Bulgarian Journal of Agricultural Science, 25 (No 2) 2019, 326–336

Floating seedbed for preparing rice seedlings under unpredictable flooding occurrence at tropical riparian wetland

Erna Siaga[1], Benyamin Lakitan[1,4*], Hasbi Hasbi[2,4], Siti M. Bernas[3], Laily I. Widuri[1], Kartika Kartika[1]

[1]*Department of Agronomy, Universitas Sriwijaya, Inderalaya 30662, Indonesia*
[2]*Department of Agricultural Engineering, Universitas Sriwijaya, Inderalaya 30662, Indonesia*
[3]*Department of Soil Sciences, Universitas Sriwijaya, Inderalaya 30662, Indonesia*
[4]*Research Centre for Sub-optimal Lands (PUR-PLSO), Universitas Sriwijaya, Palembang 30139, Indonesia*
[*]*Corresponding author:* blakitan60@unsri.ac.id

Abstract

Siaga, E., Lakitan, B., Hasbi, H., Bernas, S. M., Widuri, L. I., & Kartika, K. (2019). Floating seedbed for preparing rice seedlings under unpredictable flooding occurrence at tropical riparian wetland. *Bulgarian Journal of Agricultural Science*, *25*(2), 326–336

Preparation of rice seedlings on floating seedbed makes it possible for earlier rice growing season and more flexible time for transplanting under unpredictable flooding condition. The objective of this research was to search for appropriate procedure for producing high quality rice seedlings using floating seedbed associated with three crucial factors, i.e. level of contact between substrate and water surface, seedling population density, and seedling age at time of transplanting. Seedbeds were constructed using 120 air-tight plastic bottles as floater. Surface dimension of the seedbed was 2 x 1 m with load capacity of 40 kg m^{-2}; therefore, each seedbed can be loaded with 80 kg of growing substrate. Three experiments were sequentially carried out for optimizing knowledge on each of the three crucial factors. Seedling height, fresh weight, and SPAD value were used as primary indicators for seedling quality. Results of our experiments indicated that seedling height and weights were consistently lower in partially submerged substrate than those in no direct contact or with film-thin contact setups. Seedling population density between seed application rates of 2 and 3 kg m^{-2} were not significantly different, but these treatments were significantly higher than that of application rate at 1 kg m^{-2}. SPAD value was higher at denser seed application rates. Optimum seedling age was 21 DAP but acceptable range for transplanting was at ages between 14 and 28 DAP. Thus, open flexibility for time of transplanting during floodwater receding process.

Keywords: floating culture; rice transplanting; seedling age; seedling quality; water regime

Introduction

The major constraints in rice cultivation at riparian wetland were unpredictable flooding occurrence during rainy season and short rice growing season due to probable severe drought during dry season. Preparing rice seedlings using floating seedbed has been practiced by local farmers at some riparian wetlands in Indonesia as a strategy for managing these constraints (Lakitan et al., 2018a, 2018b, 2019a).

In practice, local farmers commenced the floating rice seedlings preparation after the floodwater was on receding process. Main target is to transplant rice seedlings at earliest possible at time that height of rice seedlings surpasses the depth of remained floodwater. It is fine if the floodwater recedes faster than predicted, but it becomes problem if floodwater does not recede to the expected depth for much longer period of time. Longer delay on floating seedbed subsequently affects seedling age at time of transplanting to paddy field. Older seedlings at transplanting were associated with less productive tillers, thus, reduced yield. Lampayan et al. (2015a) reported that rice seedling transplanted at age of 30 days consistently results in lower yield.

Local farmers at Pemulutan wetlands use indigenous swamp sedges *Scleria poaeformis* for constructing rafts for floating seedbed (Ramadhani et al., 2018; Lakitan et al., 2019b). However, there is declining trend on availability of this biomaterial due to conversion of natural wetland vegetation to cultivated rice field and for other social-economic purposes. Over-exploitation of wetland resources and inappropriate agricultural practices are further accelerating wetland conversion (Nguyen et al., 2017).

Declining availability of local biomaterial leads to search for alternative available materials. Used plastic bottles have been proven to be effective as substitute of biomaterial in constructing rafts for floating culture of chili pepper (Siaga et al., 2018) and affordable by smallholder farmers. Used plastic bottles are commonly regarded as solid waste which pollutes open waters (Li et al., 2016), such as seas, lakes, swamps, and rivers. Therefore, re-use of these plastic bottles is an environmentally-friendly practice. In this study, the plastic-bottle was used for constructing floating seedbed for rice seedling preparation prior to transplanting.

Seed germination and seedling establishment was affected by soil moisture condition (Matsushima and Sakagami, 2013). Rice seeds can germinate in moist to water-saturated substrate. In floating culture system, level of contact between substrate and water surface can be engineered by fixing ratio between substrate weight and load capacity of the floating seedbed. This principle opens possibility to figure out optimum substrate water content for seedling growth.

Seedling population density can affect seedling growth due to possible competition among seedlings in capturing water, nutrients, and light (Anten and Bastiaans, 2016). Dense population may result in weak etiolated seedlings. Good quality rice seedlings characterized by long sturdy and dark-green leaves. Seedling gains advantage from longer leaf since the seedling can avoid full submersion after being transplanted to rice field. Dark green color of the leaves reflect healthy seedling. Age of seedling at time of transplanting also had significant effect on growth and yield in rice (Sarwar et al., 2011; Lampayan et al., 2015b; Liu et al., 2017; Sowmyalatha et al., 2017).

Objectives of this study were to search for appropriate protocol in using floating seedbed to produce good quality rice seedlings based on level of contact between substrate and water surface, seedling population density, and seedling age at time of transplanting.

Materials and Methods

Research preparation and theoretical basis

Three floating seedbeds were constructed for this research. Floating seedbed consists of floater and growing substrate. Rafts made of used plastic bottles were used as floater. Structural design, materials used, and testing procedures for these rafts were similar to our previous study (Siaga et al., 2018). However, modification was made such that they were more suitable for growing rice seedlings. Instead of using 1.5-liter bottles, smaller bottles of 600 mL were used. It requires 120 small bottles for constructing a 2 x 1 m raft. The bottles were emptied, tightly sealed, and arranged in four rows of 30 bottles.

