EFFECT OF WATERLOGGING ON WEED SEED GERMINATION AND GROWTH IN LOWLAND RICE

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Abstract. Weed control is needed to avoid competition in early rice growth. A weed control method is waterlogging. The study aimed to investigate the effect of waterlogging on weed seed germination and growth in lowland rice. This research was arranged in a completely randomized design (CRD) factorial and three replications. The first factor was waterlogging, which consisted of three levels: without waterlogging, 1-15 days after planting (DAP), and 1-30 DAP. The second factor was focused on two different soil types: latosol soil (LS) and regosol soil (RS). The results showed that waterlogging could inhibit seed germination of weed in RS but not in LS. In this study, waterlogging of 1-30 DAP inhibited weed dry weight higher than 1-15 DAP in both soil types. Waterlogging of 1-30 DAP decreased the weed dry weight by 87.2% in LS and 97.3% in RS than without waterlogging. Waterlogging could change the summed dominance ratio (SDR) of weed species. The research findings show that the waterlogging period of 1-30 DAP effectively inhibits the weed seed germination and growth in RS, but in LS could extend. We recommend that waterlogging period of 1-30 DAP can be applied for weed control in lowland rice.

Keywords: *anaerobic, competition, soil types, summed dominance ratio*

Introduction

Rice (*Oryza sativa* L.) is a basic necessity that plays a role in everyday human life. Weeds in lowland rice can become a competitor for rice crops. Therefore, weed seed germination and growth must be controlled. Weed seed germination occurs a few days after rice seedlings transplanting into lowland rice. The habit of farmers after planting reduces the water volume in their rice fields. Weeds take this opportunity to germinate and eventually become competitors for rice crops.

Hence, it is essential to control weeds during early rice growth. There are many choices regarding weed control methods for lowland rice. Farmers use chemical for weed control because it gives more instant effects. However, it is unsafe for the environment. Therefore, farmers should use one safe and natural control method, waterlogging.

Waterlogging in the soil harms plants due to reduced oxygen availability in the rhizosphere (Toral-Juarez et al., 2021). However, rice crops can thrive in rice fields and tolerate excess water pressure from immersion and waterlogging. Excessive water in the soil can limit gas diffusion (Nishiuchi et al., 2012). Rice crops can be adjusted to adaptive strategies in conditions of low O_2 pressure caused by waterlogging (Ma et al., 2020). Waterlogging is one of the agricultural disasters for rice crops (Chen et al., 2020). However, waterlogging only on the soil surface does not interfere with rice crops' growth but can inhibit weed seed germination and growth.

The presence of weeds created severe problems in rice fields and greatly affected the rice quality and yield (Peng et al., 2021), and a yield loss of > 20% due to weed competition (Chhun et al., 2019). Moreover, weeds are a big problem in cultivations with conventional systems, integrated crop management, and systems of rice intensification (Zarwazi et al., 2016). Therefore, weed control in agricultural production systems has been a significant concern of farmers since the beginning of agriculture (Gonzalez-Andujar, 2013).

The crop type is one of the main factors influencing weed species composition in the soil seed bank (He et al., 2019). The soil seeds bank is the primary source of annual new weed infestations and represents most weed species (Nandan et al., 2020). Generally, weeds in rice fields produced propagation in the form of seeds and vegetative parts in large numbers. Most weed seed deposits were typically located on the soil's surface after the seeds had spread (Mesquita, 2017). In paddy fields, the number of weed seed emergence increases significantly as the depth of burial of seeds decreases (Zhang et al., 2019). Seasonal water availability has been shown to play an essential role in the annual dormancy cycle and promote secondary dormancy (Garcia et al., 2020).

