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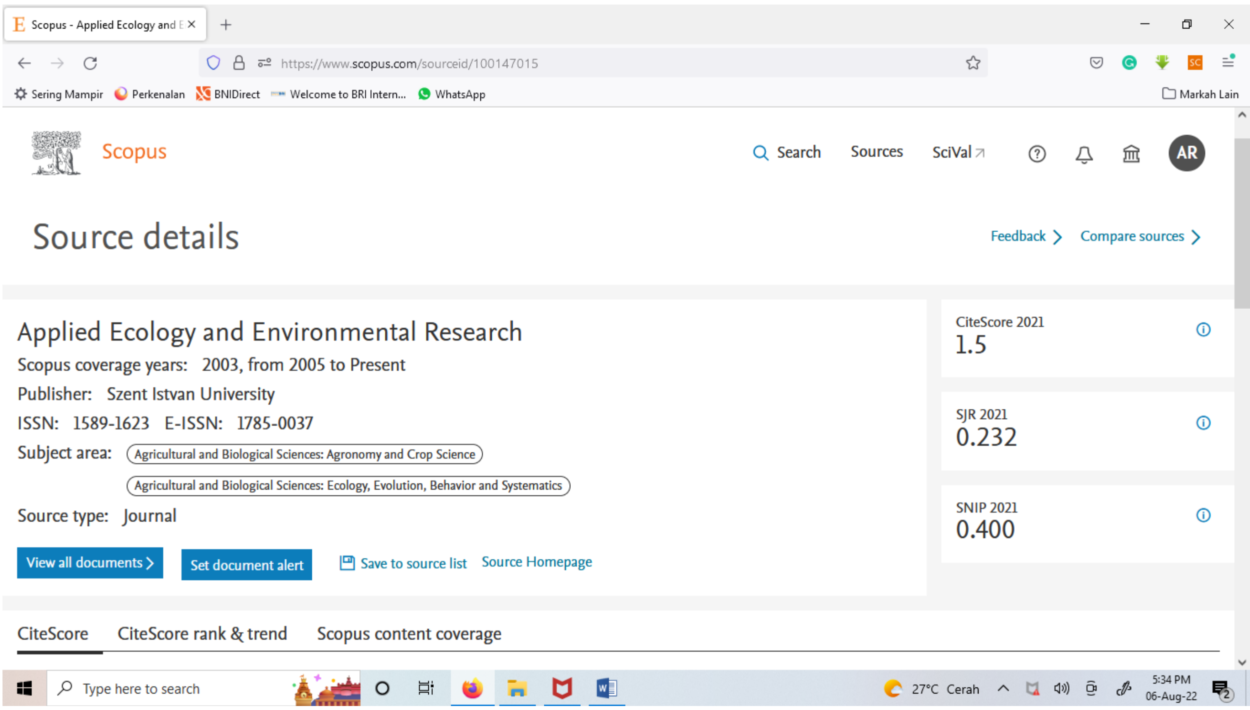

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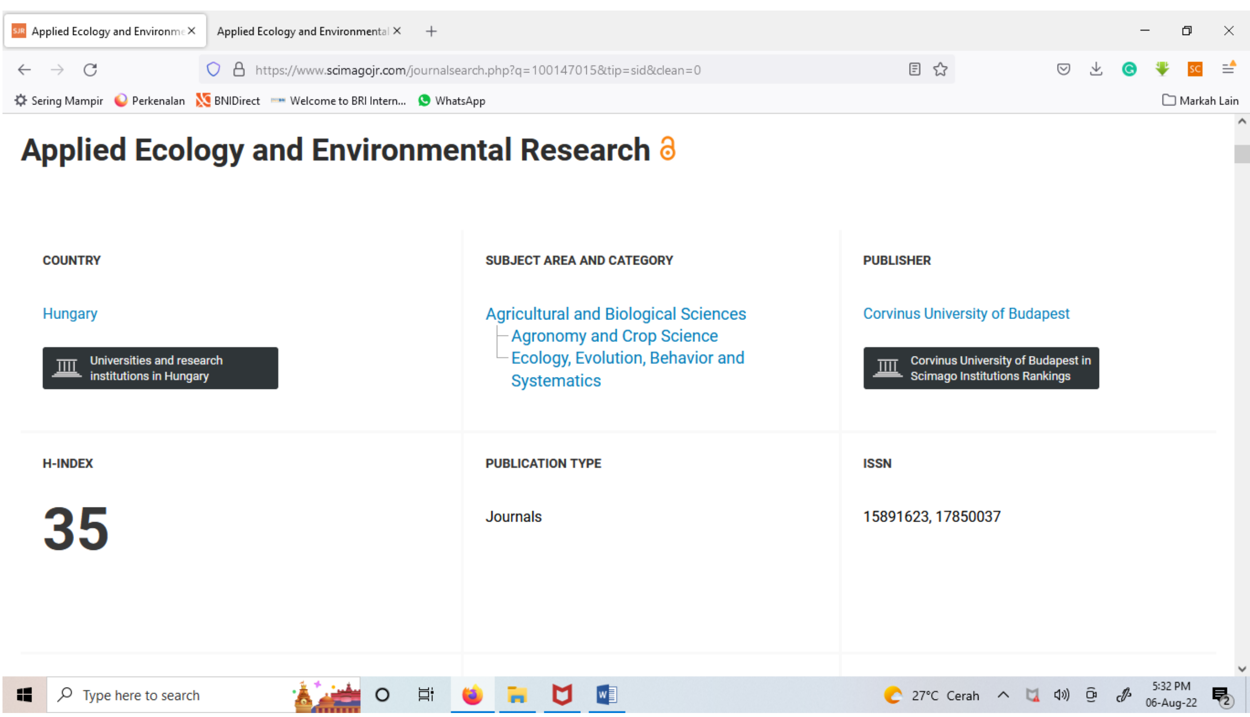

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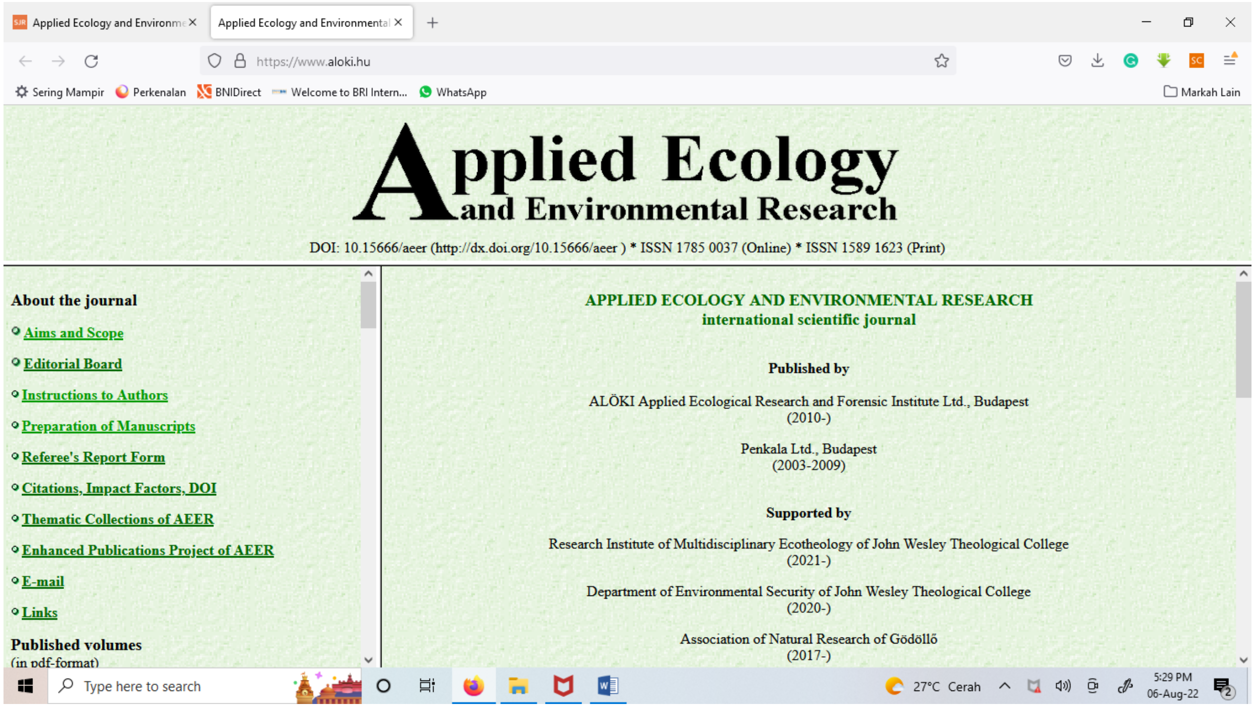

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EFFECT OF WATERLOGGING ON SEED GERMINATION AND GROWTH OF WEED IN LOWLAND RICE

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Abstract. Weed control must be done to avoid competition in the early rice growth. One of the weed controls is waterlogging. The study aimed to know the effect of waterlogging on weed seed germination and growth in lowland rice. This research was arranged in a completely randomized design (CRD) factorial with three replications. The first factor was waterlogging, which consisted of three levels, i.e., without waterlogging, 1-15 days after planting (DAP), and 1-30 DAP. The second factor was focused on two different soil types, i.e., latosol soil (LS) and regosol soil (RS). The results showed that waterlogging could inhibit weed seed germination in RS, but not in LS. In this study, waterlogging period of 1-30 DAP inhibited weed dry weight higher than 1-15 DAP in both soil types. Waterlogging could change the composition and dominance of weed species. The research findings show that the waterlogging period of 1-30 DAP effectively inhibits the weed seed germination and growth in lowland rice. For further research, we recommend that waterlogging period of 1-30 DAP can be applied for weed control in other soil types.

Keywords: anaerobic, seed germination, lowland rice, soil types, waterlogging, weed species

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). Weeds are a big problem in conventional systems cultivation, integrated crop management, and systems of rice intensification (Zarwazi et al., 2016). 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 (Zheng 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 the 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, the need for water is 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. Waterlogging will significantly contribute to inhibiting 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 know the effect of waterlogging on weed seed germination 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 with three replications. The first factor was the waterlogging period, which consisted of three levels, i.e., without waterlogging, 1-15 DAP, and 1-30 DAP. The second factor was focused on two different soil types, i.e., LS and RS. Finally, the experiment required 18 sample plots (or wooden boxes). A schematic diagram that represents the overall experimental works is served in Figure 1.

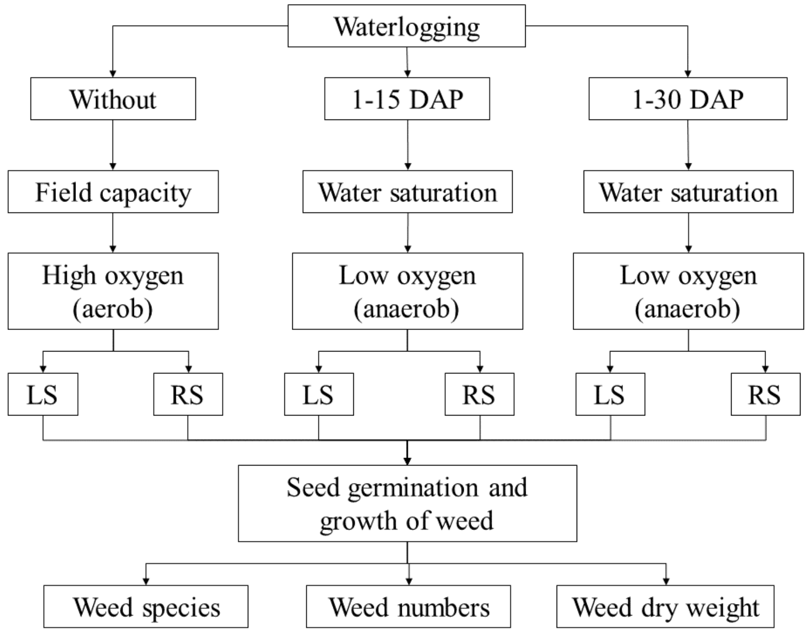

Figure 1: A schematic diagram of the overall experimental works.

Research procedures

Nurseries were carried out in plastic boxes of 0.3 × 0.25 × 0.1 m (length, length, height). The soil media used a mixture of soil and organic fertilizer, with a ratio of 1:1. The rice seeds were spread over the media and then covered with a thin layer of 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). Some wooden boxes were placed on the greenhouse table, coated with waterproof plastic, and labelled. Soil dry weight was needed 60 kg wooden box^{-1}. Each soil type was weighed nine times to fill nine 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. Rice seedlings were planted in eight holes with a 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.

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 grouped 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.

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 summed dominance ratio (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.

Results

Effect of waterlogging periods on weed seed germination and growth

The ANOVA results 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 Figure 2.

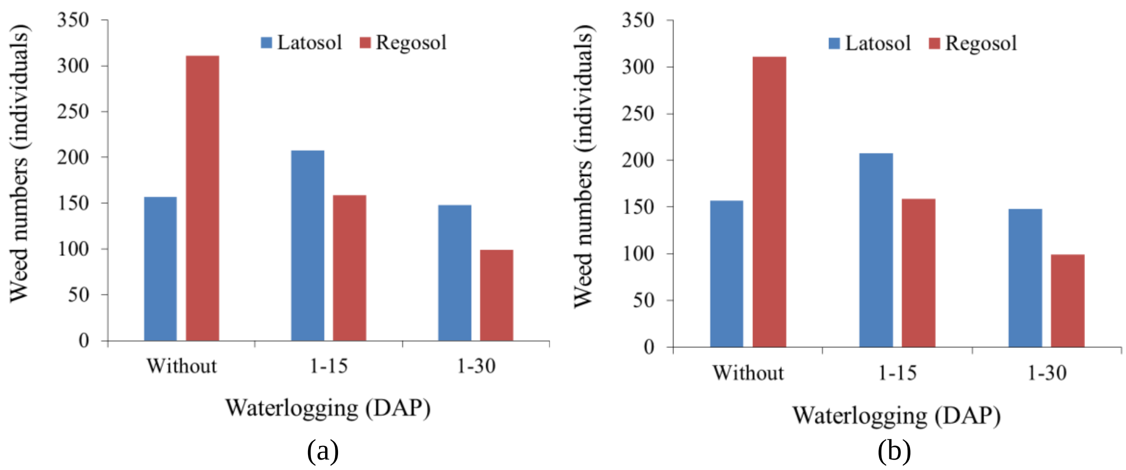

Figure 2. *Effect of waterlogging on weed numbers (a) and weed dry weight (b) in LS and RS*

Figure 2 shows that waterlogging period of 1-30 DAP effectively suppresses weed number in RS but not in LS. Interestingly, waterlogging in RS had a significant decrease in weed numbers. However, waterlogging reduced weed dry weight in both soil types. Another study found that a longer duration of waterlogging caused stress and weed death.