Each raft has load capacity of 80 kg, equivalent to 40 kg m^{-2}. Therefore, for setting up bottom surface of the substrate in direct contact with water surface requires 40 kg m^{-2} of substrate. Substrate used was mixed growing media of soil:manure:rice husk (1:1:1, v/v/v). Direct contact with water surface keeps substrate in moist condition, suitable for rice seedling growth. Since rice seedling only require about 3 cm thick substrate layer in floating seedbed procedure; meanwhile, to set up 3 cm thick substrate layer only require about half of the load capacity; therefore, load capacity of the raft was reduced by half in order to establish direct contact of substrate and water surface.

Technically, reducing load capacity of the raft can be done by making holes on some of the plastic bottles such that they are no longer functioning as floater. If substrate, as load, is kept constant at rate of 20.0 kg m^{-2}, while load capacity of rafts are varied, then this leads to variable sinking depth of the rafts. Load capacity was varied by number of functioning bottle at the floating raft, i.e. if 40, 60, and 80 bottles were perforated, then load capacity declined to 26.7 kg m^{-2}, 20.0 kg m^{-2}, and 13.3 kg m^{-2}, respectively. Furthermore, this variability in load capacity of the rafts also leads to varying position of water level with reference to bottom surface of the substrate. If load capacity of the raft is higher than actual load (weight of substrate used), water level will be below bottom surface of the substrate, therefore, there is no direct contact between substrate and water. If loading capacity is equal to actual load, then direct contact between substrate and water is established. If loading capacity is lower than actual load, then bottom layer of substrate sinks into water at certain depth. In this case, variability in water surface position were +1 cm, 0 cm, and –1 cm with reference to bottom surface of substrate.

Plant materials

Four rice varieties used were Ciherang, IR64, Inpari 30, and Inpara 8. Two varieties widely adopted by smallholder farmers in Indonesia are Ciherang and IR64. The other two varieties were newly released and specifically breed for irrigated paddy fields (Inpari 30) and for riparian wetlands (Inpara 8). Prior to sowing, rice seeds were soaked in water and then evenly spread on mixed growing media. After the seeds had been spread, the floating seedbed was covered with white air-penetrable plastic sheet for protecting the seeds from bird's attacks.

The experiments

Experiment 1. The experiment was carried out in a strip-plot design with two treatments. Each treatment consisted of 3 levels. The first treatment was degree of contact between growing substrate and water surface: (1) No direct contact between substrate and water surface (C1), done by lowering raft load capacity to 26.7 kg m^{-2}, there was gap between substrate and water surface of about 1 cm; (2) Direct contact was established between substrate and water surface (C2), done by lowering raft load capacity to 20.0 kg m^{-2}; and (3) Substrate partially submerged in water (C3), about 1 cm bottom layer of substrate was submerged in water, done by lowering raft load capacity to 13.3 kg m^{-2}. The second treatment was seedling density. Three levels of seedling densities were created based on amount of seeds used at time of sowing per surface area of substrate. Rates of the seeds applied were 1 kg m^{-2} (D1), 2 kg m^{-2} (D2), and 3 kg m^{-2} (D3). Rice variety used was Ciherang. Five rings, each covers an area of 100 cm^2, were placed on each treatment combination plot. These rings represented the replications of the 9 treatment combinations. Growth of rice seedlings was observed up to 21 days after planting (DAP).

Experiment 2. Two factors (treatments) evaluated on this experiment was the degree of contact between growing substrate and water surface as in Experiment 1; however, the second factor was rice varieties, consisted of IR64, Inpari 30, and Inpara 8. Seed sowing density was fixed at 2 kg m^{-2}. Other procedures in this experiment were similar to those of Experiment 1.

Experiment 3. It is similar to Experiment 2, except only two rice varieties were used, i.e. Inpari 30 and Inpara 8. Observation on growth of rice seedling was extended to 28 DAP. Additional measured parameter was weekly increase in dry weight of 100 seedlings.

All preparation, including load capacity and stability test of floating rafts, and the serial experiments were conducted in an off-campus research facility at Jakabaring (104°46′44″ E; 3°01′35″ S), Palembang, Indonesia from June 2017 to January 2018.

Measured parameters and growth analysis

Primary parameters measured were height of seedling, fresh and dry weights of shoot, root, and whole seedling, number of leaves, and SPAD value. In Experiment 1 and 2, measurements were done at 7, 11, 15, 19 and 21 DAP. Measurements at 21 DAP in Experiment 1 and 2 were based on seedlings within five sampling rings on each treatment. Area covered by each sampling ring is 100 cm^2. In Experiment 3, measurements were based on 100 randomly selected seedlings at 7, 14, 21, and 28 DAP. Some growth analysis parameters calculated based on collected primary data, including relative growth rate (RGR), shoot weight ratio (SWR), root weight ratio (RWR) and shoot to root ratio (SRR).

Statistical analysis

The analysis of variance (ANOVA) was done based on strip-plot design using the Statistical Analysis System (SAS) University Edition, for testing significant effect of each treatment on each measured parameter, both primary and growth analysis parameters. For significant treatments on any measured parameters, differences among means of treatment level were further evaluated using the Least Significant Differences (LSD) test at $P \leq 0.05$.

Results

Height of rice seedling as well as fresh and dry weights per substrate area at 21 days after planting (DAP) consistently decreased if lower half of the substrate was submerged in water (C3). Meanwhile, the tallest and heaviest dry weight of seedlings were achieved if substrate was not in direct contact with water surface, i.e. positioned at about 1 cm above water surface (C1). Fresh weight of 100 seedlings at 28 DAP (Experiment 3) was the heaviest if bottom surface of substrate was in direct contact with water surface but with minimal substrate submersion (C2). SPAD value was inconsistently affected by degree of contact between substrate and water surface in the three sequential experiments (Table 1).

Height, fresh weight, and SPAD value can be used as the primary indicators for seedling quality. Root length and number of leaves may not be recommendable as indicators for seedling quality, since technically it is very difficult to separate roots among seedlings at 21 DAP or older in a high density population without damaging the roots. Number of leaves in rice seedling at 21 DAP did not vary that much. They were either 3 or 4 leaves.