The water level gradients are essential factors controlling the weed species composition in lowland rice. Farmers flooded their lowland rice to control weed growth; therefore, weed management was related to the surface water of the areas (Kumalasari and Bergmeier, 2014). The remaining water is deposited in the micro pores through capillary forces (Elkheir, 2016). Therefore, flooding can cause secondary dormancy and create low O_2 (anoxia) (Fennimore, 2017), while seed germination requires O_2 in the soil. Therefore, the amount of O_2 concentration can determine the success and acceleration of seed germination (Yasin and Andreasen, 2016).

Evidence suggests that waterlogging is among the most important factors for strengthening crops' ability to control weed numbers. Since weeds frequently compete to get the remaining water and N elements, dense weed growth is often in the remaining moisture (Belford and McFarlane, 2018). At early rice growth, water needs are low due to its small habitus and low evapotranspiration. However, the water requirement for plants intensifies in the period of maximum vegetative growth (Pinem and Ichwan, 2017). Therefore, farmers can apply irrigated water up to 1 cm in their fields for planting rice (Khairi et al., 2015).

Most tolerant weeds have developed adaptive properties to grow in waterlogged soil and rapidly germinate at lower oxygen levels (Ismail et al., 2012). Soil moisture content has a more significant effect on soil compaction (De-Melo et al., 2021). Waterlogging affects the physicochemical and biochemical properties of the soil (Ferronato et al., 2019). Sandy soils have a lower cation-holding capacity and cation exchange, while clay soils capable of absorbing more water. Soil texture affected the concentration of the availability of O_2 for root growth. In addition, sandy soils are the best for maximum seed germination (Gulshan and Dasti, 2012). It can be highlighted that the soil character strongly determines the weed species and its growth in lowland rice.

Previous research has explained more about the negative impact of soil inundation on crop growth due to low oxygen levels in rice fields. However, a large amount of literature has been published indicating that no articles discussed the effect of waterlogging on weed seed germination in lowland rice. Therefore, weed control using waterlogging has not received much attention from researchers. However, Waterlogging will significantly inhibit weed seed germination in lowland rice. Therefore, it was necessary to know the effect of the waterlogging on weed seed germination in lowland rice. Therefore, this study aimed to investigate the effect of waterlogging on weed seed germination and growth in lowland rice.

Materials and methods

Study area

This research was conducted from July to September 2019 in a greenhouse, Faculty of Agriculture, Universitas PGRI Yogyakarta, Indonesia, which had an altitude of 118 m above sea levels at position S 7°33′ - 8°12′ and E 110°00′ - 110°50′. The average temperature and humidity in a greenhouse during the study were 38.2 °C and 45.7%, respectively.

Experimental design

This research was arranged in CRD factorial and three replications. The first factor was the waterlogging period, which consisted of three levels: without waterlogging, 1-15 DAP, and 1-30 DAP. The second factor was focused on two different soil types: LS and RS. Finally, this experiment required six treatment combinations. Each treatment combination was repeated three times. So in the study, 18 sample plots (or 18 wooden boxes) were needed. A schematic diagram representing the overall experimental works is served in *Fig. 1*.

