosol	0.116 de	4.34 abcd	2.38 a	0.65 b	0.36 ab
	Coastal sandy	0.070 de	3.25 e	2.62 a	0.42 ef	0.30 cd
	Volcanic	0.088 de	3.55 de	2.03 abc	0.51 cd	0.31 bcd
	Regosol	0.186 d	4.48 ab	1.67 cd	0.47 de	0.28 de
1-30	Latosol	0.087 de	4.54 abc	2.33 ab	0.75 a	0.37 a
	Coastal sandy	0.004 e	3.76 cde	2.57 a	0.48 de	0.29 cd
	Volcanic	0.029 e	3.67 de	1.69 cd	0.59 bc	0.34 abc
	Regosol	0.029 e	4.75 a	2.25 abc	0.60 b	0.28 de
Treatments interaction		(+)	(+)	(+)	(+)	(+)

Figures in the same column followed by the same letters are not significantly different based on DMRT at P = 0.05 level of probability; (+) = Significant interaction.

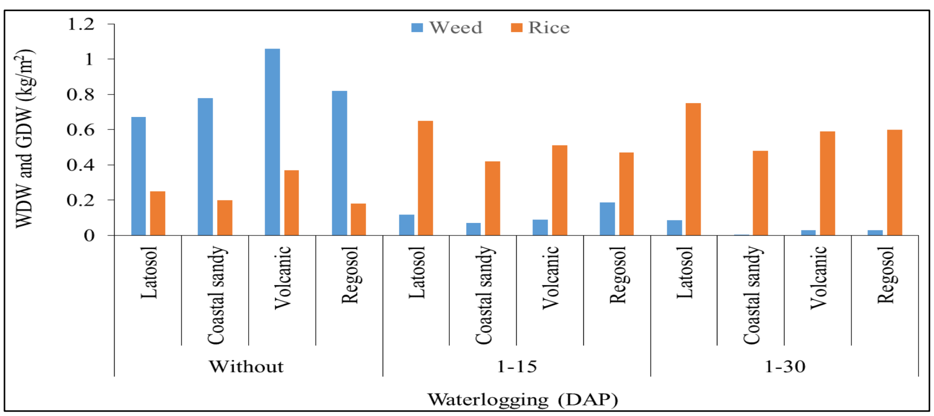

Fig. 1. Effect of waterlogging on WDW and GDW in different soil types.

Table 2. The correlation analysis between weed growth and rice growth and yield.

Variable		LAI	SRR	GDW	HI
WDW	Pearson Correlation	-.736**	-.548ns	-.776**	-.576ns
	Sig. (2-tailed)	.006	.065	.003	.050
	N	12	12	12	12

** = Correlation is significant at P = 0.01 level of probability (2-tailed); ns = Correlation is not significantly at P = 0.05 level of probability.

(a) Without waterlogging
(b) Waterlogging period of 1-15 DAP
(c) Waterlogging period of 1-30 DAP

Fig. 2. The effect of waterlogging on the weed-rice competition.

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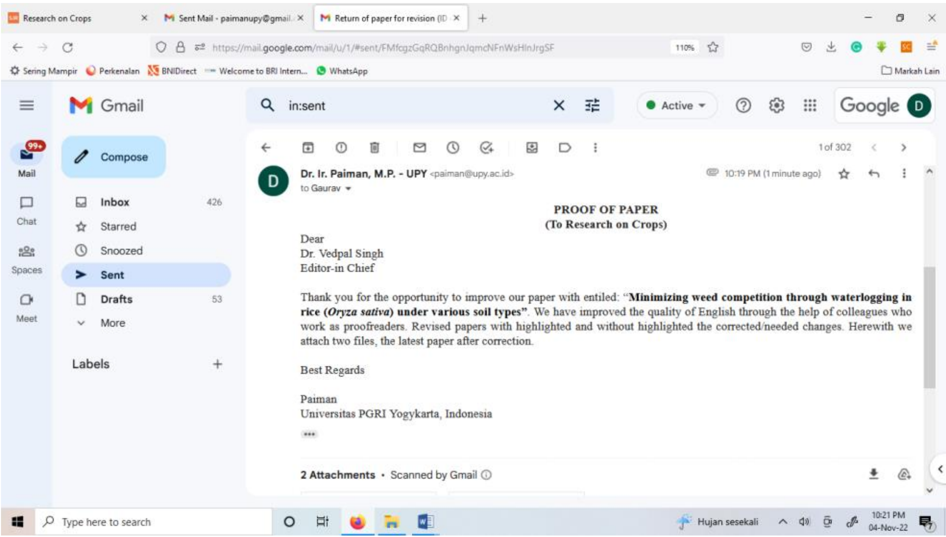