There were direct effect of seedling density on seedling fresh and dry weight per unit substrate area. Furthermore, seedling density exhibited significant effect on seedling height, root length, and number of leaves (Table 1). This result indicated that in limited available space, rice seedling preparation can be done in dense population up to 3 kg m^{-2} substrate area. The highest SPAD value, however, was ob-

Table 1. Morphological characteristics of rice seedling as affected by substrate-water setup, seedling population density, and rice variety

Treatments	Seedling height (cm)	Root length (cm)	Number of leaves	SPAD value	Fresh weight (g cm^{-2})	Dry weight (g cm^{-2})
Experiment 1 – at 21 DAP						
	Contact between substrate and water surface					
C1	22.196 a	6.373 a	3.033 b	22.278 b	0.817 a	0.144 a
C2	21.245 b	6.890 a	3.333 a	22.756 b	0.715 a	0.147 a
C3	19.524 c	6.890 a	3.500 a	24.945 a	0.527 b	0.112 b
	Seedling population density					
D1	20.920 a	7.127 a	3.400 a	22.200 b	0.553 c	0.119 b
D2	20.907 a	6.720 a	3.233 a	24.311 a	0.687 b	0.135 ab
D3	21.142 a	6.307 a	3.233 a	23.466 ab	0.818 a	0.151 a
Experiment 2 – at 21 DAP						
	Contact between substrate and water surface					
C1	22.840 a	6.277 ab	3.367 a	22.767 a	0.694 a	0.101 a
C2	22.600 a	5.883 b	3.333 a	20.667 a	0.568 b	0.093 a
C3	22.230 b	6.973 a	3.533 a	24.700 a	0.557 b	0.082 b
	Rice varieties					
IR64	22.933 a	6.293 a	3.267 b	–	0.606 b	0.088 a
Inpari 30	22.457 b	6.526 a	3.600 a	–	0.688 a	0.094 a
Inpara 8	22.280 b	6.313 a	3.367 ab	–	0.525 c	0.094 a
Experiment 3 – at 28 DAP					g/100 seedlings	
	Seedling age					
W1	5.536 d	6.326 b	–	–	8.981 d	2.702 c
W2	14.944 c	7.462 a	–	–	16.321 c	3.430 b
W3	21.744 b	6.902 ab	–	21.189 b	19.344 b	3.536 b
W4	28.828 a	6.531 b	–	28.628 a	25.184 a	3.957 a
	Contact between substrate and water surface					
C1	17.294 a	6.854 a	–	24.625 ab	17.001 b	3.224 b
C2	16.894 a	6.975 a	–	25.775 a	18.351 a	3.368 ab
C3	16.102 b	6.586 a	–	24.325 b	17.015 b	3.627 a
	Rice varieties					
Inpara 8	17.442 a	6.658 a	–	23.911 b	15.708 b	2.885 b
Inpari 30	16.085 b	6.952 a	–	25.906 a	19.207 a	3.928 a

Note: Means followed by the same letters within columns of each treatment and measured trait are not significantly different based on the LSD at $P \leq 0.05$. Dash means the data were not or unable to be collected.

served at moderate seedling density of 2 kg m^{-2} substrate area (D2).

It is very logical if older rice seedlings are taller and heavier as shown in Table 1. However, it was important to note in this study that the older seedling (28 DAP) exhibited shorter ‘recoverable’ root than younger seedlings (at 14 and 21 DAP). The shorter recoverable root was associated with more severe damage during separation among seedlings. Seedling separation was necessary prior to transplanting of the seedlings to paddy field.

SPAD value was not affected by seedling population density. There was no difference in SPAD value between Inpara-8 and Inpari-30 varieties at 3 WAP, but significant difference was detected between the two varieties at 4 WAP (Fig. 1). Inpari-30 variety was not only exhibited higher SPAD value but also higher fresh weight per unit substrate area and per 100 seedlings (Table 1). As the seedling grew up to 28 days, Inpari-30 variety exhibited faster growth than Inpara-8 variety as indicated by widening difference in dry weight of 100 seedlings at 21 and 28 DAP (Fig. 2).

SRR and SWR were consistently higher but RWR was consistently lower if there was no direct contact between substrate and water surface (C1), based on both fresh weight and dry weight. Seedling population density did not signifi-