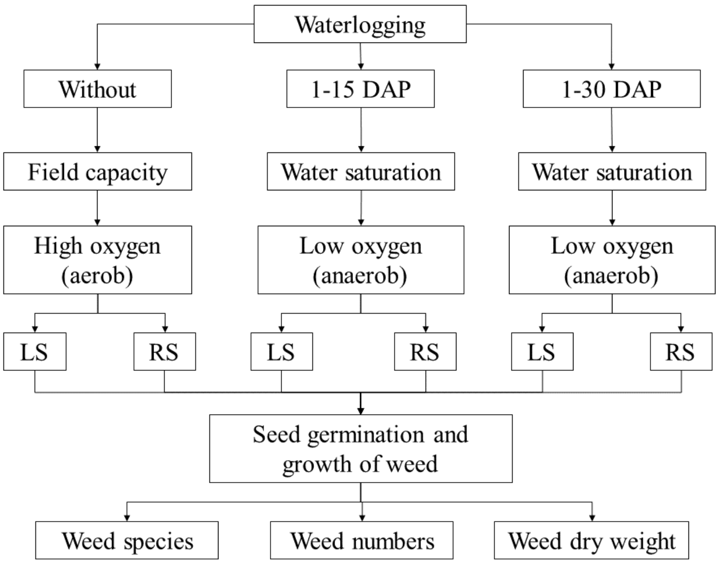

Figure 1. *A schematic diagram representing the overall experimental works*

Research procedures

Nurseries were carried out in plastic boxes of 0.3 × 0.25 × 0.1 m (width, length, and height). The soil media used a mixture of soil and organic fertilizer, with a ratio of 1:1. The Ciherang variety was used in this study. The rice seeds were spread over the media and then covered with a high of 0.2-0.3 cm soil. The seeds germinated for four days after spreading them in soil media. Rice seedlings were ready to be planted 14 days after sowing (DAS).

The soil of LS and RS were used in the study, taken from different places (two districts) in a Special Territory of Yogyakarta, Indonesia. Each soil type sample was taken at a soil depth of 0-20 cm, and the amount was adjusted according to the research needs. The soil was dried for one week under sunlight, then taken to the greenhouse were placed in the wooden boxes that had been prepared.

In this study, a wooden box was used as a sample plot with a size of 0.8 m × 0.5 m × 0.25 m (length, width, and height). The surface area of the soil (as a sample plot) was a size of 0.8 m × 0.5 m (or 0.4 m^2), as many as 18 wooden boxes. All the wooden boxes were placed on the greenhouse table. The inside of wooden boxes was coated with waterproof plastic. Then, coded treatment was applied according to the results of the randomization.

Soil dry weight was needed 60 kg wooden box^{-1} and mixed with cow manure as much as 0.5 kg. Each soil type was weighed six times to fill six wooden boxes, and then the soil medium was put into wooden boxes suitable for the research layout. This way was done on each soil type. After all soil types were put into the wooden boxes, the soil was watered until the field capacity condition. Field capacity was determined by providing water to the soil until it was saturated and could no longer absorb water. Then, rice seedlings were planted in eight holes with a plant spacing of 0.20 m × 0.25 m in two rows of planting. Therefore, it was needed 16 rice seedlings for each wooden box.

The waterlogging was done in a wooden box based. Treatment of waterlogging was started on the first day of planting seedlings. In without waterlogging, the water application was only in field capacity conditions until 1-30 DAP. In a waterlogging period of 1-15 DAP, the soil media was only flooded for 1-15 DAP, the next time only in field capacity conditions until 30 DAP. In the waterlogging period of 1-30 DAP, the soil media was flooded for 1-30 DAP. The waterlogging height was 3 cm from the soil surface level. After the crop's age of 30 DAP, all treatments were sufficiently watered.

After 5 DAP of waterlogging treatment, the weed species germinated in both soil types. The weeds were allowed to grow until 60 DAP in the wooden boxes. Photo of the experimental culture (plant and weed growth) at 60 DAP are presented in *Fig. 2*.

Measurement

The weed species were observed at 60 DAP in the soil media from wooden boxes. Weeds species around rice clumps were removed and counted, including the weed species number, weed number, and weed dry weight. Weed observations were carried out one by one in each treatment. The first step was removing weeds from each soil medium in the wooden box, then sorting and grouping them according to each weed species. The weed numbers were counted from each species. Then each weed species was put in a paper bag and labelled according to the treatment.

Figure 2. *Photo of the experimental culture at 60 DAP*

The same works were done for all weed species that grew in all sample plots. Each weed species from each treatment was entered in paper bags and was dried for one week in the solar thermal. All treatments were done in the same way. Each weed species in the paper bag was dried in a Binder drying oven ED series for 48 hours at 80 °C or until the dry weight was constant. The weed dry weight was calculated according to the species, while weed dry weight was calculated from all weed species in one wooden box. Weed dry weight was measured using the ACIS AD-i Series digital analytical balance.