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* (SDR 42.1%).

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.

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 rufifogon* (SDR 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.

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. 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 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 at without waterlogging was *Echinochloa colona*, 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 period of 1-30 DAP inhibited weed dry weight higher than 1-15 DAP in both soil types. Waterlogging could change the composition and dominance of weed species. The research findings show that a waterlogging period of 1-30 DAP effectively inhibits the weed seed germination and growth in lowland rice. According to the results of this study, we recommend that waterlogging period of 1-30 DAP can be tried for weed control in other soil types in lowland rice.

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REFERENCES

[1] Belford, B., McFarlane, D. J. (2018): Managing waterlogging and inundation in crops. Crops/Drainage and Flooding. Australia: University of Western Australia.

[2] Chen, H., Zeng, W., Jin, Y., Zha, Y., Mi, B., Zang, S. (2020): Development of a waterlogging analysis system for paddy fields in irrigation districts. – Journal of Hydrology 591: 125325.

[3] Chhun, S., Kumar, V., Martin, R. J., Srean, P., Hadi, B. A. R. (2019): Weed management practices of smallholder rice farmers in Northwest Cambodia. – Crop Protection: 1–17.

[4] De-Melo, B. B., Silva, B. M., Peixoto, D. S., Chiarini, T. P. A., De-Oliveira, G. C., Curi, N. (2021): Effect of compaction on the relationship between electrical resistivity and soil water content in Oxisol. – Soil and Tillage Research 208: 104876.

[5] Elkheir, H. A. (2016): Duration of soil water content between field capacity and wilting point and its effect on the growth of some aerobic rice cultivars (*Oryza sativa* L.). – International Journal of Agriculture System (IJAS) 4(1): 36–45.

[6] Fennimore, S. A. (2017): Weed seed biology, seedbanks, and management. In Weed Science School (pp. 14–49). University of California, Davis, (US).
[7] Ferronato, C., Marinari, S., Francioso, O., Bello, D., Trasar-Cepeda, C., Antisari, L. V. (2019): Effect of waterlogging on soil biochemical properties and organic matter quality in different salt marsh systems. – Geoderma 338: 302–312.
[8] Garcia, Q. S., Barreto, L. C., Bicalho, E. M. (2020): Environmental factors driving seed dormancy and germination in tropical ecosystems: a perspective from campo rupestre species. – Environmental and Experimental Botany 178: 104164.
[9] Gonzalez-Andujar, J. L. (2013): Population dynamics: weed control models. In Reference Module in Earth Systems and Environmental Sciences (pp. 1–7). Instituto de Agricultura Sostenible (CSIC), Cordoba, Spain.
[10] Gulshan, A. B., Dasti, A. A. (2012): Role of soil texture and depths on the emergence of buried weed seeds. – Journal of Agricultural and Biological Science 7(4): 223–228.
[11] He, Y., Gao, P., Qiang, S. (2019): An investigation of weed seed banks reveals similar potential weed community diversity among three different farmland types in Anhui Province, China. – Journal of Integrative Agriculture 18(4): 927–937.
[12] Hwang, J., Yu, S., Lee, B., Lee, D. (2020): Modulation of energy metabolism is important for low-oxygen stress adaptation in Brassicaceae species. – International Journal of Molecular Sciences: 1–21.
[13] Ismail, A. M., Johnson, D. E., Ella, E. S., Vergara, G. V., Baltazar, A. M. (2012): Adaptation to flooding during emergence and seedling growth in rice and weeds, and implications for crop establishment. – AoB Plants 19: 1–18.
[14] Jia, B., Niu, Z., Wu, Y., Kuzyakov, Y., Li, X. G. (2020): Waterlogging increases organic carbon decomposition in grassland soils. – Soil Biology and Biochemistry 148: 1–9.
[15] Kaspary, T. E., Roma-burgos, N., Merotto, A. (2020): Snorkeling strategy: Tolerance to flooding in rice and potential application for weed management. – Genes 11: 1–13.
[16] Khairi, M., Nozulaidi, M., Afifah, A., Jahan, M. S. (2015): Effect of various water regimes on rice production in lowland irrigation. – Australian Journal of Crop Science 9(2): 153–159.
[17] Kumalasari, N. R., Bergmeier, E. (2014): Weed communities of Javanese paddy fields in response to altitude and agronomic practices. Dissertation. Diversity of rice weeds vegetation and its potential as local forage resource in Java, Indonesia. Georg-August University School of Science (GAUSS). Göttingen, Germany.
[18] Liu, Z., Ge, X., Fu, Z., Liu, J. (2020): Alternanthera philoxeroides invasion affects the soil seed bank of weed community. Environmental and Experimental Botany 180: 104196.
[19] Ma, M., Cen, W., Li, R., Wang, S., Luo, I. (2020): The molecular regulatory pathways and metabolic adaptation in the seed germination and early seedling growth of rice in response to low. – Plants 9: 1–14.
[20] Mesquita, M. L. R. (2017): Weed seed bank in rice fields. In Advances in International Rice Research (pp. 33–47). Maranhão State University, Bacabal, Brazil.
[21] Nandan, R., Singh, V., Kumar, V., Singh, S. S., Hazra, K. K., Nath, C. P., Malik, K., Poonia, S. P. (2020): Viable weed seed density and diversity in soil and crop productivity under conservation agriculture practices in rice-based cropping systems. – Crop Protection 136: 105210.
[22] Nishiuchi, S., Yamauchi, T., Takahashi, H., Kotula, L., Nakazono, M. (2012): Mechanisms for coping with submergence and waterlogging in rice. – Rice 5(1): 1–14.
[23] Peng, Y., Cheng, X., Liu, D., Liu, X., Ma, G., Li, S., Yang, Y., Zhang, Y., Bai, L. (2021): Quintrione: A new selective herbicide for weed control in rice (*Oryza sativa* L.). – Crop Protection 141: 105501.
[24] Pinem, R. R., & Ichwan, N. (2017): Study of various provison of water paddy methods (*Oryza sativa* L.) Ciherang variety rice in greenhouse. – J. Rekayasa Pangan dan Pertanian 5(2): 406–411 (in Indonesian).

[25] Singh, M., Bhullar, M. S., Chauhan, B. S. (2017): Relative time of weed and crop emergence is crucial for managing weed seed production : A study under an aerobic rice system. – Crop Protection 99: 33–38.
[26] Toral-juarez, M. A., Avila, R. T., Cardoso, A. A., Brito, F. A. L., Machado, K. L. G., Almeida, W. L., Souza, R. P. B., Martins, S. C. V., Damatta, F. M. (2021): Drought-tolerant coffee plants display increased tolerance to waterlogging and post-waterlogging reoxygenation. – Environmental and Experimental Botany 182: 104311.
[27] Yasin, M., Andreasen, C. (2016): Effect of reduced oxygen concentration on the germination behavior of vegetable seeds. – Horticulture Environment and Biotechnology 57(5): 453–461.
[28] Yasin, Muhammad, & Andreasen, C. (2016): Effect of reduced oxygen concentration on the germination behavior of vegetable seeds. – Horticulture Environment and Biotechnology 57(5): 453–461.
[29] Zarwazi, L. M., Chozin, M. A., Guntoro, D. (2016): Potential of weed problem on three paddy cultivation systems. – Jurnal Agronomi Indonesia 44(2): 147–153 (in Indonesian).
[30] Zheng, Z., Ping-lei, G. A. O., Wei-min, D. A. I., Xiao-ling, S., Feng, H. U., Sheng, Q. (2019): Effect of tillage and burial depth and density of seed on viability and seedling emergence of weedy rice. Journal of Integrative Agriculture 18(8): 1914–1923.
[31] Zhou, W., Chen, F., Meng, Y., Chandrasekaran, U., Luo, X., Yang, W., Shu, K. (2020): Plant waterlogging/flooding stress responses: From seed germination to maturation. – Plant Physiology and Biochemistry 148: 228–236.

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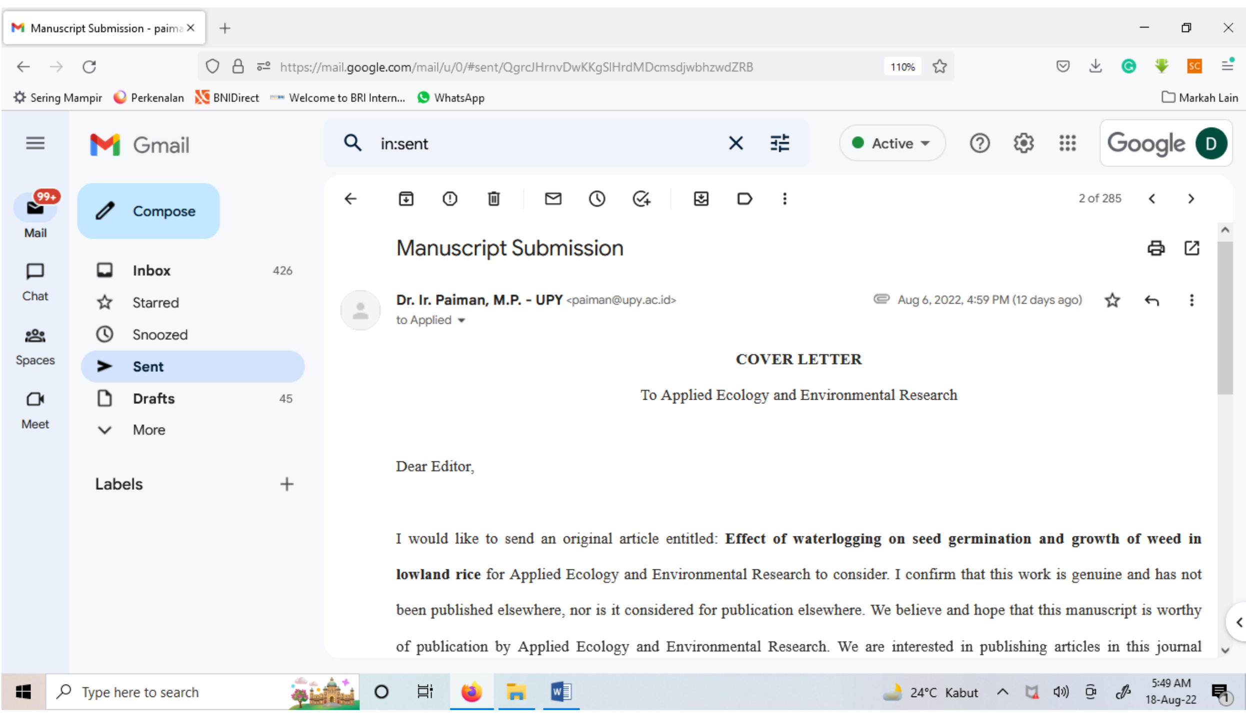