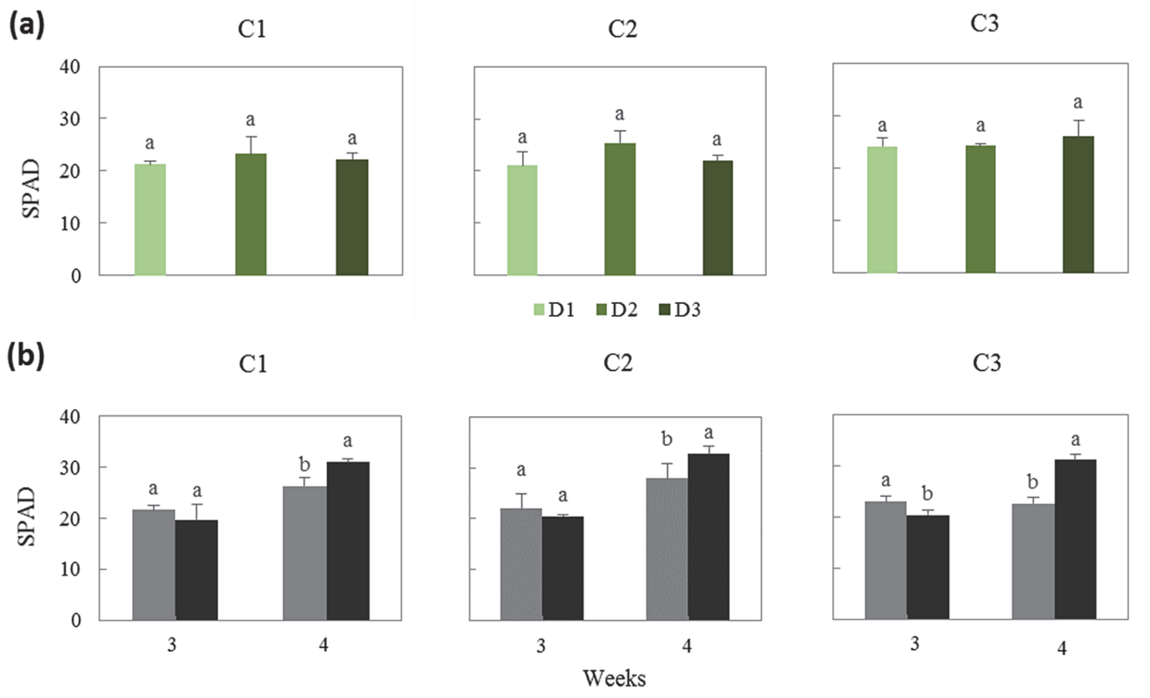

Fig. 1. SPAD value at 21 DAP was not affected by seedling population density (*a*) but responded differently by Inpara-8 and Inpari-30 varieties at 3 and 4 weeks (*b*). Statistical difference was based on the LSD at $P \leq 0.05$.

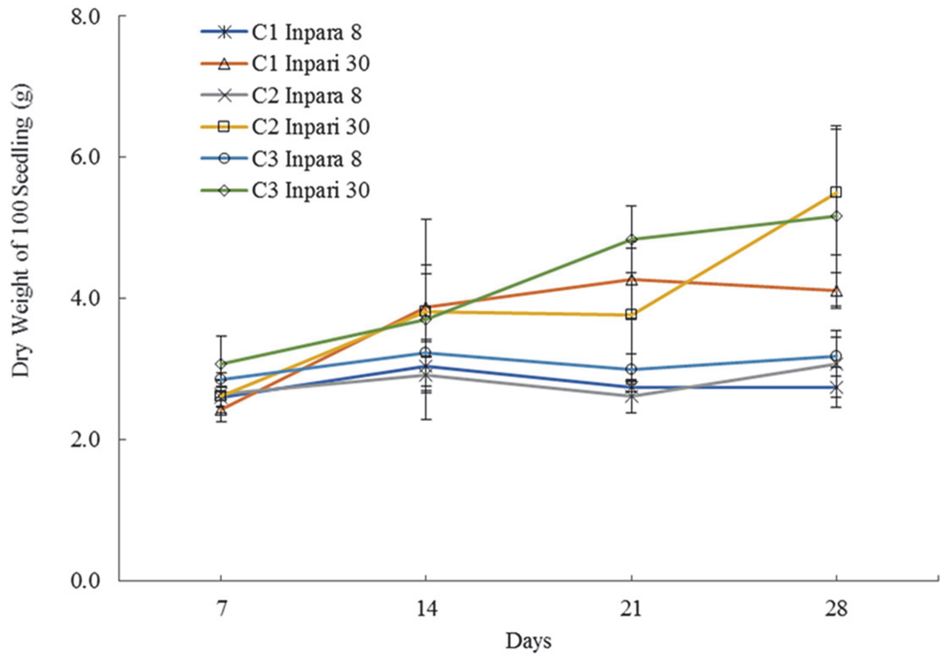

Fig. 2. Weekly increase in dry weight of 100 rice seedlings of Inpara-8 and Inpari-30 varieties in different substrate-water setups

Table 2. Shoot/root ratio (SRR), root weight ratio (RWR), and shoot weight ratio (SWR) based on fresh and dry weights as affected by substrate-water setup, seedling density, and rice variety in rice seedling

Treatments	Fresh weight			Dry weight		
	SRR	RWR	SWR	SRR	RWR	SWR
	-- ($g\ g^{-1}$) --					
Experiment 1 – at 21 DAP						
	Contact between substrate and water surface					
C1	1.514 a[z]	0.408 b	0.592 a	1.475 a	0.409 b	0.591 a
C2	1.270 b	0.450 a	0.551 b	1.323 a	0.435 b	0.565 a
C3	1.177 b	0.464 a	0.536 b	1.052 b	0.489 a	0.511 b
	Seedling density					
D1	1.223 a	0.458 a	0.542 a	1.252 a	0.451 a	0.549 a
D2	1.368 a	0.431 a	0.568 a	1.307 a	0.443 a	0.557 a
D3	1.370 a	0.432 a	0.568 a	1.291 a	0.441 a	0.559 a
Experiment 2 – at 21 DAP						
	Contact between substrate and water surface					
C1	1.472 a	0.413 b	0.587 a	1.373 a	0.424 b	0.587 a
C2	1.201 b	0.459 a	0.541 b	1.242 b	0.449 a	0.541 b
C3	1.116 b	0.475 a	0.525 b	1.154 b	0.466 a	0.525 b
	Rice varieties					
IR64	1.202 b	0.457 ab	0.543 ab	1.277 ab	0.443 ab	0.543 ab
Inpari-30	1.394 a	0.426 b	0.574 a	1.310 a	0.435 b	0.574 a
Inpara-8	1.193 b	0.465 a	0.535 b	1.182 b	0.460 a	0.535 b
Experiment 3 – at 28 DAP						
	Seedling age					
W1	0.318 d[z]	0.759 a	0.241 d	0.183 d	0.848 a	0.152 d
W2	0.721 c	0.582 b	0.418 c	0.747 c	0.575 b	0.425 c
W3	1.005 b	0.501 c	0.499 b	1.084 b	0.483 c	0.517 b
W4	1.569 a	0.395 d	0.605 a	1.678 a	0.383 d	0.617 a
	Contact between substrate and water surface					
C1	0.994 a	0.539 b	0.461 a	0.967 a	0.559 b	0.441 a
C2	0.913 b	0.553 b	0.447 a	0.987 a	0.550 b	0.450 a
C3	0.803 c	0.586 a	0.414 b	0.814 b	0.608 a	0.392 b
	Rice varieties					
Inpara-8	0.933 a	0.555 a	0.445 a	0.894 a	0.580 a	0.420 a
Inpari-30	0.873 b	0.563 a	0.437 a	0.951 a	0.564 a	0.436 a

Note: Means followed by the same letters within columns of each treatment and measured trait are not significantly different based on the LSD at $P \leq 0.05$.

cantly affected SRR, RWR, and SWR. As the seedling grew up to 28 DAP (W4), SRR and SWR increased accordingly but RWR significantly decreased. SRR of Inpara-8 at 28 DAP was significantly higher than that of Inpari-30 variety (Table 2).