The important value (IV) was obtained from the amount of relative density, relative frequency, and relative dominance. Therefore, formula IV is calculated as in *Equation 1*.

$$\text{IV} = \text{relative density} + \text{relative frequency} + \text{relative dominance} \qquad \text{(Eq.1)}$$

The SDR is calculated from the IV divided by three. The formula of SDR (%) is presented in *Equation 2*.

$$\text{SDR} = \frac{\text{IV}}{3} \qquad \text{(Eq.2)}$$

Statistical analysis

The data observations were analyzed with analysis of variance (ANOVA) at 5% significant level by using IBM SPSS Statistics 23 software. Differences between treatments were compared using Duncan′s new multiple range test (DMRT) at 5% significant level. The dominance of weed species was determined by SDR and calculated with Excel software.

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Results

Effect of waterlogging periods on weed seed germination and growth

The ANOVA results (*Appendix 1 and 2*) show significant interaction between soil types and waterlogging on weed numbers and weed dry weight. The DMRT at 5% significant level on weed number and weed dry weight can be seen in *Table 1*.

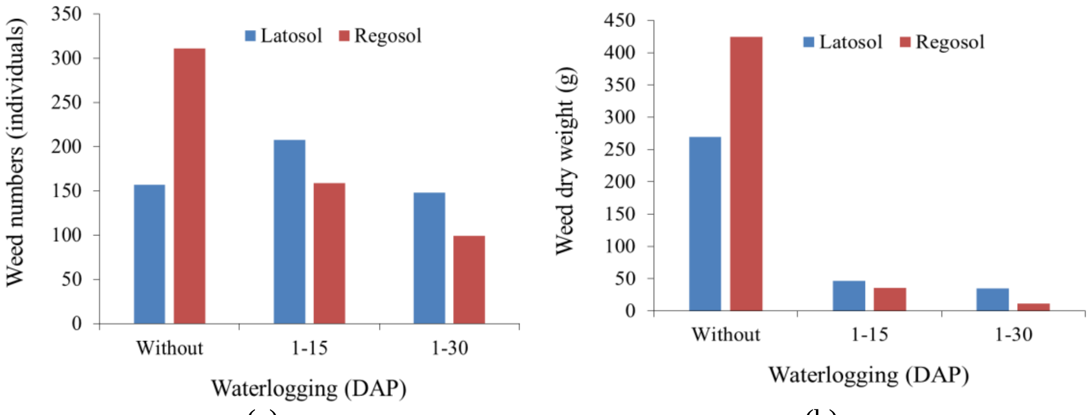
Table 1. *Effect of waterlogging on weed number and weed dry weight per sample plot in both soil types*

Soil types	Waterlogging (DAP)	Weed numbers (individuals per 0.4 m^2)	Weed dry weight (g per 0.4 m^2)
LS	Without	156.7 a	269.3 a
	1-15	207.7 a	46.6 b
	1-30	148.0 a	34.5 b
RS	Without	310.7 a	424.0 a
	1-15	158.7 b	35.3 b
	1-30	99.0 b	11.6 b

Remarks: The number followed by the same character in a column is not significantly different based on DMRT at 5% significant level.

Table 1 shows that the treatment combination between RS and waterlogging of 1-15 or 1-30 DAP gave weed numbers lower than others. Waterlogging periods of 1-15 and 1-30 DAP significantly reduced the weed number in RS but not in LS. Waterlogging period of 1-15 DAP stimulated the weed number in the LS (32.5%) and decreased RS (48.9%) than without waterlogging. On the other hand, waterlogging periods of 1-15 and 1-30 DAP were not effective in reducing the weed number in the LS (5.6%) but effectively in RS (68.1%). However, waterlogging periods of 1-15 and 1-30 DAP significantly differed from without waterlogging on weed dry weight in both soil types. Waterlogging period of 1-15 DAP suppressed the weed dry weight in the LS (82.7%) and RS (91.7%). On the other hand, Waterlogging period of 1-30 DAP decreased the weed dry weight in the LS (87.2%) and RS (97.3%) than without waterlogging.