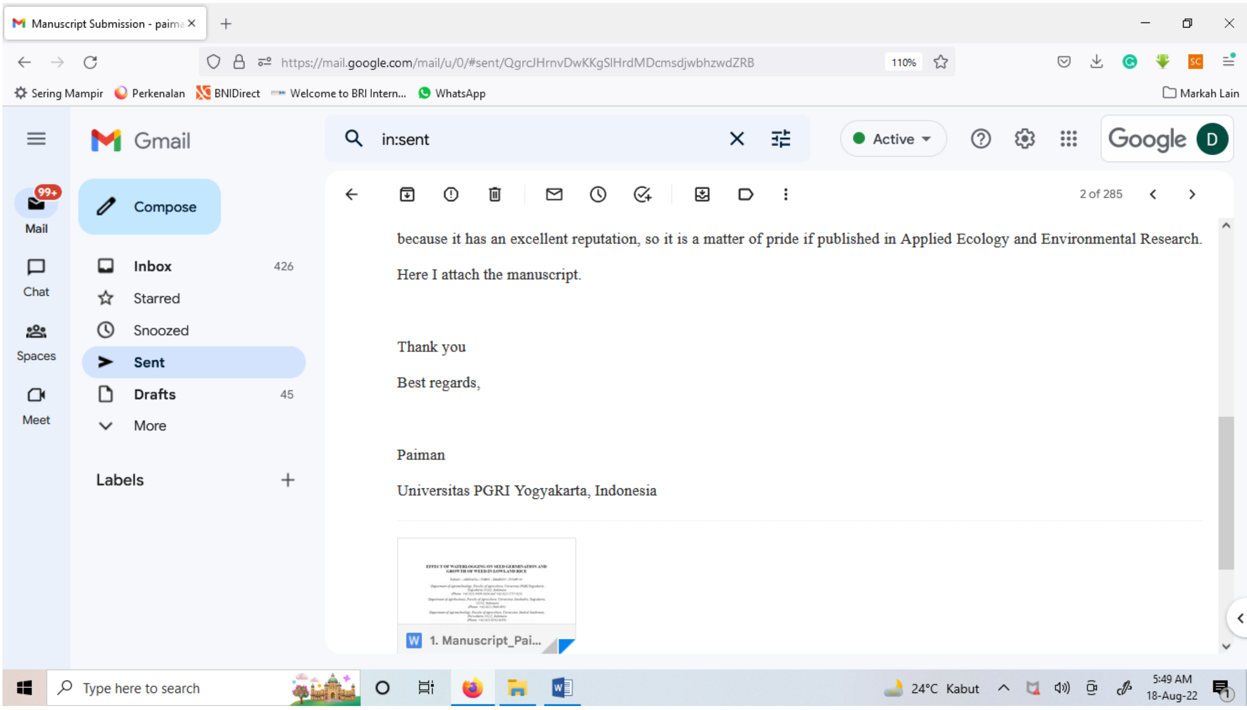

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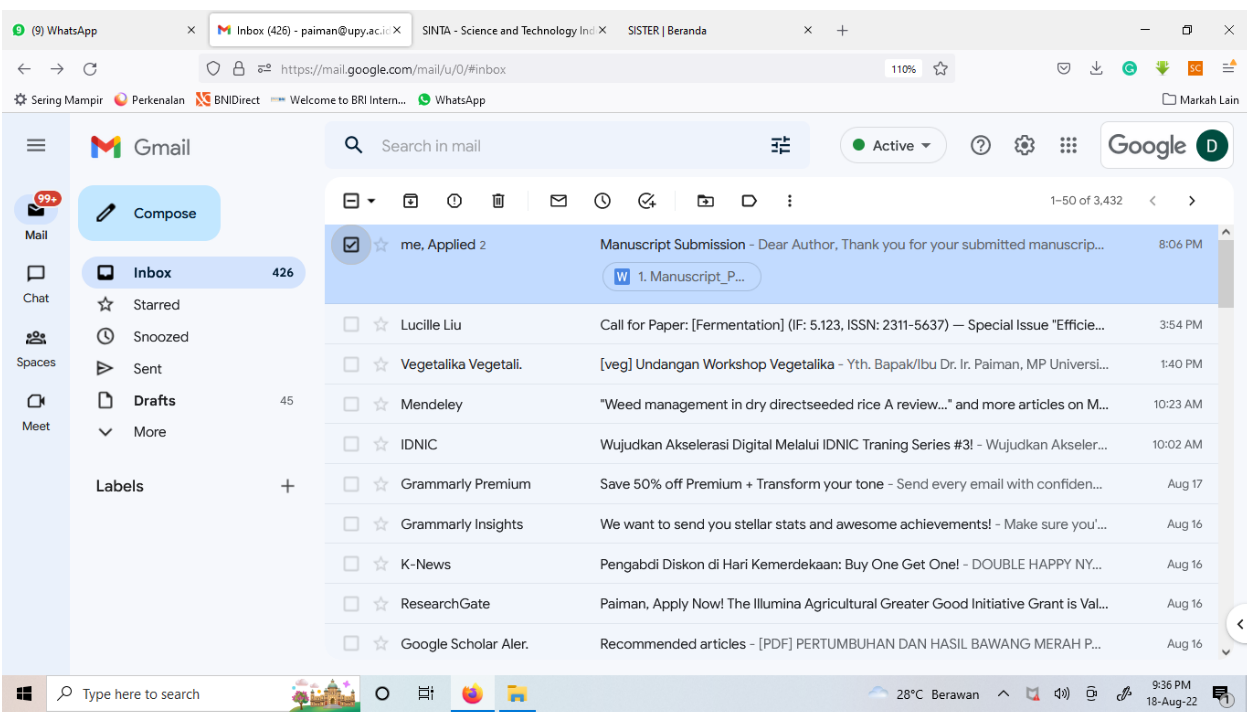

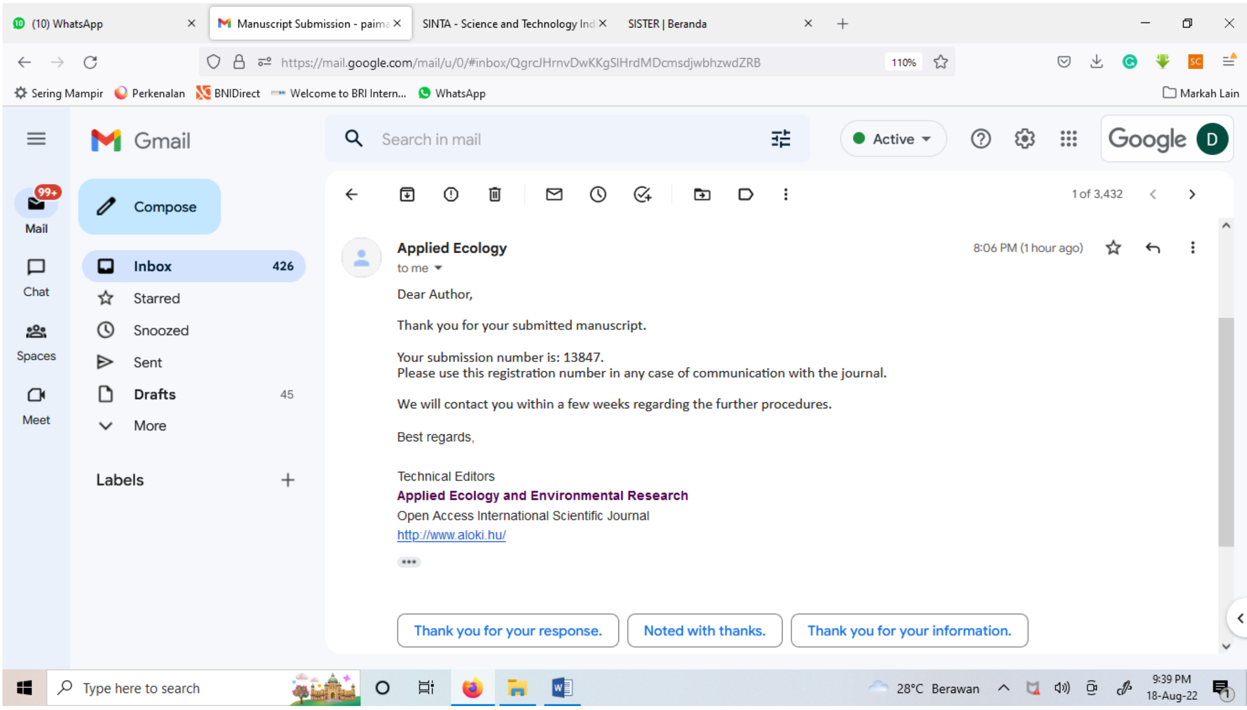

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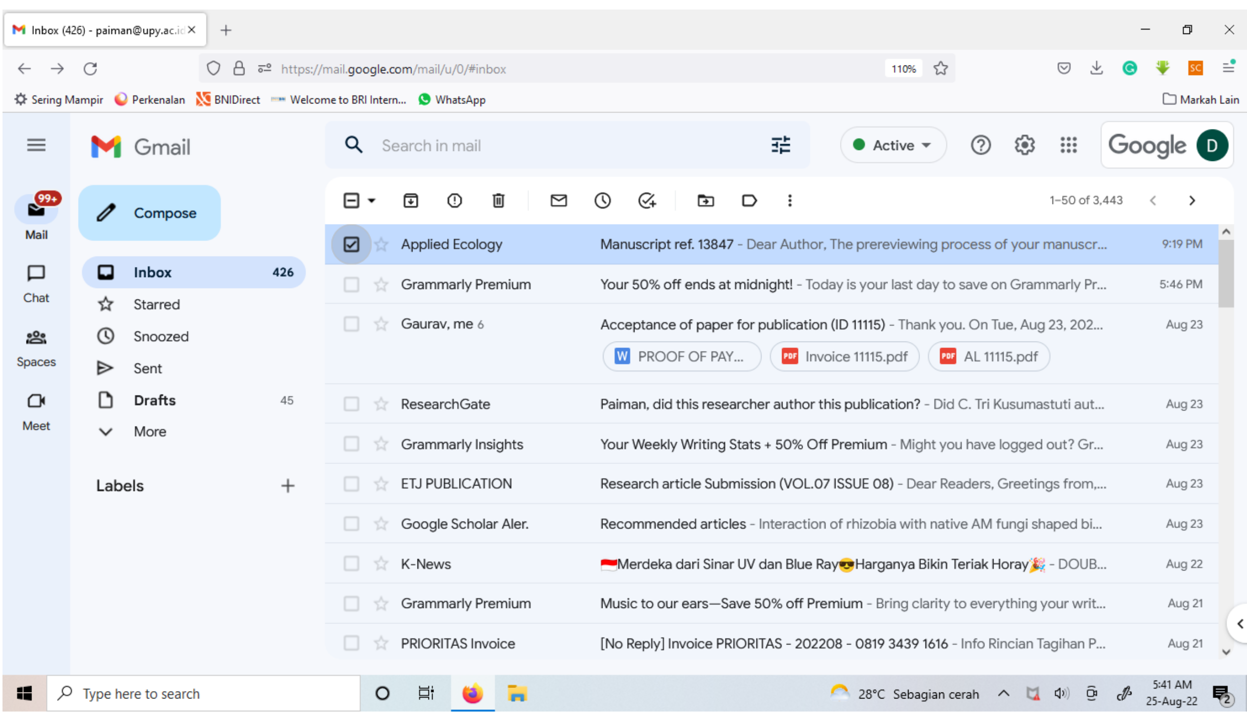

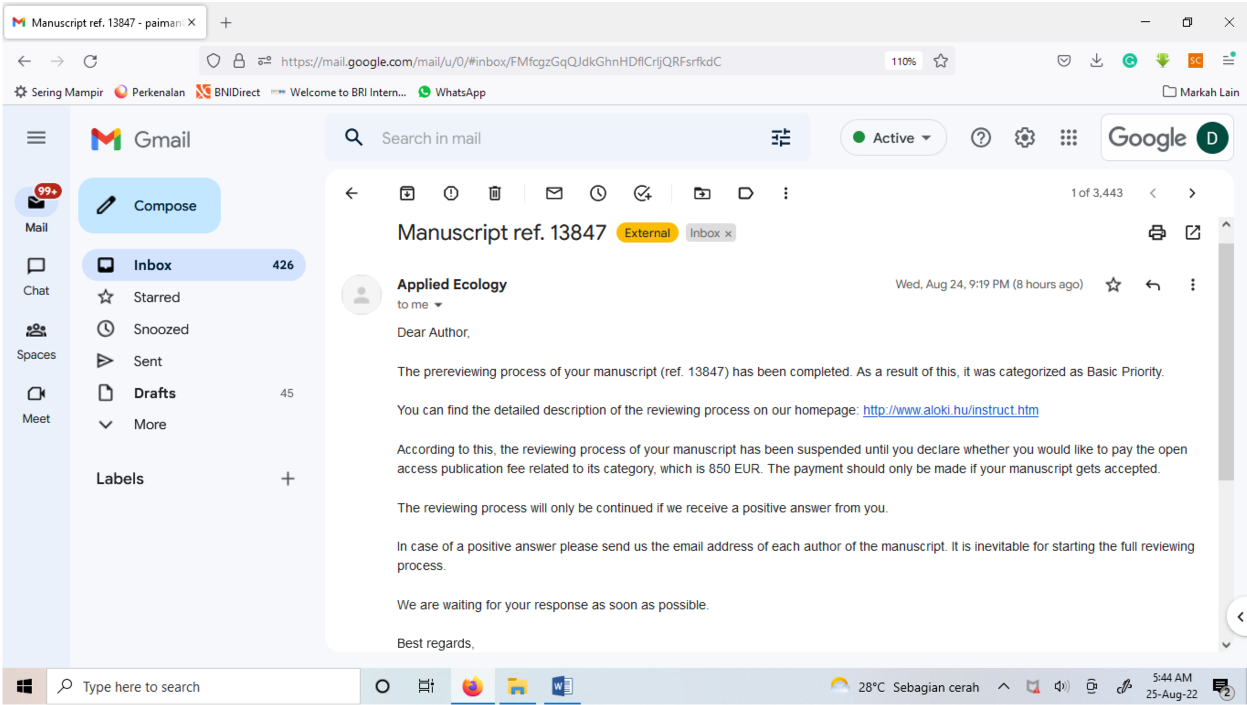

Manuscript ref. 13847

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Wed, Aug 24, 9:19 PM (8 hours ago)

Dear Author,

The prereviewing process of your manuscript (ref. 13847) has been completed. As a result of this, it was categorized as Basic Priority.

You can find the detailed description of the reviewing process on our homepage: http://www.aloki.hu/instruct.htm

According to this, the reviewing process of your manuscript has been suspended until you declare whether you would like to pay the open access publication fee related to its category, which is 850 EUR. The payment should only be made if your manuscript gets accepted.

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In case of a positive answer please send us the email address of each author of the manuscript. It is inevitable for starting the full reviewing process.

We are waiting for your response as soon as possible.

Best regards,

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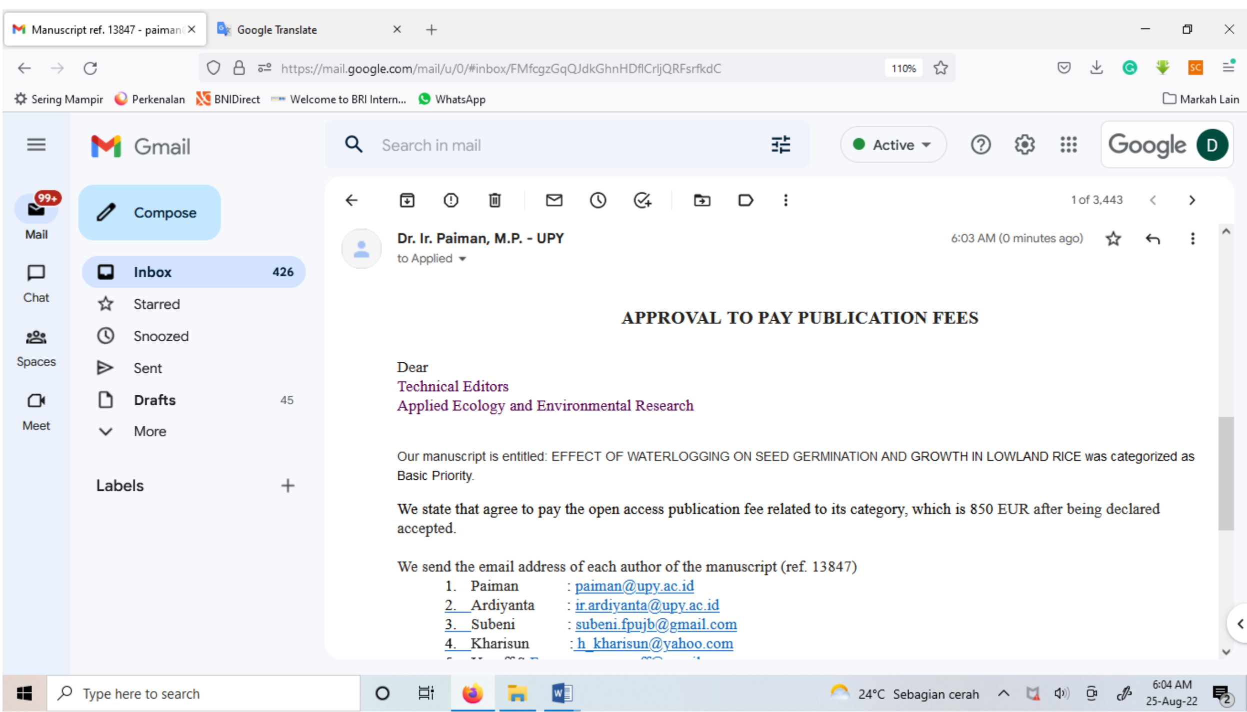

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Our manuscript is entitled: EFFECT OF WATERLOGGING ON SEED GERMINATION AND GROWTH IN LOWLAND RICE was categorized as Basic Priority.