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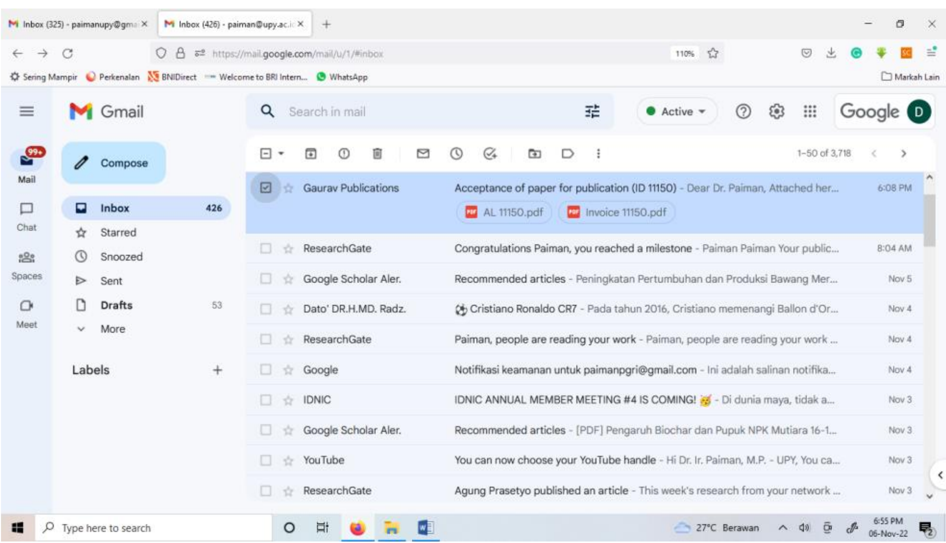