For more details, the effect of waterlogging on weed number and weed dry weight can be seen in *Fig. 3*.



(a) (b)

Figure 3. *Effect of waterlogging on weed numbers (a) and weed dry weight (b) in LS and RS*

Effect of waterlogging on weed seed germination and SDR

Based on the observation, the effect of waterlogging periods on weed species and SDR in LS and RS are presented in *Tables 2 and 3*, respectively. There were differences in the weed species that grew on both soil types. Differences in the weed species were caused by differences in each characteristic of soil type.

Table 2. *Effect of waterlogging on weed seed germination and SDR (%) in LS*

No.	Weed species	Waterlogging		
		Without	1-15 DAP	1-30 DAP
1.	Alternanthera philoxeroides (Mart.) Griseb.	5.9	9.6	19.2
2.	Alternanthera sesillis (L.) R.Br. ex DC.	3.1	0.0	0.0
3.	Cleome rutidosperma DC.	3.2	0.0	0.0
4.	Cyperus cephalotes Vahl.	0.0	4.0	2.6
5.	Cyperus rotundus L.	0.0	8.1	10.3
6.	Cyanthillium cinerum (L.) H.Rob.	4.2	0.0	0.0
7.	Digitaria sanguinalis (L.) Scop.	6.6	5.0	11.2
8.	Echinochloa colona (L.) Link.	42.1	12.0	8.9
9.	Ehrharta erecta Lamp.	2.3	0.0	0.0
10.	Fimbristylis miliacea (L.) Vahl.	0.0	2.1	5.6
11.	Galinsoga parviflora Cav.	1.6	0.0	0.0
12.	Geomphrena serrata L.	0.0	5.3	13.4
13.	Heliotropium indicum L.	0.0	6.4	0.0
14.	Ludwigia octovalvis (Jacq.) P.H. Raven	7.6	17.4	8.4
15.	Moehringia lateriflora (L.) Fenzl.	6.4	0.0	0.0
16.	Oryza rufifogon Griff.	1.8	0.0	0.0
17.	Perilla frutescens (L.) Britt.	6.8	9.8	0.0
18.	Phedimus aizoon (L.) ′t Hart	0.0	4.2	6.3
19.	Phyllanthus urinaria L.	8.4	5.5	12.2
20.	Limnocharis flava (L.) Buchenau	0.0	0.0	1.9
21.	Sphenoclea zeylanica Gaertn.	0.0	10.4	0.0

Remarks: The number of 0.0 in Table 2 indicates that weeds are not growing

Table 2 shows that eight weed species were intolerant to waterlogging periods of 1-15 and 1-30 DAP, namely *Alternanthera sesillis*, *Cleome rutidosperma*, *Cyanthillium cinerum*, *Ehrharta erecta*, *Galinsoga parviflora*, *Moehringia lateriflora*, *Oryza rufifogon*, and *Perilla frutescens*. Six weed species were tolerant to waterlogging: *Cyperus cephalotes*, *Cyperus rotundus*, *Fimbristylis miliacea*, *Geomphrena serrata*, *Phedimus aizoon*, and *Limnocharis flava*. The presence of weed species *Alternanthera philoxeroides*, *Digitaria sanguinalis*, *Echinochloa colona*, *Ludwigia octovalvis*, and *Phyllanthus urinaria* were not affected by waterlogging. The dominant weed species in without waterlogging was *Echinochloa colona* (with an SDR of 42.1%).