We state that agree to pay the open access publication fee related to its category, which is 850 EUR after being declared accepted.

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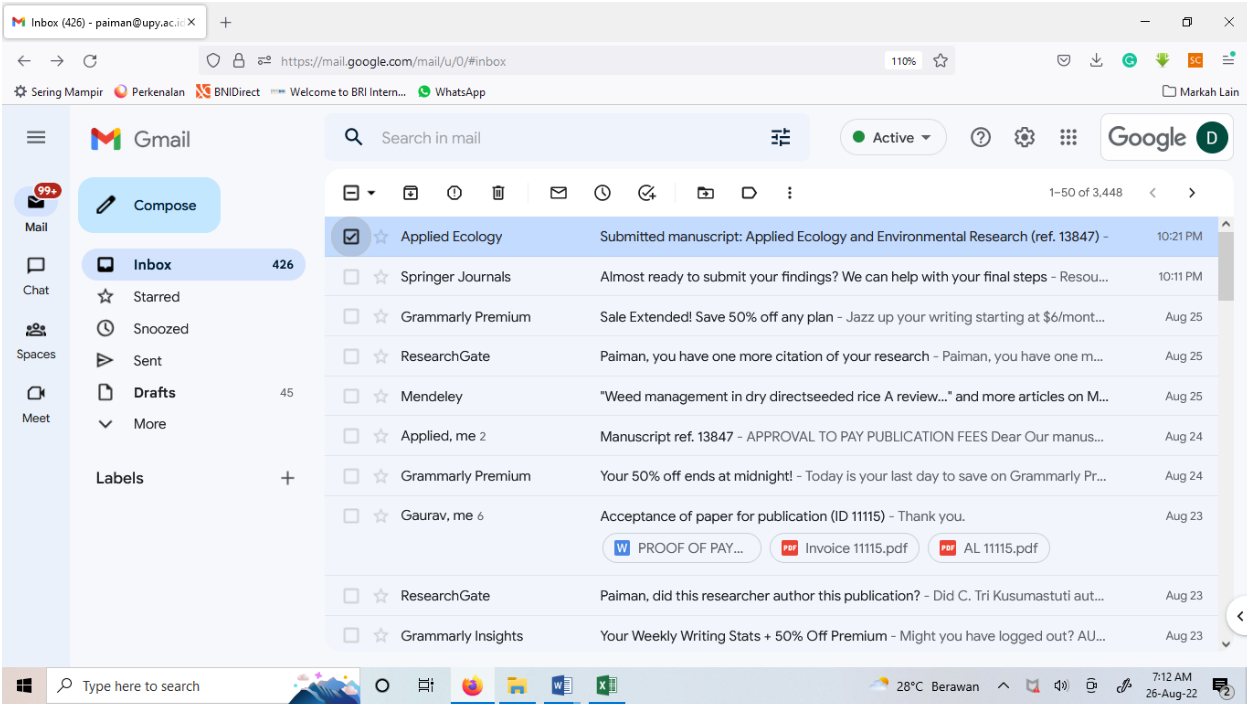
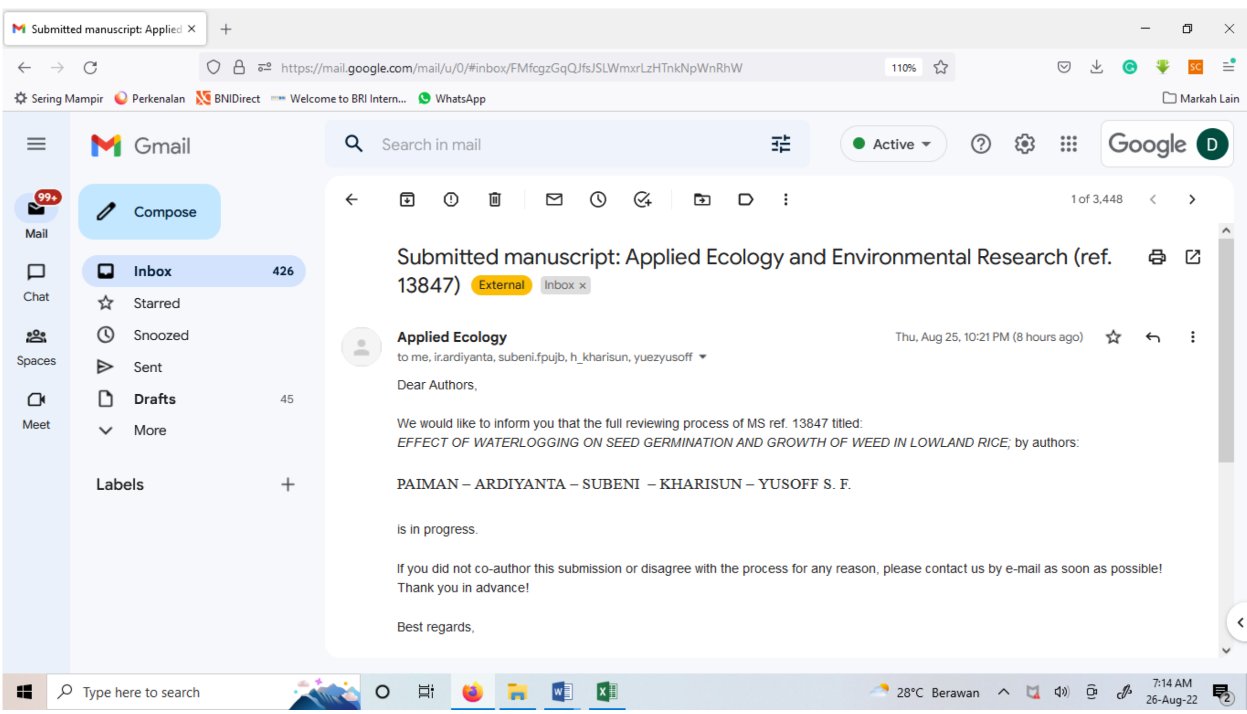
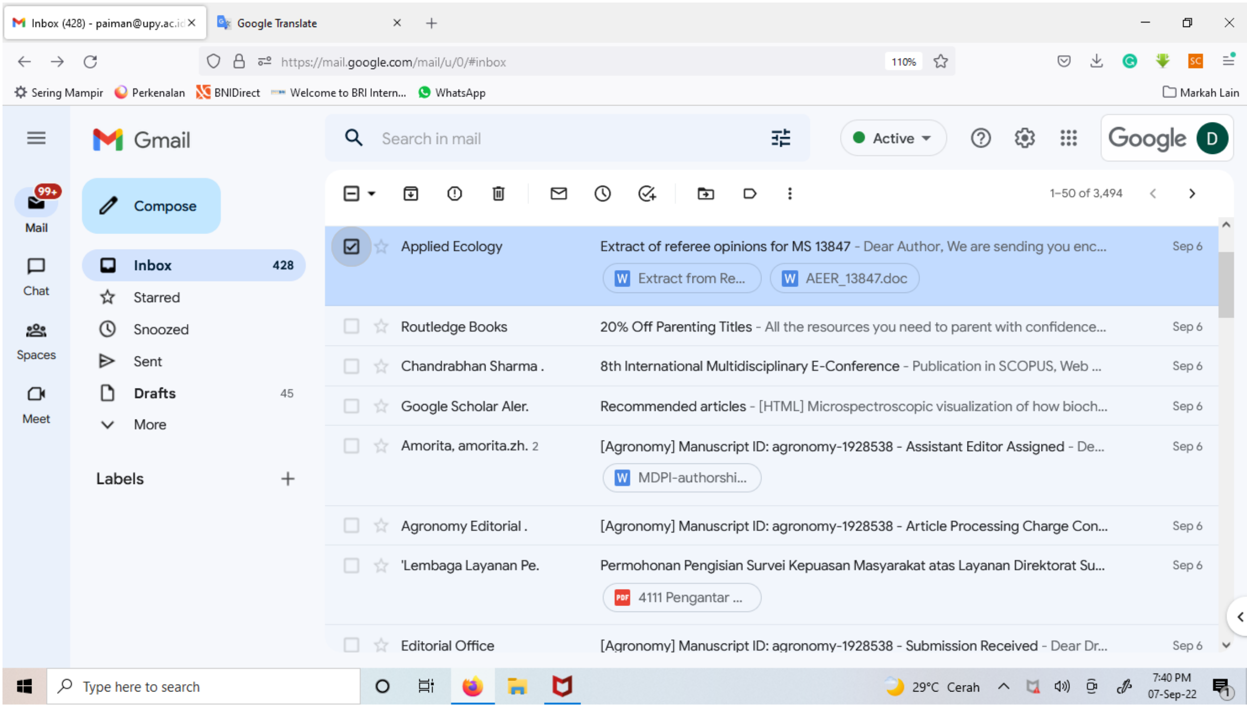
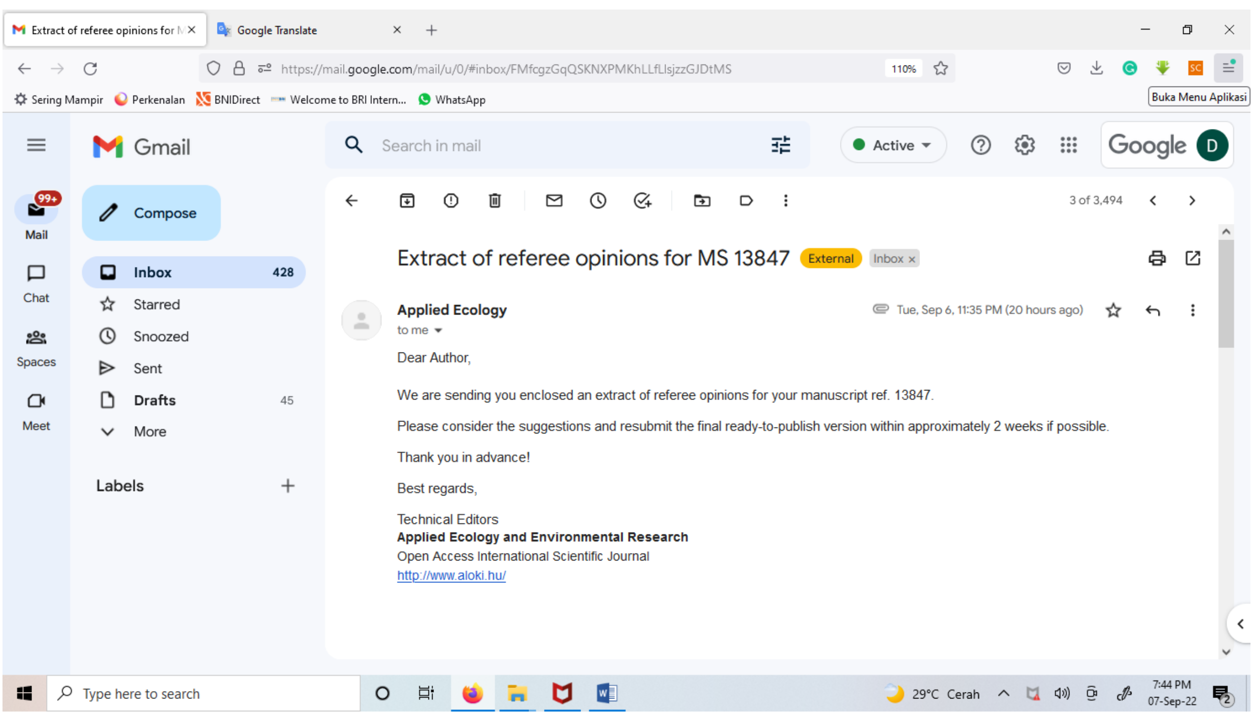
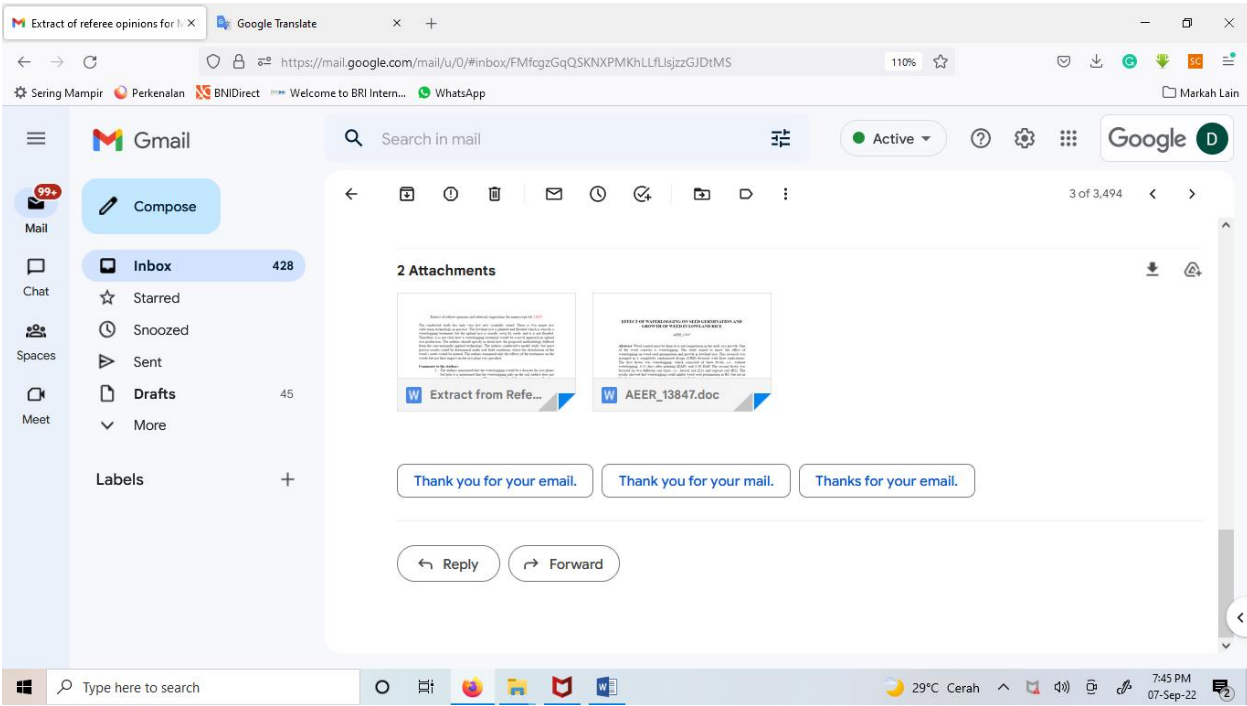




07 September 2022: Extract referee opinions for MS 13847







Comment to the authors:

Extract of referee opinions and editorial suggestions for manuscript ref. 13847

The conducted study has only very low new scientific sound. There is two major rice cultivation technology in practice. The lowland rice is planted and flooded which is exactly a waterlogging treatment, but the upland rice is usually sown by seeds, and it is not flooded. Therefore, it is not clear how a waterlogging treatment would be a novel approach in upland rice production. The authors should specify in detail how the proposed methodology differed from the conventionally applied technology. The authors conducted a model study, but more precise results could be determined under real field conditions where the distribution of the weed's seeds would be natural. The authors examined only the effects of the treatments on the weeds but not their impact on the rice plant was specified.