Ratio of total dry weight to seedling height can be used as indicator of etiolation in rice seedling. Etiolation is commonly indicated by long, narrow and weak leaf blade. Etiolated seedling has lower value of the weight to height ratio. In this study, the ratio was higher at early growing stage but then the ratio was relatively constant starting at 15 DAP (Fig. 3).

Visually, all seedlings were not etiolated. There were no significant differences among seedlings treated with different levels of contact between substrate and water surface, population density, or between different varieties at 15 DAP or later (Fig. 3). It should be noted that rice seedlings are commonly transplanted by rice farmers at age of 2 to 4 weeks after sowing, never at age younger than 2 weeks after sowing.

Seedling density at seed application rates of 2 and 3 kg m^{-2} was not significantly different; therefore, using application rate of 3 kg m^{-2} did not give any advantage. Seed use efficiency was significantly higher at application rate

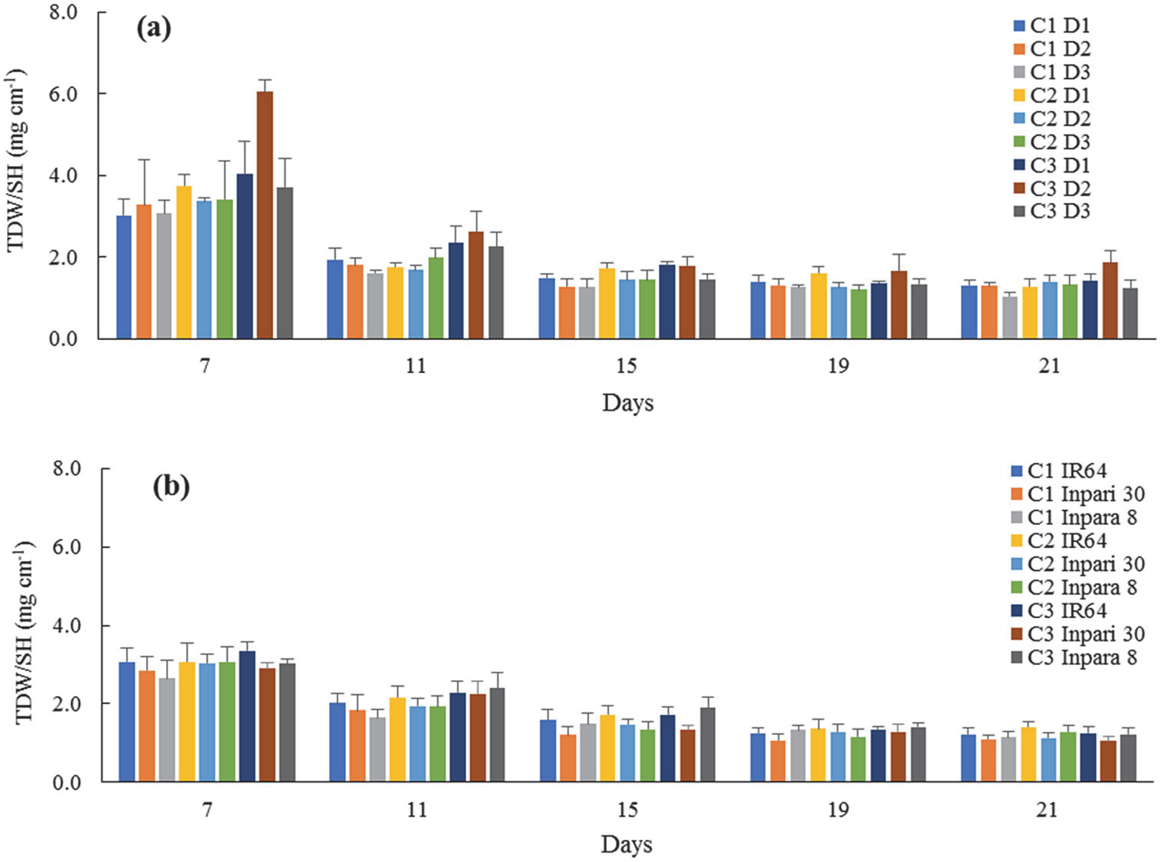

Fig. 3. Ratio of dry weight to height, measured on selected days up to 21 DAP as affected by population densities (*a*) and varieties (*b*) in rice seedlings grown at different settings of contact between substrate and water surface

of 1 kg m^{-2}, compared to 2 and 3 kg m^{-2} (Fig. 4). Based on this result, application rate of 1 kg m^{-2} is recommended for maximizing seed use efficiency but rate of 2 kg m^{-2} is recommended for maximizing number of seedlings produced if available space is limited, as commonly is the case at riparian wetland during flooding period. Rice seedling preparation was mostly done before floodwater was completely subsided such that transplanting of the seedling to paddy field can be done earlier at riparian wetland.

Discussion

At riparian wetlands in Indonesia, transplanting of rice seedlings to paddy field is conducted during transition from rainy to dry season, after floodwater has subsided to a depth of 15 cm or less. Early transplanting of rice seedlings is preferred by local farmers in order to avoid drought stress during generative growth phase (Lakitan et al., 2018a). For increasing chance of successful transplanting under this circumstance, local farmers select rice seedlings with some criteria, including: (1) fast growing and taller, therefore, less risk due to full submersion; (2) sturdier, such that the seedling is easy to handle and less broken seedling during transplanting; and (3) dark green leaf, as indicator of healthy seedling. Sturdiness of seedling can be predetermined by ratio of fresh weight to height. Leaf greenness can be measured based on SPAD value. Intensity in green color of leaf strongly correlated with chlorophyll and nitrogen content (Lakitan et al., 2018b).

A series of experiments has been conducted in searching of technically-simple and financially-affordable techniques for smallholder farmers to produce good quality rice seedlings using floating seedbed. The floating seedbed was modified from raft used in our chili floating culture (Siaga et al., 2018). Different variables had been tested, including: (1) level of contact between substrate and water surface in floating seedbed; (b) seedling population density, and (3) age of seedling at time of transplanting.