Table 3 explains that weed species intolerant to waterlogging were *Bonnaya antipoda*, *Cleome rutidosperma*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Erigeron canadensis*, *Galinsoga parviflora*, *Geomphrena serrata*, *Lactuca muralis*, and *Trianthema portulacastrum*. *Ludwigia octovalvis* was not affected by waterlogging. However, waterlogging treatment stimulated the emergence of new weed species, namely, *Alternanthera philoxeroides*, *Cyperus cephalotes*, *Limnocharis flava*, and *Sphenoclea zeylanica*. The observations on the weed species in RS showed that *Oryza*

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rufifogon (with an SDR of 28.9%) was dominant growth without waterlogging. *Ludwigia octovalvis* was dominant in waterlogging period of 1-15 DAP, and *Cyperus cephalotes* (SDR 34.4%) was dominant in waterlogging period of 1-30 DAP.

Table 3. *Effect of waterlogging on weed seed germination and SDR (%) in RS*

No.	Weed species	Waterlogging		
		Without	1-15 DAP	1-30 DAP
1.	*Alternanthera philoxeroides* (Mart.) Griseb.	0.0	10.1	15.9
2.	*Alternanthera sesillis* (L.) R.Br. ex DC.	0.0	14.8	0.0
3.	*Amaranthus gracilis* Desf.	0.0	1.9	0.0
4.	*Blumea lacera* (Burm.f.) DC.	0.0	0.0	4.3
5.	*Bonnaya antipoda* (L.) Druce	3.1	0.0	0.0
6.	*Cleome rutidosperma* DC.	7.4	0.0	0.0
7.	*Cyperus cephalotes* Vahl.	0.0	7.5	34.4
8.	*Cyperus compressus* L.	19.2	7.7	0.0
9.	*Dactyloctenium aegyptium* (L.) Willd.	3.6	0.0	0.0
10.	*Digitaria sanguinalis* (L.) Scop.	7.3	0.0	0.0
11.	*Drymaria villossa* Champ. & Schltdl.	2.6	0.0	4.8
12.	*Erigeron canadensis* (L.)	2.7	0.0	0.0
13.	*Galinsoga parviflora* Cav.	4.2	0.0	0.0
14.	*Geomphrena serrata* L.	3.2	0.0	0.0
15.	*Lactuca muralis* (L.) Dumort.	2.0	0.0	0.0
16.	*Ludwigia octovalvis* (Jacq.) P.H. Raven	8.8	34.3	4.1
17.	*Oryza rufifogon* Griff.	28.9	7.2	0.0
18.	*Perilla frutescens* (L.) Britt.	2.6	0.0	12.9
19.	*Phyllanthus niruri* L.	0.0	0.0	3.7
20.	*Limnocharis flava* (L.) Buchenau	0.0	4.4	16.6
21.	*Sphenoclea zeylanica* Gaertn.	0.0	12.2	3.3
22.	*Trianthema portulacastrum* Linn.	4.6	0.0	0.0

Remarks: The number of 0.0 in *Table 3* indicates that weeds are not growing

Discussion

Waterlogging treatment caused anaerobic soil conditions. The results show that waterlogging period of 1-30 DAP effectively suppresses weed seed germination, especially in RS. Furthermore, the growth of the rice canopy could substitute for controlling the new weed seed germination and growth. On the other hand, according to Zhou et al. (2020), waterlogging negatively affects seed germination due to low oxygen conditions.

Without waterlogging, the weed number in RS was higher than in LS. In addition, it indicated that the weed seed bank was higher in RS than LS. The LS is clay soil that binds water and is very hard when dry. In contrast, the RS is dominated by sand and crumb soil. They also stated that in field capacity, weed seeds had enough O_2 to respirate and stimulate seed germination to regenerate. Jia et al. (2020) said that waterlogging caused anaerobic soil. Yasin and Andreasen (2016) stated that the germination of several weeds was significantly reduced by the O_2 concentration of 20.9 to 15%. However, certain weed species could germinate on O_2 deficient of soils at 2.5 and 5% concentrations.