Comments to the Authors:

1. The authors mentioned that the waterlogging would be a disaster for rice plants but later it is mentioned that the waterlogging only on the soil surface does not interfere with the rice crops. Please specify the differences between flooding the cultured crops and shallow surface waterlogging.
2. The authors should indicate the name of the applied rice variety.
3. Please specify the type and nutrient content of the organic fertilizer.
4. The "thin layer" is not explanatory from a scientific point of view. Please add an exact value or an interval.
5. It must be specified how the field capacity of the soil had been determined.
6. The authors made the analysis 30 days after the end of the longest treatment. But their prompt effects could be determined after just those were finished. Otherwise, during the 45 and 30 days after the end of the treatment weeds could germinate and start growing immediately. The results confirmed this fact because the variability in the weed biomass was much larger than that of the number of weeds.

7. The proposed approach is not effective against waterlogging tolerant weeds which are the most problematic in rice cultivation.
8. Please indicate the accuracy of the applied balance.
9. The number of technical repetitions must be indicated by the description of the applied statistical analysis in the M&M chapter.
10. Submitting the base ANOVA tables would be favourable as supplements.
11. Data presented in Table 1 and Fig 2 are completely overlapping. In this case, using only the tabular form would be beneficial.
12. Subfigures *a* and *b* are the same within Fig. 2. The weed dry weight data were not displayed.
13. The authors proposed the waterlogging treatment from 1-30 DAP but this was the longest waterlogging treatment. It remains an open question what would happen if longer waterlogging would be tested.

- Keywords should not be the repetitions of the title words, please find such words which are not in the title, this way search engines on the web will find your manuscript with higher probability.
- When first using an abbreviation, please write the whole name and abbreviation in brackets the first time.
- Reference no. 12 listed at the end is not cited in the text.
- References 27 and 28 are duplications.
- The English throughout needs revision and careful proofreading.
- There should be a photo included of the experimental culture or equipment in the Methodical section if possible.

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

The format of the manuscript is not appropriate. Otherwise, the text is grammatically correct, but its style needs considerable improvement in some cases.

Issues involved:
Line 4: "Weed control must be done to" 'is needed' or 'is essential' is suggested to be used instead of 'must be done'
Line 5: "One of the weed controls is" 'A weed control method is' is suggested to be used to improve style
Line 5: "to know" 'to examine' or 'to investigate' is suggested to be used instead
Line 42: "in conventional systems cultivation, " 'in cultivations with conventional system' is suggested to be used.

Pengantar Perbaikan Paper: 11 September 2022

AN ITEMIZED RESPONSE SHEET

1. Respond to all issues/recommendations of reviewers.
2. All amendments made are highlighted in yellow on the revision paper.

Comments of Reviewer 1:	Addressed (Y/N)	Reply/Action taken
1. The authors mentioned that the waterlogging would be a disaster for rice plants but later it is mentioned that the waterlogging only on the soil surface does not interfere with the rice crops. Please specify the differences	Y	Rice plants affected by floods will cause part or all of the plant's body to be covered with water, thereby disrupting physiological processes, especially potosynthesis. Flooding on the soil surface with a height of about

	between flooding the cultured crops and shallow surface waterlogging.		3 cm will not interfere with the physiological processes of rice plants.
2.	The authors should indicate the name of the applied rice variety.	Y	The Ciherang variety was used in this study.
3.	Please specify the type and nutrient content of the organic fertilizer.	Y	This study used organic fertilizer from cow manure.
4.	The “thin layer” is not explanatory from a scientific point of view. Please add an exact value or an interval	Y	covered with a 0.2-0.3 cm soil to maintain soil moisture
5.	It must be specified how the field capacity of the soil had been determined.	Y	Field capacity is determined by providing water to the soil until it is saturated and no longer able to absorb water
6.	The authors made the analysis 30 days after the end of the longest treatment. But their prompt effects could be determined after just those were finished. Otherwise, during the 45 and 30 days after the end of the treatment weeds could germinate and start growing immediately. The results confirmed this fact because the variability in the weed biomass was much larger than that of the number of weeds.	Y	The flooding period of 1-30 DAP was terminated because it is already quite significant in weed control compared to control and efficient water use. Furthermore, the growth of the canopy of rice crops as a substitute to control the germination and growth of new weeds.
7.	The proposed approach is not effective against waterlogging tolerant weeds which are the most problematic in rice cultivation	N	Although certain types of weeds are tolerant of waterlogging 1-30 DAP, their growth was still stunted and not optimal.
8.	Please indicate the accuracy of the applied balance.	Y	Waterlogging period of 1-30 DAP decreased the weed dry weight in the LS (87.2%) and RS (97.3%) than without waterlogging.
9.	The number of technical repetitions must be indicated by the description of the applied statistical analysis in the M&M chapter.	Y	Finally, this experiment required six treatment combinations. Each treatment combination was repeated three times. So that in the study 18 sample plots (or 18 wooden boxes) were needed.
10.	Submitting the base ANOVA tables would be favourable as supplements.	Y	Thank you. We add it to the manuscript
11.	Data presented in Table 1 and Fig 2 are completely overlapping. In this case, using only the tabular form would be beneficial.	Y	Thanks for the suggestion. Figure 2 was just to clarify Table 1.
12.	Subfigures *a* and *b* are the same within Fig. 2. The weed dry weight data were not displayed	Y	Thanks for the correction. An error occurred entering a subfigures on b. Subfigures b has been replaced and was correct.
13.	The authors proposed the waterlogging treatment from 1-30 DAP but this was the longest waterlogging treatment. It remains an	Y	Waterlogging treatment from 1-30 DAP in regusol soil (RS) was the longest waterlogging treatment, but in latosol soil (LS) can still be extended.

open question what would happen if longer waterlogging would be tested.		
Comments of Reviewer 2:	**Addressed (Y/N)**	**Reply/Action taken**
1. Keywords should not be the repetitions of the title words, please find such words which are not in the title, this way search engines on the web will find your manuscript with higher probability.	Y	We have replaced keywords with words that are not in the title
2. When first using an abbreviation, please write the whole name and abbreviation in brackets the first time.	Y	Done
3. Reference no. 12 listed at the end is not cited in the text.	Y	We have removed.
4. References 27 and 28 are duplications	Y	We have removed.
5. The English throughout needs revision and careful proofreading.	Y	We have asked colleagues who work on proofreading for help
6. There should be a photo included of the experimental culture or equipment in the Methodical section if possible.	Y	I added to the methodical section in M&M.
7. The format of the manuscript is not appropriate. Otherwise, the text is grammatically correct, but its style needs considerable improvement in some cases	Y	The format of the manuscript I have adapted with the journal template. The use of English grammar has been improved.
8. Line 4: "Weed control must be done to" 'is needed' or 'is essential' is suggested to be used instead of 'must be done'	Y	'Must be done' has been replaced by 'is needed'
9. Line 5: "One of the weed controls is" 'A weed control method is' is suggested to be used to improve style	Y	'One of the weed controls is' has been replaced by 'A weed control method is'
10. Line 5: "to know" 'to examine' or 'to investigate' is suggested to be used instead	Y	'to know' has been replaced by 'to investigate'
11. Line 42: "in conventional systems cultivation, " 'in cultivations with conventional system' is suggested to be used.	Y	"in conventional systems cultivation" we have replaced it with "in cultivations with conventional system"

Submission of Paper Revised: 11 September 2022

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

AEER_13847

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 (Zheng 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*.

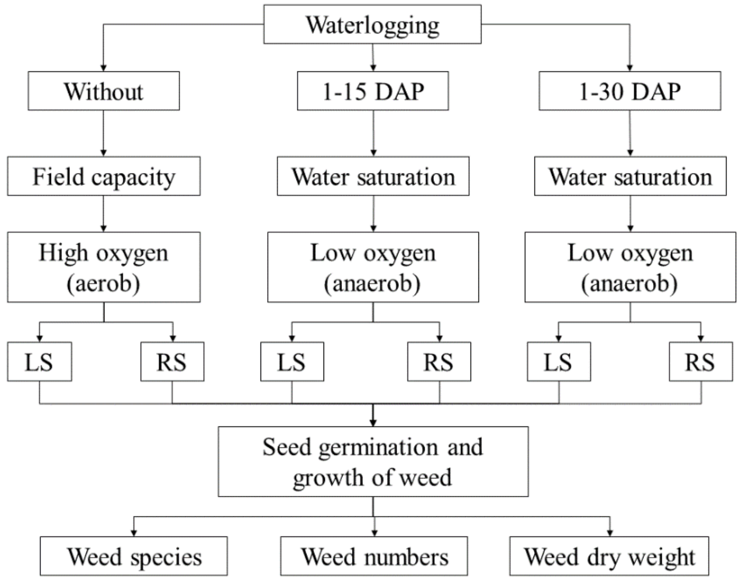


***Figure 1**. A schematic diagram representing the overall experimental works*

Research procedures

Nurseries were carried out in plastic boxes of 0.3 × 0.25 × 0.1 m (width, length, 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. Foto of the experimental culture (plant and weed growth) at 60 DAP are presented in *Fig. 2*.

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

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.

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.

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

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

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

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.

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*.

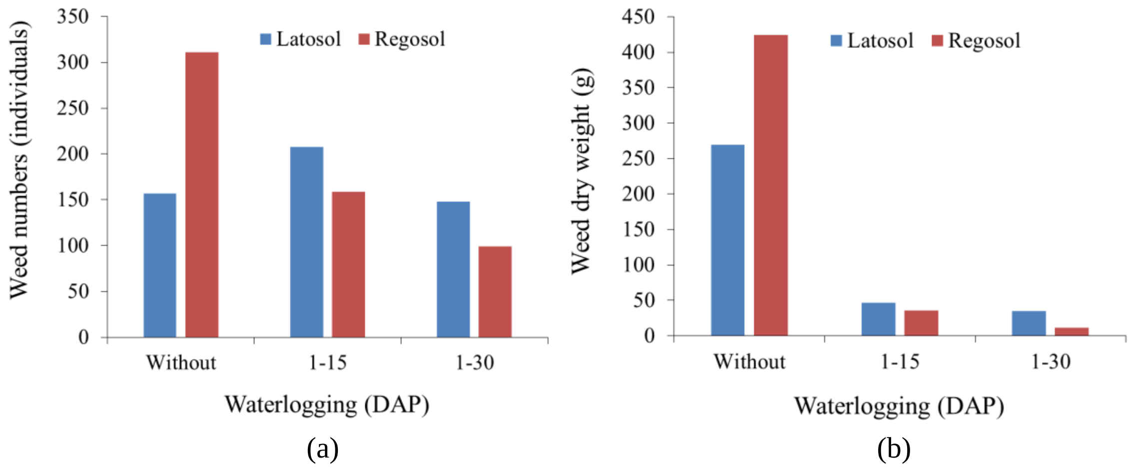


Figure 3*. Effect of waterlogging on weed numbers (a) and weed dry weight (b) in LS and RS*

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. *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

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 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.