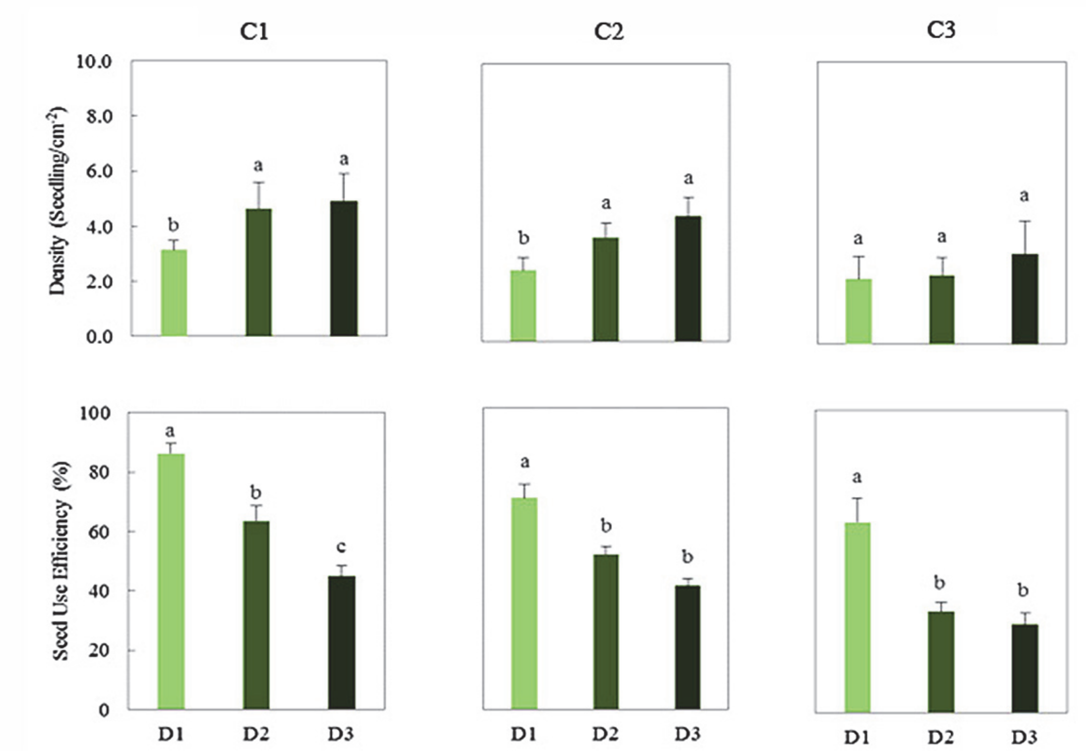

Fig. 4. Comparison of seedling density and seed use efficiency within each substrate-water setup. Statistical difference was based on the LSD at P < 0.05

Contact setup between substrate and water surface

In floating seedbed system, different level of contact between substrate and water surface was varied from close (1 cm) but no direct contact (C1), direct contact but with minimal (less than 2 mm) substrate submersion (C2), and direct contact with 1 cm substrate submersion (C3). Even there was no direct contact between substrate and water surface beneath it, at close distance, substrate moisture content still be affected by presence of saturated water vapor in air space trapped between substrate and water surface. Due to hygroscopic nature of the substrate, water vapor was continuously absorbed and keeps the substrate in moist condition. Direct contact facilitated water movement to the bottom part of substrate, hence, increased substrate moisture content. Further, deeper contact caused lower layer of substrate saturated with water, thus, reducing oxygen availability in this submerged layer.

Water is absolutely required for seed germination and seedling growth. However, excessive water availability inhibits germination and growth. Result of this study proved that presence of water saturated layer at lower part of substrate limited growth of rice seedlings. Height of rice seedling as well as seedling fresh and dry weights at 21 days after planting (DAP) were lower if half of the substrate was submerged in water. Even though, this condition did not cause a lethal effect on rice seedlings.

Hussain et al. (2016) also reported that submergence stress severely hampered the germination and seedling growth of rice, however, seed priming (selenium and salicylic acid priming) alleviated the detrimental effects of submergence stress. Wang et al. (2016) linked better emergence and vigorous seedling growth of rice treated with seed priming was associated with higher respiration rate. Jackson and Ismail (2015) argued that excessive extracellular water (due to excessive water condition) interfered with the union of CO_2 and O_2 gases with photosynthetic or respiratory electrons and protons. Thus, it reduces not only respiration but also photosynthetic rates.

In water saturated part of substrate, air is replaced by water in the pores. Since O_2 diffusion is much slower in water that in air, the submersion condition directly causes O_2 deficiency or hypoxic condition which, in turn, severely limits aerobic respiration. Pedersen et al. (2017) added that physiological issues related to excess water is not only oxygen deficiency but also CO_2 accumulation and increases in ethylene at tissue as well as on the cellular level.

Significant decrease in growth of rice seedling occurred if substrate was even only partially submerged in water. Therefore, the most important technique to be considered in floating seedbed system in producing good quality rice seedlings is keeping closed distance (less than 1 cm) up to direct contact between substrate and water surface but avoiding too much (more than 1 cm deep) substrate submersion.

Seedling population density

Dense plant population commonly associated with etiolation due to competition among plants for direct sunlight. Song et al. (2015) confirmed that allometric relationships of organ development were modified by the increased plant densities. Etiolation reflects allometric changes in organ shape. For instance, de Oliveira et al. (2017) reported that reducing the spacing between castor bean plants promoted an increase in plant height.

Ethylene has been found to play a major role in elongation of rice seedling. Xiong et al. (2017) confirmed that ethylene inhibited the expression of GY1 (gene isolated from Gaoyao-1 rice mutant that exhibited longer mesocotyl and coleoptile than normal rice plant did) in jasmonic acid biosynthesis pathway to reduce jasmonic acid level and enhanced mesocotyl and coleoptile growth by promoting cell elongation.

Coleoptile is light and hormone-sensitive tissue. Less light and high ethylene concentration enhanced elongation of coleoptile cells. However, later growth of rice seedlings at 21 DAP in our study did not affected by seedling population density up to 5 seedlings per cm^2 (Fig. 4), as indicated by no significant difference in seedling height (Table 1), shoot weight ratio and shoot to root ratio (Table 2), and weight to height ratio (Fig. 3).