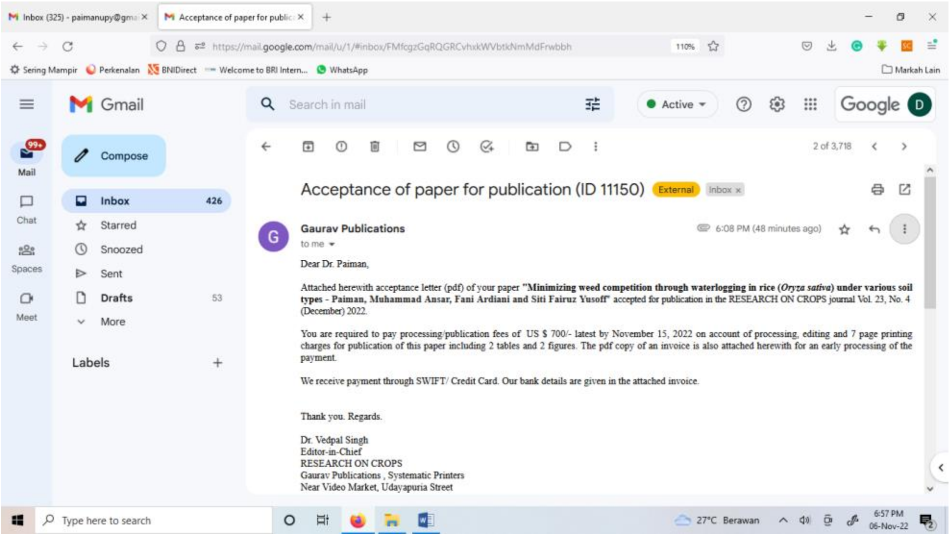

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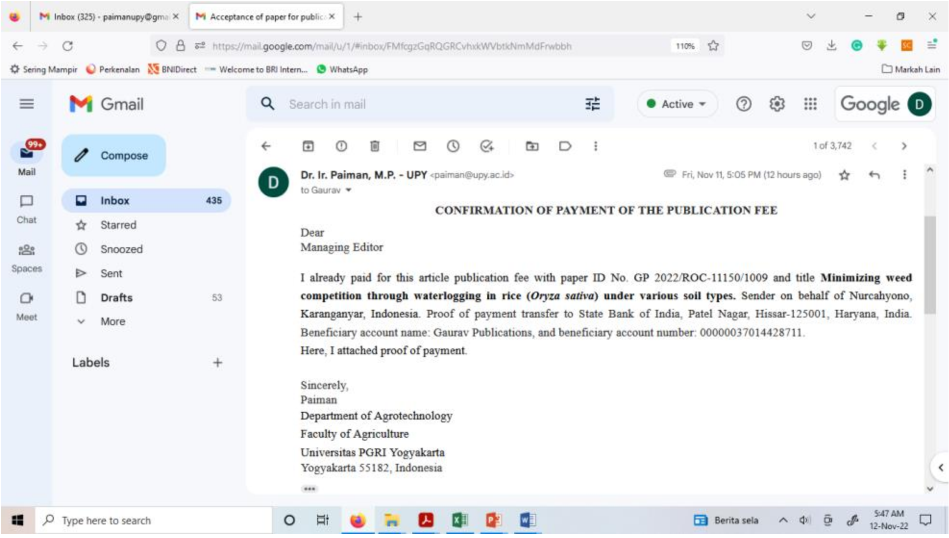

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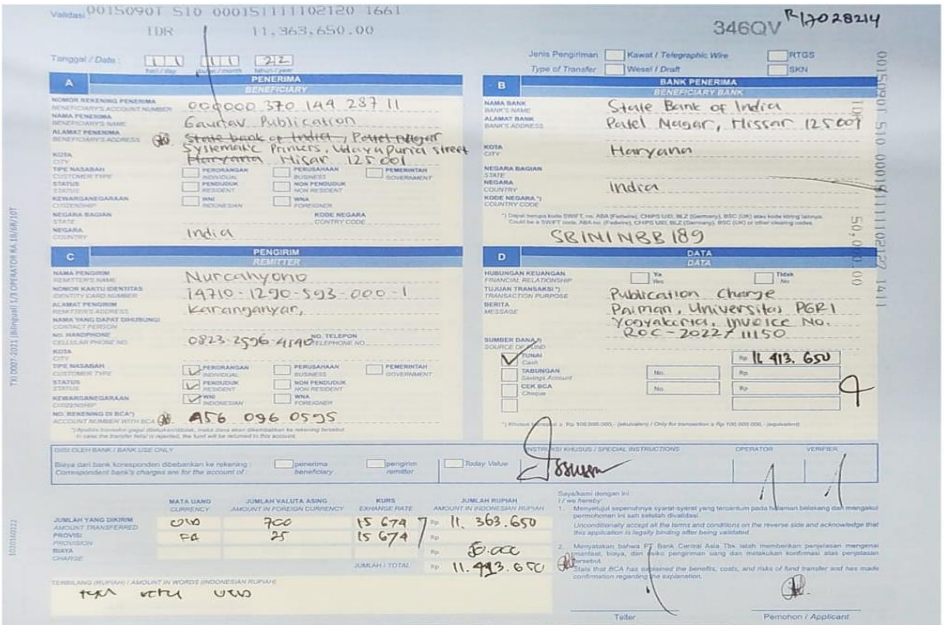

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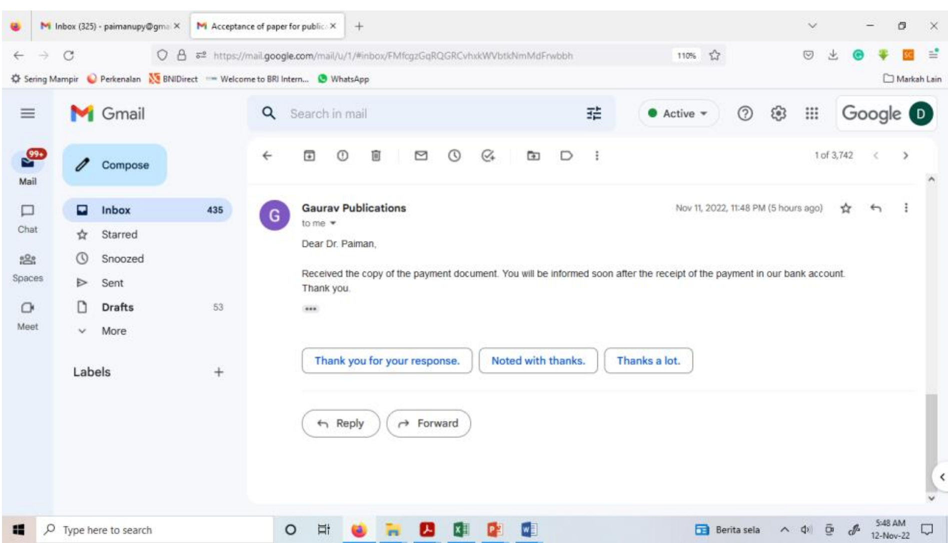