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 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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REFERENCES

[32] Belford, B., McFarlane, D. J. (2018): Managing waterlogging and inundation in crops. Crops/Drainage and Flooding. Australia: University of Western Australia.
[33] Chen, H., Zeng, W., Jin, Y., Zha, Y., Mi, B., Zang, S. (2020): Development of a waterlogging analysis system for paddy fields in irrigation districts. – Journal of Hydrology 591: 125325.
[34] Chhun, S., Kumar, V., Martin, R. J., Srean, P., Hadi, B. A. R. (2019): Weed management practices of smallholder rice farmers in Northwest Cambodia. – Crop Protection: 1–17.
[35] De-Melo, B. B., Silva, B. M., Peixoto, D. S., Chiarini, T. P. A., De-Oliveira, G. C., Curi, N. (2021): Effect of compaction on the relationship between electrical resistivity and soil water content in Oxisol. – Soil and Tillage Research 208: 104876.
[36] Elkheir, H. A. (2016): Duration of soil water content between field capacity and wilting point and its effect on the growth of some aerobic rice cultivars (*Oryza sativa* L.). – International Journal of Agriculture System (IJAS) 4(1): 36–45.
[37] Fennimore, S. A. (2017): Weed seed biology, seedbanks, and management. In Weed Science School (pp. 14–49). University of California, Davis, (US).
[38] Ferronato, C., Marinari, S., Francioso, O., Bello, D., Trasar-Cepeda, C., Antisari, L. V. (2019): Effect of waterlogging on soil biochemical properties and organic matter quality in different salt marsh systems. – Geoderma 338: 302–312.
[39] Garcia, Q. S., Barreto, L. C., Bicalho, E. M. (2020): Environmental factors driving seed dormancy and germination in tropical ecosystems: a perspective from campo rupestre species. – Environmental and Experimental Botany 178: 104164.
[40] Gonzalez-Andujar, J. L. (2013): Population dynamics: weed control models. In Reference Module in Earth Systems and Environmental Sciences (pp. 1–7). Instituto de Agricultura Sostenible (CSIC), Cordoba, Spain.
[41] Gulshan, A. B., Dasti, A. A. (2012): Role of soil texture and depths on the emergence of buried weed seeds. – Journal of Agricultural and Biological Science 7(4): 223–228.
[42] He, Y., Gao, P., Qiang, S. (2019): An investigation of weed seed banks reveals similar potential weed community diversity among three different farmland types in Anhui Province, China. – Journal of Integrative Agriculture 18(4): 927–937.
[43] Ismail, A. M., Johnson, D. E., Ella, E. S., Vergara, G. V., Baltazar, A. M. (2012): Adaptation to flooding during emergence and seedling growth in rice and weeds, and implications for crop establishment. – AoB Plants 19: 1–18.
[44] Jia, B., Niu, Z., Wu, Y., Kuzyakov, Y., Li, X. G. (2020): Waterlogging increases organic carbon decomposition in grassland soils. – Soil Biology and Biochemistry 148: 1–9.
[45] Kaspary, T. E., Roma-burgos, N., Merotto, A. (2020): Snorkeling strategy: Tolerance to flooding in rice and potential application for weed management. – Genes 11: 1–13.
[46] Khairi, M., Nozulaidi, M., Afifah, A., Jahan, M. S. (2015): Effect of various water regimes on rice production in lowland irrigation. – Australian Journal of Crop Science 9(2): 153–159.
[47] Kumalasari, N. R., Bergmeier, E. (2014): Weed communities of Javanese paddy fields in response to altitude and agronomic practices. Dissertation. Diversity of rice weeds vegetation and its potential

as local forage resource in Java, Indonesia. Georg-August University School of Science (GAUSS). Göttingen, Germany.
[48] Liu, Z., Ge, X., Fu, Z., Liu, J. (2020): Alternanthera philoxeroides invasion affects the soil seed bank of weed community. – Environmental and Experimental Botany 180: 104196.
[49] Ma, M., Cen, W., Li, R., Wang, S., Luo, I. (2020): The molecular regulatory pathways and metabolic adaptation in the seed germination and early seedling growth of rice in response to low. – Plants 9: 1–14.
[50] Mesquita, M. L. R. (2017): Weed seed bank in rice fields. In Advances in International Rice Research (pp. 33–47). Maranhão State University, Bacabal, Brazil.
[51] Nandan, R., Singh, V., Kumar, V., Singh, S. S., Hazra, K. K., Nath, C. P., Malik, K., Poonia, S. P. (2020): Viable weed seed density and diversity in soil and crop productivity under conservation agriculture practices in rice-based cropping systems. – Crop Protection 136: 105210.
[52] Nishiuchi, S., Yamauchi, T., Takahashi, H., Kotula, L., Nakazono, M. (2012): Mechanisms for coping with submergence and waterlogging in rice. – Rice 5(1): 1–14.
[53] Peng, Y., Cheng, X., Liu, D., Liu, X., Ma, G., Li, S., Yang, Y., Zhang, Y., Bai, L. (2021): Quintrione: A new selective herbicide for weed control in rice (*Oryza sativa* L.). – Crop Protection 141: 105501.
[54] Pinem, R. R., & Ichwan, N. (2017): Study of various provison of water paddy methods (*Oryza sativa* L.) Ciherang variety rice in greenhouse. – J. Rekayasa Pangan dan Pertanian 5(2): 406–411 (in Indonesian).
[55] Singh, M., Bhullar, M. S., Chauhan, B. S. (2017): Relative time of weed and crop emergence is crucial for managing weed seed production: A study under an aerobic rice system. – Crop Protection 99: 33–38.
[56] Toral-juarez, M. A., Avila, R. T., Cardoso, A. A., Brito, F. A. L., Machado, K. L. G., Almeida, W. L., Souza, R. P. B., Martins, S. C. V., Damatta, F. M. (2021): Drought-tolerant coffee plants display increased tolerance to waterlogging and post-waterlogging reoxygenation. – Environmental and Experimental Botany 182: 104311.
[57] Yasin, M., Andreasen, C. (2016): Effect of reduced oxygen concentration on the germination behavior of vegetable seeds. – Horticulture Environment and Biotechnology 57(5): 453–461.
[58] Zarwazi, L. M., Chozin, M. A., Guntoro, D. (2016): Potential of weed problem on three paddy cultivation systems. – Jurnal Agronomi Indonesia 44(2): 147–153 (in Indonesian).
[59] Zheng, Z., Ping-lei, G. A. O., Wei-min, D. A. I., Xiao-ling, S., Feng, H. U., Sheng, Q. (2019): Effect of tillage and burial depth and density of seed on viability and seedling emergence of weedy rice. – Journal of Integrative Agriculture 18(8): 1914–1923.
[60] Zhou, W., Chen, F., Meng, Y., Chandrasekaran, U., Luo, X., Yang, W., Shu, K. (2020): Plant waterlogging/flooding stress responses: From seed germination to maturation. – Plant Physiology and Biochemistry 148: 228–236.

APPENDIXES

***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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To: Applied Ecology <aeerjournal@gmail.com>

LETTER OF PAPER REVISED

To

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Dear Editors,

Thanks for the correction and suggestions for manuscript ref. 13847. We've improved and added reviewers' suggestions in the text and references. We have improved the quality of English through the help of colleagues who work as proofreading. There was a slight improvement in the title to: "**EFFECT OF WATERLOGGING ON WEED SEED GERMINATION AND GROWTH IN LOWLAND RICE**". All amendments made are highlighted in yellow on the revision paper. Herewith I attach the required files:

1) An itemized response sheet.
2) A revised paper with the highlights addressed all issues and required corrections/changes.

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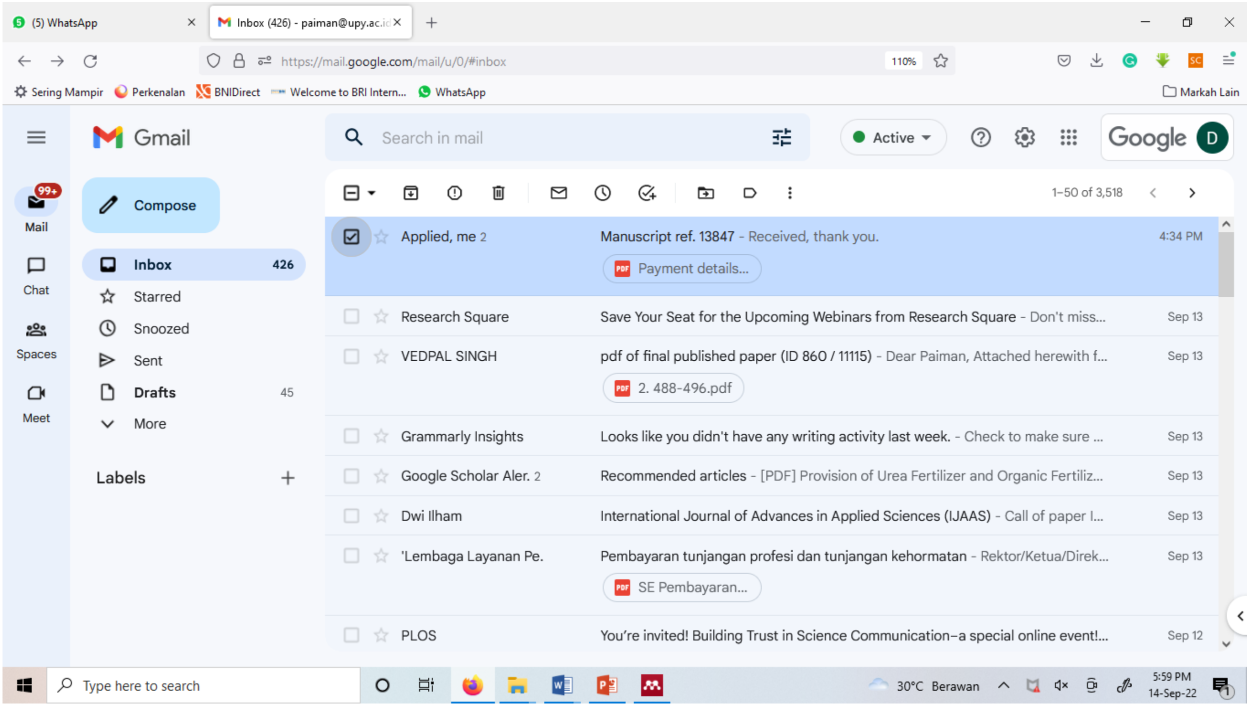

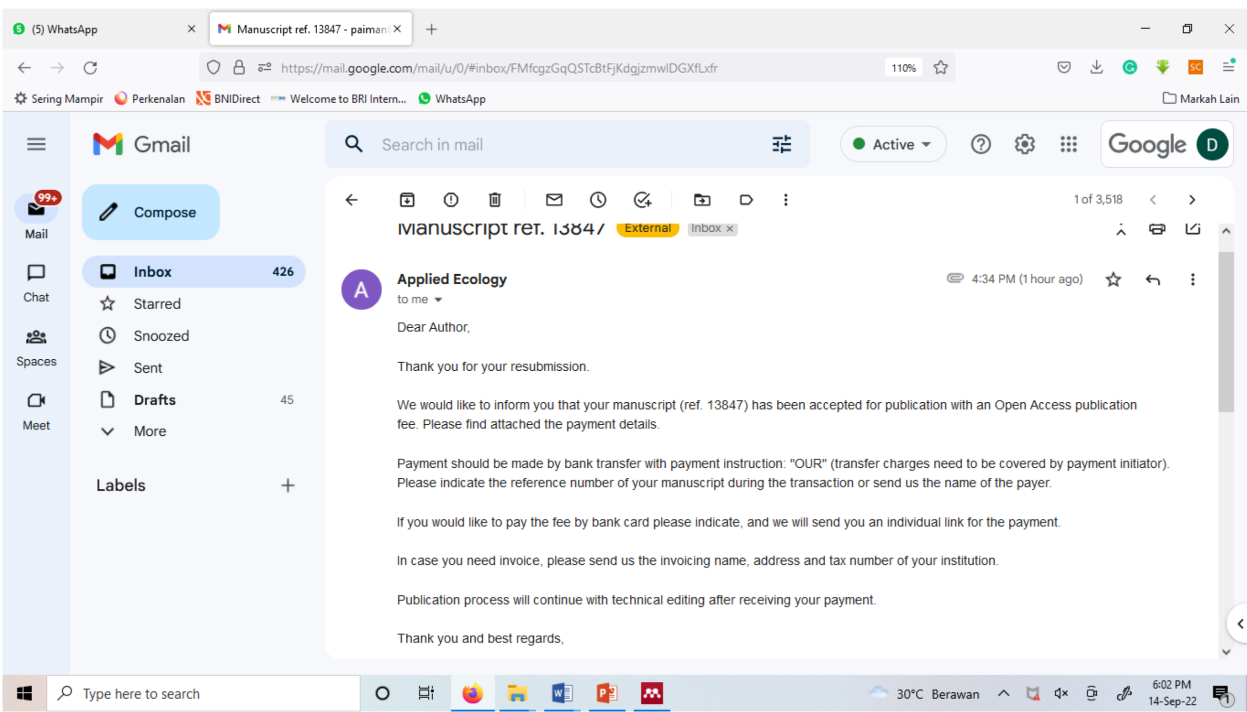

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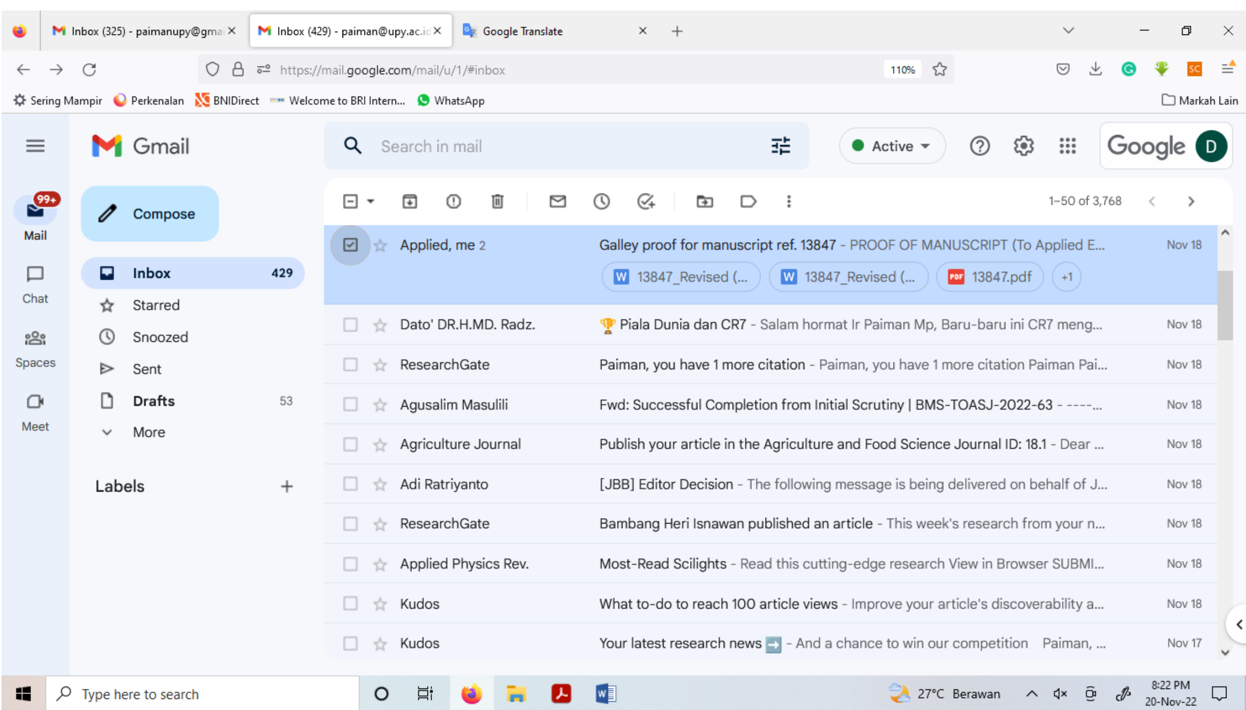