In addition, SPAD value was higher in rice seedlings under higher population density at 21 DAP (Table 1). Higher SPAD value in dense seedling population is assumed due to increase in chlorophyll content for capturing sufficient light in overlaid leaves. Wang et al. (2015) reported that rice adaptive capacity to low light was enhanced by increasing the chlorophyll content to improve light-harvesting potential. Also, there was no significant difference in SPAD value among different water regimes applied in this study but the difference was observed between varieties at 28 DAP (Fig 1). Therefore, difference in SPAD values is more genetically regulated than due to environmental factors in rice seedlings at 21 and 28 DAP.

SPAD value is a reliable proxy for leaf chlorophyll content (Sim et al., 2015; Lakitan et al., 2018b). Sone and Sakagami (2017) reported that rice plant exposed to fully submerged condition was experiencing chlorophyll breakdown and photo damage. However, in this study, partial submersion of growing substrate did not affect SPAD value of rice at pre-transplanted seedling phase.

Seedling population density was not significantly different between seed planting rates of 2 and 3 kg m^{-2} (D2 and D3, respectively). Therefore, considering seed use efficiency, seed planting rates of 2 kg m^{-2} is recommended.

Age of seedling at time of transplanting

There are multiple objectives of using transplanting system in rice cultivation. Some might be driven by need to increase productivity and others – driven by certain local condition of agro-ecosystem. The latter is the main objective of smallholder farmers at riparian wetlands in Indonesia opting to practice transplanting system, i.e. to start rice growing season as early as possible in order to avoid drought condition during reproductive phase which eventually threatens local farmers of losing or significant decrease in their potential rice grain yield.

Direct seed planting can only be done after floodwater had fully subsided at paddy field. Meanwhile, transplanting system opens opportunity for local farmers to start seedling preparation as early as one month before floodwater completely subsided since transplanting of seedlings can be started prior to floodwater has completely subsided, as long as the seedlings are tall enough such that they are not fully submerged under water (Lakitan et al., 2018a).

Most results of study related to seedling age reported and recommended that rice seedlings would be better if transplanted at age around 21 DAP (Sarwar et al., 2011; Lampayan et al., 2015b; Liu et al., 2017; Sowmyalatha et al., 2017). In general, younger seedlings are fragile and not easy to handle; whereas, older seedlings yield less. The optimal seedling age, however, influence by many other factors. Slightly older seedling might be better under low population density (Sarwar et al., 2011; Liu et al., 2017), low temperature, using mechanized transplanting (Sowmyalatha et al., 2017), or for increasing water use efficiency (Lampayan et al., 2015b). Seedling age at transplanting also affected effectiveness of ameliorant application and cultural practices in rice (Kartika et al., 2018a, 2018b). In this study, delaying transplanting to 28 DAP was tolerable since the seedling still grew even at slower rate (Table 1, Fig 2) and SPAD value significantly increased (Table 1, Fig 1).

Another essential advantage of using floating seedbed at riparian wetlands is flexibility in time for transplanting. If floodwater has not receded to a feasible depth for transplanting, farmers can wait until floodwater subsides further and at the same time seedling grows taller. This flexibility in timing of transplanting and opportunity to start rice growing season earlier are the clear advantage of practicing floating seedbed system at riparian wetlands. Flexibility in time of rice seedling transplantation are from as early as 14 DAP to as late as 28 DAP.

Conclusion

Results of this study suggested that seedling quality can be classified based on height, weight/height ratio, and leaf SPAD value. Floating seedbed system is the only available and affordable technique in providing rice seedlings for earlier rice growing season. For producing high quality rice seedlings using floating seedbed, three crucial factors should be considered: (1) seed sowing density, (2) substrate-water contact setup, and (3) range of seedling age suitable for transplanting. For producing optimum number of seedlings per unit area and maximizing seed use efficiency, recommended seed sowing density is at 2 kg m^{-2}. Optimal setup for interface between bottom substrate layer and water surface is at distance less than 1 cm or no direct contact. It is very crucial to optimally manage moisture content and oxygen availability in the substrate. Under condition of unpredictable flooding occurrence, acceptable seedlings ages for transplanting are within range of 14 to 28 DAP.

Acknowledgements

We would like to thank editor-in-chief of this journal and all of reviewers for their constructive suggestions. This work was supported by Program PMDSU 2018 Nomor 093/SP2H/LT/DRPM/IV/2018 and Penelitian Unggulan Profesi Universitas Sriwijaya 2018, grant No. 0006/UN9/SK.LP2M.PT/2018.

References

Anten, N. P., & Bastiaans, L. (2016). The use of canopy models to analyze light competition among plants. In *Canopy Photosynthesis: From Basics to Applications* (pp. 379-398). Springer, Dordrecht.

de Oliveira, A. B., de Brito Neto, J. F., Cardoso, G. D., & do Vale, L. S. (2017). Growth and yield of castor bean (*Ricinus communis* L.) cv. BRS Energia under different spacing. *Tropical and Subtropical Agroecosystems*, *20*(2), 289-295.

Hussain, S., Yin, H., Peng, S., Khan, F. A., Khan, F., Sameeullah, M., Hussain, H.A., Huang, J., Cui, K & Nie, L. (2016). Comparative transcriptional profiling of primed and non-primed rice seedlings under submergence stress. *Frontiers in plant science*, *7*, 1125.

Kartika, K., Lakitan, B., Sanjaya, N., Wijaya, A., Kadir, S., Kurnianingsih, A., Widuri, L.I., Siaga, A. & Meihana, M. (2018a). Internal versus edge row comparison in jajar legowo 4:1 rice planting pattern at different frequency of fertilizer applications. *AGRIVITA Journal of Agricultural Science*, *40*(2), 222–232.

Kartika, K., Lakitan, B., Wijaya, A., Kadir, S., Widuri, L.I., Erna Siaga, E. & Meihana, M. (2018b). Effects of particle size and application rate of rice husk biochar on chemical properties of tropical wetland soil, rice growth, and yield. *Australian Journal of Crop Science*, *12*(5), 817-826.