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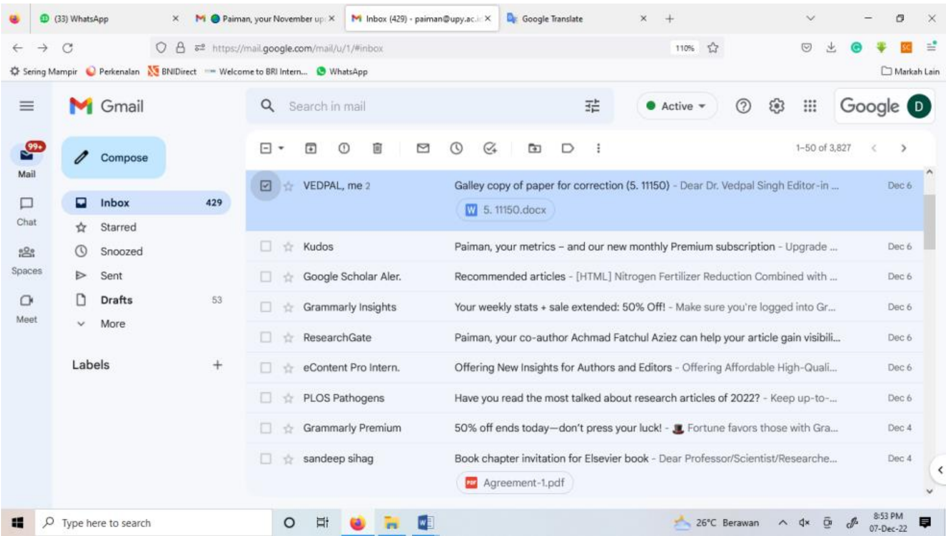

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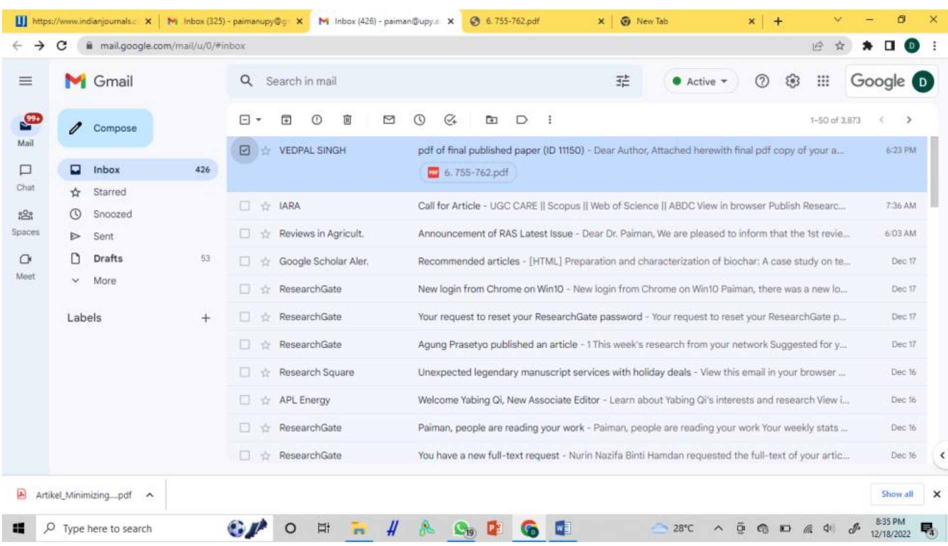