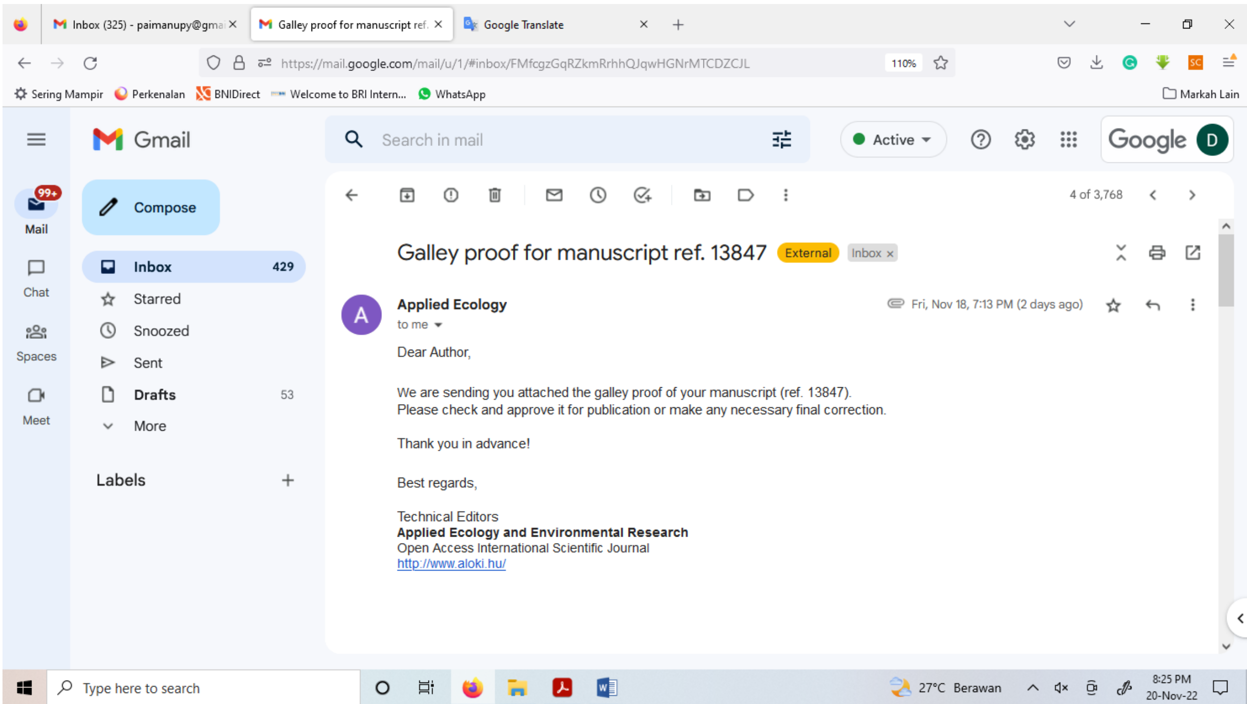

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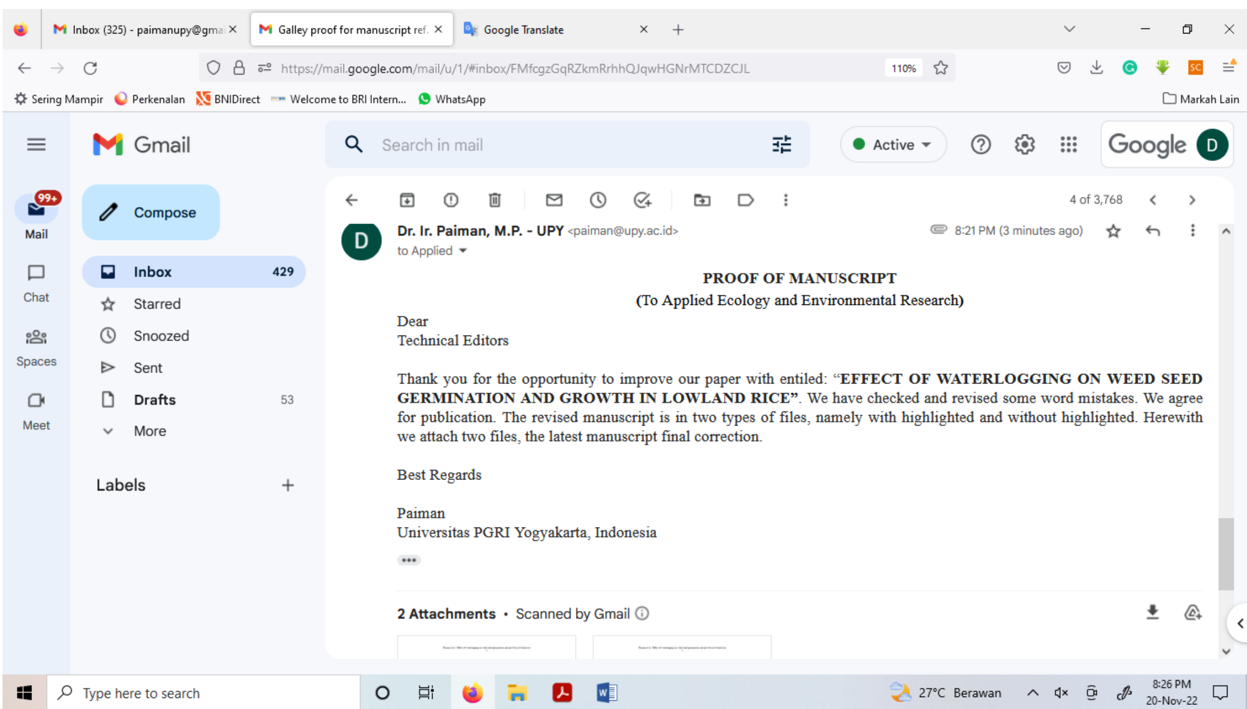

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EFFECT OF WATERLOGGING ON WEED SEED GERMINATION AND GROWTH IN LOWLAND RICE

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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*.

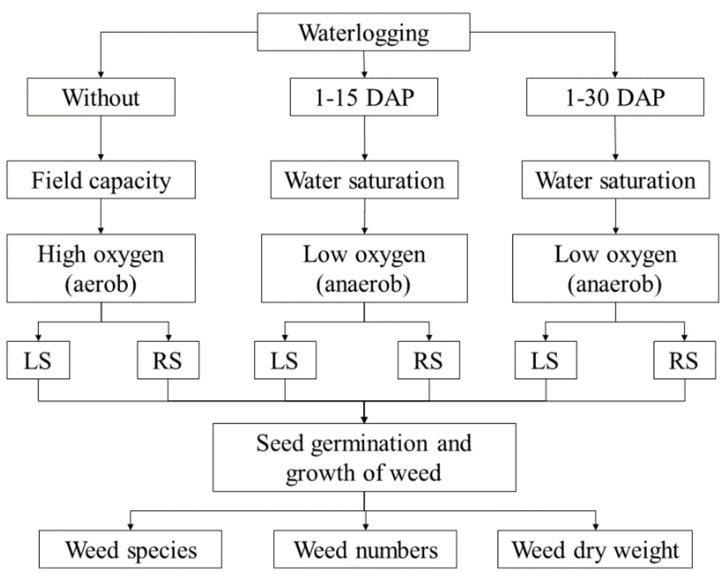

Figure 1. *A schematic diagram representing the overall experimental works*

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.

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*.

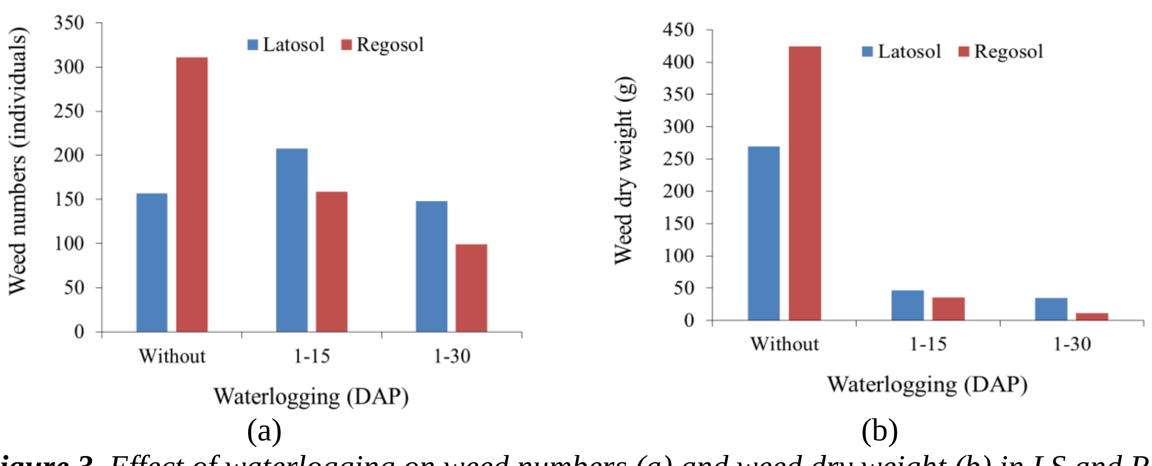

***Figure 3.** Effect of waterlogging on weed numbers (a) and weed dry weight (b) in LS and RS*

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 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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REFERENCES

[1] Belford, B., McFarlane, D. J. (2018): Managing waterlogging and inundation in crops. – Crops/Drainage and Flooding. Australia: University of Western Australia.

[2] Chen, H., Zeng, W., Jin, Y., Zha, Y., Mi, B., Zang, S. (2020): Development of a waterlogging analysis system for paddy fields in irrigation districts. – Journal of Hydrology 591: 125325.

[3] Chhun, S., Kumar, V., Martin, R. J., Srean, P., Hadi, B. A. R. (2019): Weed management practices of smallholder rice farmers in Northwest Cambodia. – Crop Protection 135: 104793.

[4] De-Melo, B. B., Silva, B. M., Peixoto, D. S., Chiarini, T. P. A., De-Oliveira, G. C., Curi, N. (2021): Effect of compaction on the relationship between electrical resistivity and soil water content in Oxisol. – Soil and Tillage Research 208: 104876.

[5] Elkheir, H. A. (2016): Duration of soil water content between field capacity and wilting point and its effect on the growth of some aerobic rice cultivars (*Oryza sativa* L.). – International Journal of Agriculture System (IJAS) 4(1): 36-45.

[6] Fennimore, S. A. (2017): Weed seed biology, seedbanks, and management. – In Weed Science School, University of California, Davis (US), pp. 14-49.

[7] Ferronato, C., Marinari, S., Francioso, O., Bello, D., Trasar-Cepeda, C., Antisari, L. V. (2019): Effect of waterlogging on soil biochemical properties and organic matter quality in different salt marsh systems. – Geoderma 338: 302-312.

[8] Garcia, Q. S., Barreto, L. C., Bicalho, E. M. (2020): Environmental factors driving seed dormancy and germination in tropical ecosystems: a perspective from campo rupestre species. – Environmental and Experimental Botany 178: 104164.

[9] Gonzalez-Andujar, J. L. (2013): Population dynamics: weed control models. – In Reference Module in Earth Systems and Environmental Sciences, Instituto de Agricultura Sostenible (CSIC), Cordoba, Spain, pp. 1-7.

[10] Gulshan, A. B., Dasti, A. A. (2012): Role of soil texture and depths on the emergence of buried weed seeds. – Journal of Agricultural and Biological Science 7(4): 223-228.

[11] He, Y., Gao, P., Qiang, S. (2019): An investigation of weed seed banks reveals similar potential weed community diversity among three different farmland types in Anhui Province, China. – Journal of Integrative Agriculture 18(4): 927-937.

[12] Ismail, A. M., Johnson, D. E., Ella, E. S., Vergara, G. V., Baltazar, A. M. (2012): Adaptation to flooding during emergence and seedling growth in rice and weeds, and implications for crop establishment. – AoB Plants 19: 1-18.

[13] Jia, B., Niu, Z., Wu, Y., Kuzyakov, Y., Li, X. G. (2020): Waterlogging increases organic carbon decomposition in grassland soils. – Soil Biology and Biochemistry 148: 1-9.

[14] Kaspary, T. E., Roma-burgos, N., Merotto, A. (2020): Snorkeling strategy: Tolerance to flooding in rice and potential application for weed management. – Genes 11: 1-13.

[15] Khairi, M., Nozulaidi, M., Afifah, A., Jahan, M. S. (2015): Effect of various water regimes on rice production in lowland irrigation. – Australian Journal of Crop Science 9(2): 153-159.

[16] Kumalasari, N. R., Bergmeier, E. (2014): Weed communities of Javanese paddy fields in response to altitude and agronomic practices. – Dissertation. Diversity of rice weeds vegetation and its potential as local forage resource in Java, Indonesia. Georg-August University School of Science (GAUSS). Göttingen, Germany.

[17] Liu, Z., Ge, X., Fu, Z., Liu, J. (2020): Alternanthera philoxeroides invasion affects the soil seed bank of weed community. – Environmental and Experimental Botany 180: 104196.

[18] Ma, M., Cen, W., Li, R., Wang, S., Luo, I. (2020): The molecular regulatory pathways and metabolic adaptation in the seed germination and early seedling growth of rice in response to low. – Plants 9: 1-14.

[19] Mesquita, M. L. R. (2017): Weed seed bank in rice fields. – In Advances in International Rice Research, Maranhão State University, Bacabal, Brazil, pp. 33-47.