Lakitan, B., Alberto, A., Lindiana, L., Kartika, K., Herlinda, S., & Kurnianingsih, A. (2018a). The benefits of biochar on rice growth and yield in tropical riparian wetland, South Sumatera, Indonesia. *CMUJ Natural Sciences*, *17*(2), 111-126.

Lakitan, B., Hadi, B., Herlinda, S., Siaga, E., Widuri, L. I., Kartika, K., Lindiana, L., Yunindyawati, Y. & Meihana, M. (2018b). Recognizing farmers' practices and constraints for intensifying rice production at Riparian Wetlands in Indonesia. *NJAS Wageningen Journal of Life Sciences*, *85*, 10-20.

Lakitan, B., Lindiana, L., Widuri, L.I., Kartika, K., Siaga, E., Meihana, M. & Wijaya, A. (2019a). Inclusive and Ecologically-Sound Food Crop Cultivation at Tropical Non-Tidal Wetlands in Indonesia. *AGRIVITA Journal of Agricultural Science*, *41*(1), 23-31.

Lakitan, B., Siaga, E., Kartika, K. & Yunindyawati, Y. (2019b). Use of *Scleria poaeformis* as biomaterial in etno-agricultural practice at riparian wetlands in Indonesia. *Bulgarian Journal of Agricultural Science*, *25*(2), 320-325.

Lampayan, R. M., Faronilo, J. E., Tuong, T. P., Espiritu, A. J., De Dios, J. L., Bayot, R. S., Bueno, C.S. & Hosen, Y. (2015a). Effects of seedbed management and delayed transplanting of rice seedlings on crop performance, grain yield, and water productivity. *Field Crops Research*, *183*, 303-314.

Lampayan, R. M., Samoy-Pascual, K. C., Sibayan, E. B., Ella, V. B., Jayag, O. P., Cabangon, R. J., & Bouman, B. A. M. (2015b). Effects of alternate wetting and drying (AWD) threshold level and plant seedling age on crop performance, water input, and water productivity of transplanted rice in Central Luzon, Philippines. *Paddy and Water Environment*, *13*(3), 215-227.

Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *Science of the Total Environment*, *566*, 333-349.

Liu, Q., Zhou, X., Li, J., & Xin, C. (2017). Effects of seedling age and cultivation density on agronomic characteristics and grain yield of mechanically transplanted rice. *Scientific Reports*, *7*(1), 14072.

Matsushima, K. I., & Sakagami, J. I. (2013). Effects of seed hydropriming on germination and seedling vigor during emergence of rice under different soil moisture conditions. *American Journal of Plant Sciences*, *4*(08), 1584-1593.

Jackson, M. B., & Ismail, A. M. (2015). Introduction to the Special Issue: Electrons, water and rice fields: plant response and adaptation to flooding and submergence stress. *AoB Plants*, *7*.

Nguyen, H. H., Dargusch, P., Moss, P., & Aziz, A. A. (2017). Land-use change and socio-ecological drivers of wetland conversion in Ha Tien Plain, Mekong Delta, Vietnam. *Land Use Policy*, *64*, 101-113.

Pedersen, O., Perata, P., & Voesenek, L. A. (2017). Flooding and low oxygen responses in plants. *Functional Plant Biology*, *44*(9), 3-6.

Ramadhani, F., Lakitan, B., & Hasmeda, M. (2018). Decaying Utricularia-biomass versus soil-based substrate for production of high quality pre-transplanted rice seedlings using floating seedbeds. *Australian Journal of Crop Science, 12*(12), 1983-1988.

Sarwar, N., Maqsood, M., Wajid, S. A., & Anwar-ul-Haq, M. (2011). Impact of nursery seeding density, nitrogen, and seedling age on yield and yield attributes of fine rice. *Chilean Journal of Agricultural Research*, *71*(3), 343-349.

Siaga, E., Lakitan, B., Bernas, S. M., Wijaya, A., Lisda, R., Ramadhani, F., Widuri, L. I., Kartika, K., & Meihana, M. (2018). Application of floating culture system in chili pepper (*Capsicum annum* L.) during prolonged flooding period at riparian wetland in Indonesia. *Australian Journal of Crop Science*, *12*(5), 808-816.

Sim, C. C., Zaharah, A., Tan, M., & Goh, K. (2015). Rapid determination of leaf chlorophyll concentration, photosynthetic activity and NK concentration of Elaies guineensis via correlated SPAD-502 chlorophyll index. *Asian J. Agric. Res*, *9*(3), 132-138.

Sone, C., & Sakagami, J. I. (2017). Physiological mechanism of chlorophyll breakdown for leaves under complete submergence in rice. *Crop Science*, *57*(5), 2729-2738.

Song, Y., Birch, C., Rui, Y., & Hanan, J. (2015). Allometric relationships of maize organ development under different water regimes and plant densities. *Plant Production Science*, *18*(1), 1-10.

Sowmyalatha, B. S., Ramachandra, C., Krishnamurthy, N., & Shivakumar, N. (2017). Influence of seedling age on growth and yield of rice (*Oryza sativa* L.) under mechanized system of rice intensification (MSRI). *Journal of Progressive Agriculture*, *8*(2), 40-45.

Wang, L., Deng, F., & Ren, W. J. (2015). Shading tolerance in rice is related to better light harvesting and use efficiency and grain filling rate during grain filling period. *Field Crops Research*, *180*, 54-62.

Wang, W., Chen, Q., Hussain, S., Mei, J., Dong, H., Peng, S., Huang, J., Cui, K. & Nie, L. (2016). Pre-sowing seed treatments in direct-seeded early rice: consequences for emergence, seedling growth and associated metabolic events under chilling stress. *Scientific Reports*, *6*, 19637.

Xiong, Q., Ma, B., Lu, X., Huang, Y. H., He, S. J., Yang, C., Yin, C. C., Zhao, H., Zhou, Y., Zhang, W. K. & Wang, W. S. (2017). Ethylene-inhibited jasmonic acid biosynthesis promotes mesocotyl/coleoptile elongation of etiolated rice seedlings. *The Plant Cell*, *29*(5), 1053-1072.

Received: 28.07.2018; *Accepted*: 11.08.2018