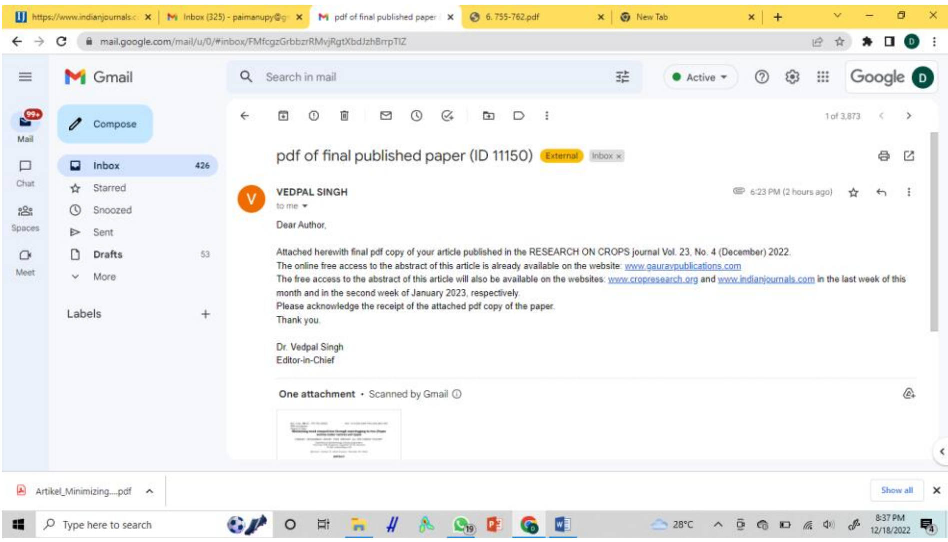

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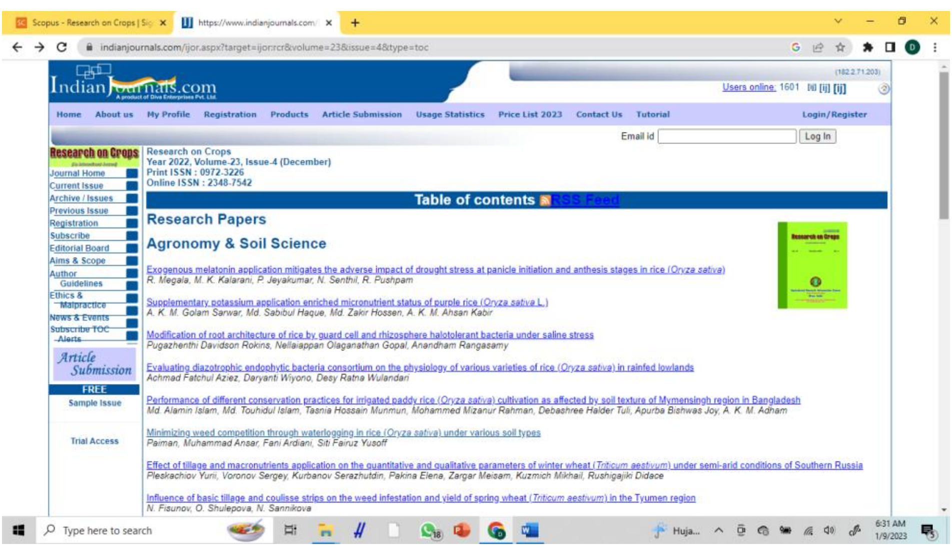

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Minimizing weed competition through waterlogging in rice (*Oryza sativa*) under various soil types

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Abstract

National rice production continues to be increased to meet the needs of food security in Indonesia. But in reality, every rice cultivation always raises the problem of weed disturbances. One way to control weeds can be through waterlogging. Waterlogging can suppress weed growth and increase rice yields. This study was conducted from August 2019-January 2020 at greenhouse conditions, Faulty of Agriculture, Universitas PGRI Yogyakarta. The study aimed at knowing the waterlogging period to minimize weed competition and increase the rice yield. This study was arranged in a completely randomized design (CRD) factorial with three replications. The first factor was the waterlogging period, which consisted of three levels: without waterlogging, 1–15 days after planting (DAP) and 1–30 DAP. The second factor was soil types, which consisted of four kinds: latosol, coastal sandy, volcanic and regosol soil. The weed observation was carried out at 60 DAP, and the rice was done at 104 DAP. The results showed that waterlogging could minimize weed competition in rice fields. Furthermore, waterlogging period of 1–30 DAP could inhibit the weed dry weight (WDW) and increase the leaf area index (LAI), shoot: root ratio (SRR), grain dry weight (GDW) and harvest index (HI) in different soil types. Waterlogging period of 1–30 DAP gave the highest GDW in latosol (7.5 t/ha), then decreased in volcanic (6.0 t/ha), regosol (5.9 t/ha) and the lowest in coastal sandy (4.8 t/ha). The research findings showed that waterlogging period of 1–30 DAP could minimize the weed competition and increase the rice yield. Thus, it was highly recommended to be practised as cultural weed control in rice cultivation. In future research, weed types that are tolerant to waterlogging treatment need to be combined with weeding treatment.