[20] Nandan, R., Singh, V., Kumar, V., Singh, S. S., Hazra, K. K., Nath, C. P., Malik, K., Poonia, S. P. (2020): Viable weed seed density and diversity in soil and crop productivity under conservation agriculture practices in rice-based cropping systems. – Crop Protection 136: 105210.

[21] Nishiuchi, S., Yamauchi, T., Takahashi, H., Kotula, L., Nakazono, M. (2012): Mechanisms for coping with submergence and waterlogging in rice. – Rice 5(1): 1-14.
[22] Peng, Y., Cheng, X., Liu, D., Liu, X., Ma, G., Li, S., Yang, Y., Zhang, Y., Bai, L. (2021): Quintrione: A new selective herbicide for weed control in rice (*Oryza sativa* L.). – Crop Protection 141: 105501.
[23] Pinem, R. R., Ichwan, N. (2017): Study of various provison of water paddy methods (*Oryza sativa* L.) Ciherang variety rice in greenhouse. – J. Rekayasa Pangan dan Pertanian 5(2): 406-411. (in Indonesian).
[24] Singh, M., Bhullar, M. S., Chauhan, B. S. (2017): Relative time of weed and crop emergence is crucial for managing weed seed production: A study under an aerobic rice system. – Crop Protection 99: 33-38.
[25] Toral-juarez, M. A., Avila, R. T., Cardoso, A. A., Brito, F. A. L., Machado, K. L. G., Almeida, W. L., Souza, R. P. B., Martins, S. C. V., Damatta, F. M. (2021): Drought-tolerant coffee plants display increased tolerance to waterlogging and post-waterlogging reoxygenation. – Environmental and Experimental Botany 182: 104311.
[26] Yasin, M., Andreasen, C. (2016): Effect of reduced oxygen concentration on the germination behavior of vegetable seeds. – Horticulture Environment and Biotechnology 57(5): 453-461.
[27] Zarwazi, L. M., Chozin, M. A., Guntoro, D. (2016): Potential of weed problem on three paddy cultivation systems. – Jurnal Agronomi Indonesia 44(2): 147-153. (in Indonesian).
[28] Zhang, Z., Gao, P. L., Dai, W. M., Song, X. L., Hu, F., Qiang, S. (2019): Effect of tillage and burial depth and density of seed on viability and seedling emergence of weedy rice. – Journal of Integrative Agriculture 18(8): 1914-1923.
[29] Zhou, W., Chen, F., Meng, Y., Chandrasekaran, U., Luo, X., Yang, W., Shu, K. (2020): Plant waterlogging/flooding stress responses: From seed germination to maturation. – Plant Physiology and Biochemistry 148: 228-236.

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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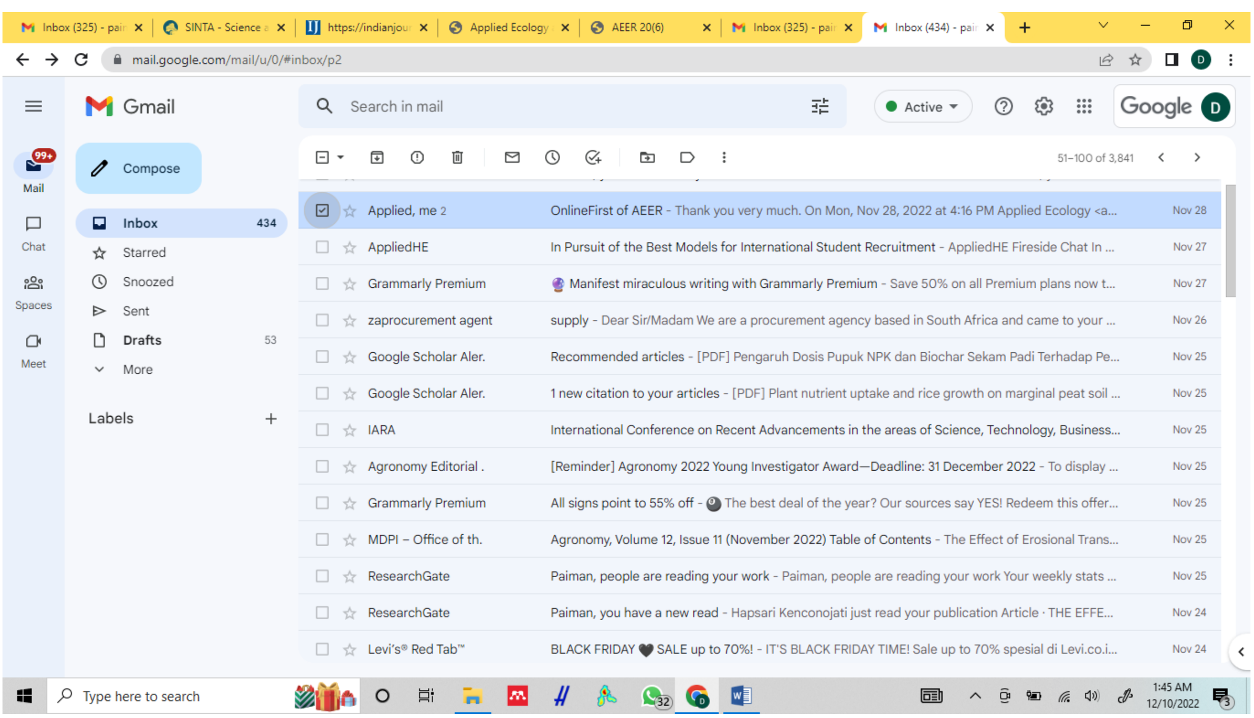

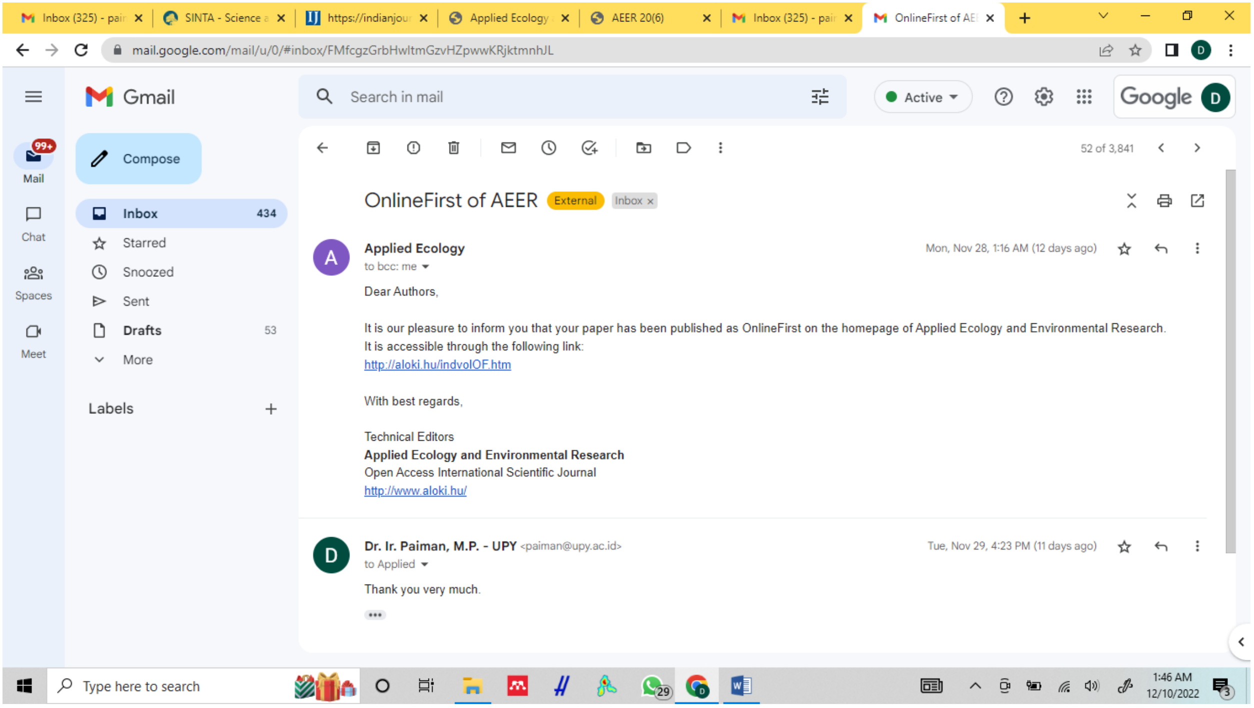

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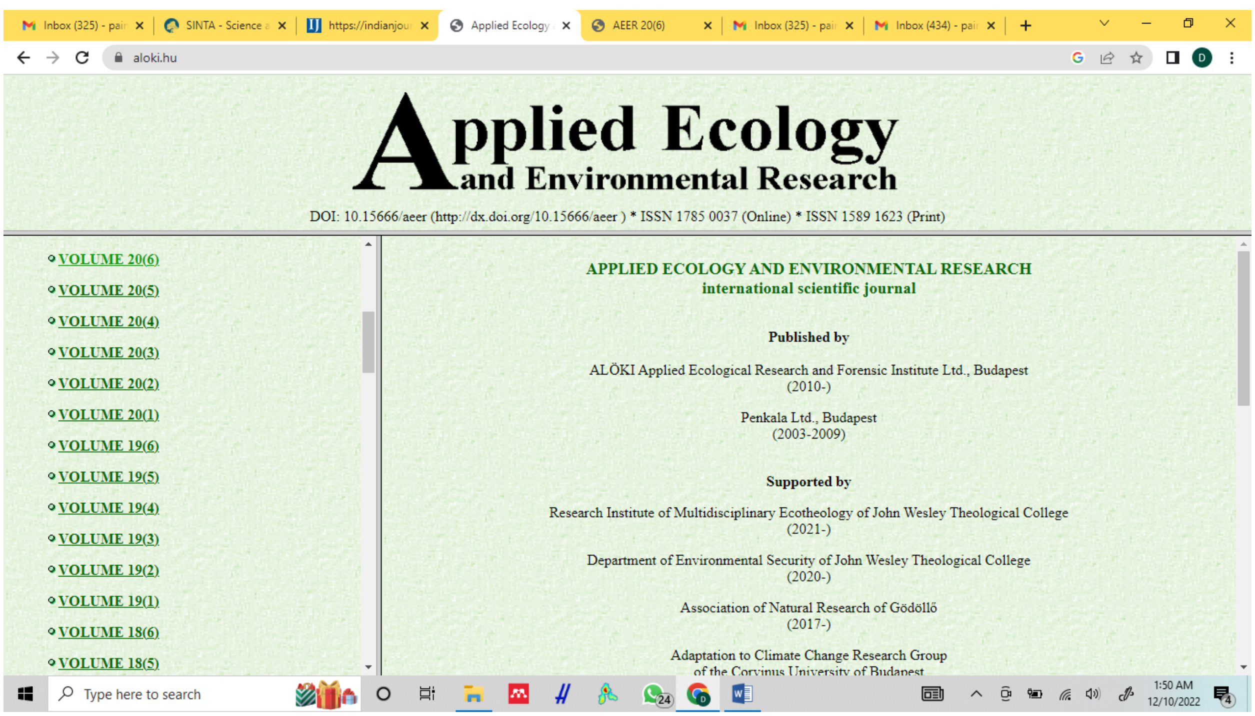

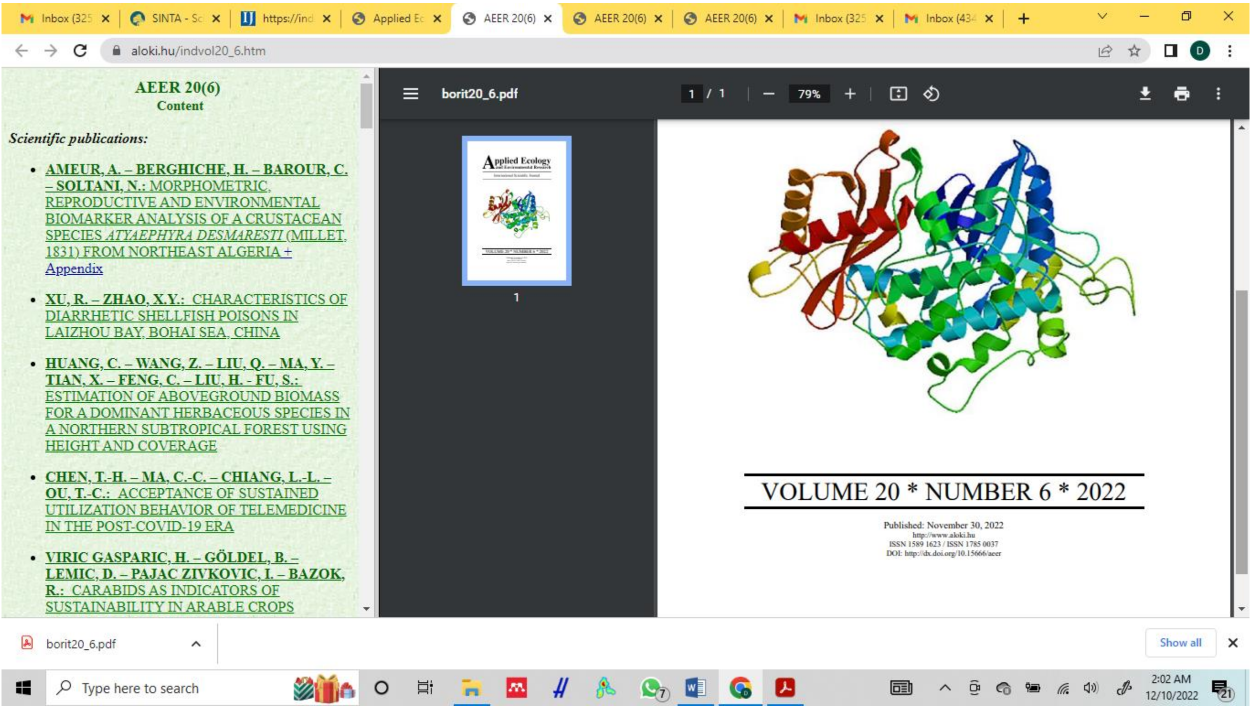

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