To wrap up, the waterlogging periods of 1-15 and 1-30 DAP were effective in suppressing weed dry weight in LS and RS. Waterlogging can inhibit weed seed germination and growth, as evidenced by the decrease in weed dry weight. Intolerant weed species to water saturation disrupted the respiration process in their roots. Therefore, excessive water in rice fields could suppress weed seed germination and growth. In addition, waterlogging caused oxygen low at the soil surface than without waterlogging. Low oxygen content would inhibit weed respiration, eventually hindering weed dry weight growth. In general, O_2 levels in water-saturated soils reached a dangerous point for the growth of intolerant weeds. Although in some cases, the weeds could survive under low O_2 levels, they would not thrive and grow to stunt.

However, certain weeds were found in both soil types because they were more suitable to grow in extreme water conditions, namely, *Limnocharis flava*. Waterlogging could suppress weed seed germination and growth in LS or RS. According to Liu et al. (2020), waterlogging inhibited the weed seed germination from the soil seed bank. Besides Singh et al. (2017) stated that delaying the emergence of weeds in the crop could reduce weed seed production. Under the opinion of Kaspary et al. (2020), waterlogging was an essential strategy for weed control in rice fields. However, terrestrial weeds had developed flood tolerance mechanisms and produced new ecotypes.

Waterlogging could change the dominant weed species in LS and RS. The dominant weed species was *Echinochloa colona* in without waterlogging, but its growth could be suppressed by waterlogging of 1-15 and 1-30 DAP. Waterlogging was very effective in inhibiting the growth of dominant weed species in LS. However, there were differences in dominant weed species in the RS, i.e., *Oryza rufifogon* without waterlogging, *Ludwigia octovalvis* in waterlogging period of 1-15 DAP, and *Cyperus cephalotes* in waterlogging period of 1-30 DAP. Therefore, waterlogging could suppress the dominant weed species. However, it could make the surviving weed species dominate the soil surface. In addition, waterlogging could change the weed species' dominance in both soil types.

Conclusion

In conclusion, our study found that waterlogging could inhibit weed seed germination and growth in lowland rice. In addition, waterlogging could reduce weed numbers in RS but not in LS. Waterlogging of 1-30 DAP inhibited weed dry weight higher than 1-15 DAP in both soil types. Waterlogging of 1-30 DAP decreased the weed dry weight by 87.2% in LS and 97.3% in RS than without waterlogging. Waterlogging could change the composition and dominance of weed species. The research findings show that a waterlogging period of 1-30 DAP effectively inhibits weed seed germination and growth in RS, but a waterlogging period in LS could extend. According to the results of this study, we recommend that treatment of waterlogging period of 1-30 DAP can be applied for weed control in lowland rice.

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APPENDIX

Appendix 1. *ANOVA on weed number*

Source of variance	**Degree of freedom**	**Sum of Squares**	**Mean square**	**F. calc.**	**F table 5%**
Treatment	5	433,803.670	86,760.734	73.32*	3.11
Soil types (A)	1	7,247.277	7,247.277	6.12*	4.75
Waterlogging (B)	2	396,956.149	198,478.074	167.74*	4.62
A × B interaction	2	29,600.244	14,800.122	12.51*	4.62
Residual	12	14,199.283	1,183.274		
Total	17	448,002.953			

Remarks: * = significance different at 5%, and coefficient of variation (CV) = 29.2%

Appendix 2. *ANOVA on weed dry weight*

Source of variance	**Degree of freedom**	**Sum of Squares**	**Mean squares**	**F. calc.**	**F table 5%**
Treatment	5	79,271.111	15,854.222	5.74*	3.11
Soil types (A)	1	1,568.000	1,568.000	0.57ns	4.75
Waterlogging (B)	2	36,494.111	18,247.056	6.60*	4.62
A × B interaction	2	41,209.000	20,604.500	7.46*	4.62
Residual	12	33,152.667	2,762.722		
Total	17	112,423.778			

Remarks: * = significance different at 5%, ns = non significance different at 5%, and coefficient of variation (CV) = 25.1%

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