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Strength assessment of rice hills from different planting distance by loading simulation

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ABSTRACT

Plant spacing arrangement might benefit hill strength from the impact of strong wind velocity during extreme weather situations. Here, a loading test to evaluate rice hill strength was performed on Ciherang variety grown in square and double row spacing 2:1. The research was conducted at Cilubang village, Dramaga, Bogor, West Java, Indonesia from March to May 2017. Weight holding capacity was evaluated in 85 days after transplanting on four levels of hill height, i.e., 80 cm, 60 cm, 40 cm, and 20 cm above soil level with three-time replication. The results showed that double-spaced hills had 66.0 % ± 3.1 % stronger than those of square spacing at all height measurement. To lodge a hill into 20 cm to 40 cm from soil level, it required 346.7 g to 741.7 g in square spacing, and 555.2 g to 1149.2 g in double row spacing. Stronger hills in double row spacing seemed to correlate with a higher number of tiller and hills architecture; it requires further study in the role of both factors on the hill strength improvement. The present study recommends applying double row spacing to improve rice hill strength especially at a time with a high chance of lodging by strong wind incident.

INTRODUCTION

Rice (*Oryza sativa* L.) is an important food in Asia, and the demand increases steadily in line with the increasing population. Consequently, lots of Asian governments are encouraged to sustain rice production (United Nations, 2017; International Rice Research Institute, 2019). However, in some areas, high cropping intensity increases the chance of rice plant to get the extreme weather impact, e.g., strong wind and heavy rainfall, causing physiological disorder and plant lodging. Strong wind velocity is a kind of abiotic stress, and it causes detriment to rice production through shreds leaves and rice grain shattering, and lodging (Baker et al., 2014; Sridevi and Chellamuthu, 2015; Gardiner et al., 2016; Martinez-Vazquez, 2016). In Indonesia, Santosa et al. (2016) estimate that annual rice loss due to lodging was about US$ 270 million. Since the incident of the extreme weather tends to increase as the effect of climate change (Niu et al., 2016; Carvalho et al., 2017; Soares et al., 2017), lodging mitigation is important to sustain rice production.

Recently, double row spacing (jajar legowo) becomes popular in Indonesia to increase rice production (Ruminta et al., 2017) and facilitates integrated rice-fish cultivation (minapadi) (Mahmudiyah and Soedradjad, 2018). Adoption of double row spacing is also believed to reduce lodging incident from strong wind impact due to border effect. However, evaluation of the effect of planting distance on plant strength is limited. In this case, we assume that lodging is due to weak rice hill. It is well known that crop sensitivity to strong wind impact and lodging is determined by wind speed, species, variety, growth stage, plant architecture, nutrient status, plant biometry and leaf orientation (Hayashi et al., 2011; Ishimaru et al., 2012; Selino and Jones, 2013; Sridevi and Chellamuthu, 2015; Tadrist et al., 2015; Martinez-Vazquez, 2016). According to Niu et al. (2016) combination between strong wind and heavy rainfall causes more marked damage in wheat.

Ideally, the measurement of the strong wind impact is conducted directly or inside a wind simulator (Cao et al., 2012; Cataldo et al., 2013; Zhu and Shao, 2017). However, access to such measurement is technically difficult in developing countries. Moreover, the characteristics of strong wind incident are local, temporal and unpredictable (Santosa et al., 2016). Fortunately, some authors have developed indirect methods, e.g., mechanical load (Niu et al., 2012), tree pulling (Kane and Clouston, 2008), digital measurement (James and Kane, 2008), torsion (Virot et al., 2016), and electrical measurement (Wu and Ma, 2016). According to Gan and Salim (2014), the wind has velocity (kinetic power) and pressure (potential power) characteristics. Therefore, those indirect methods mostly work based on the critical point of breakage due to bending which exceeds the rupture modulus of the material (Mochida et al., 2008; Gan and Salim, 2014; Virot et al., 2016).

Here, the strength of rice hills of different planting distance is contrasted using indirect method and it is expressed in weight holding capacity (WHC); high WHC means less lodged. The concept of WHC refers to Muthu and Li (2014) with modification for rice hills, i.e., the maximum amount of load hills bears for a fixed amount of time and can be recorded. The objective of the experiment was to evaluate the effect of different planting distances on hill strength of Ciherang as leading rice variety in Indonesia.

MATERIALS AND METHODS

The research was conducted during the rainy season in farmer field at Cilubang village Dramaga (240 m above sea level), Bogor District, West Java, Indonesia from March–May 2017. Average temperature and relative air humidity during the research were 28 °C to 32 °C and 65 % to 72 %, respectively. Soil was harrowed twice by incorporating rice straw from the previous harvest. Ciherang seedling aged 20 days after showing was planted on 11 March 2017 with two seedlings per hole.

The treatment consisted of two factors, i.e., plant spacing (square/*ubinan*; 20 cm × 20 cm and double row spacing/legowo 2:1; 30 cm × [20 cm × 15 cm]) as main plot and loading height (80 cm, 60 cm, 40 cm and 20 cm from soil level) as sub plot. Sub plot sized 2.5 m × 2.5 m; a main plot sized 200 m^2 including border plants.

Loading simulation was conducted on 25 May 2017 or 85 days after transplanting (DAT). The simulation followed the concept of Niu et al. (2012) with modification. Time of treatment was determined according to the initial critical stage for lodging by Sridevi and Chellamuthu (2015). Plastic panel was

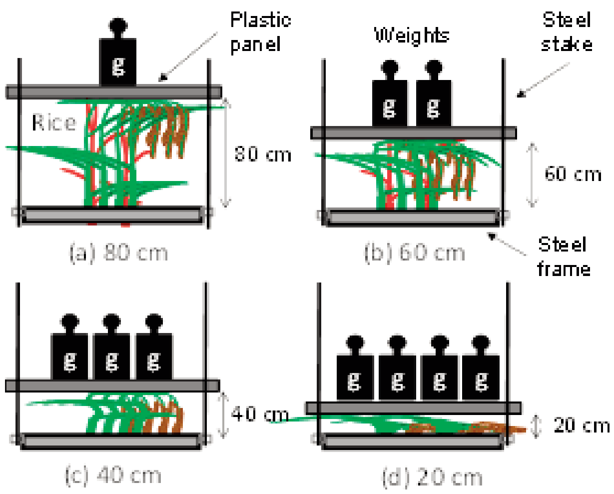

Figure 1. Loading simulation to estimated weight holding capacity. (a)–(d) Scheme of panel penetration to hills at 80 cm, 60 cm, 40 cm, and 20 cm from soil level, respectively.

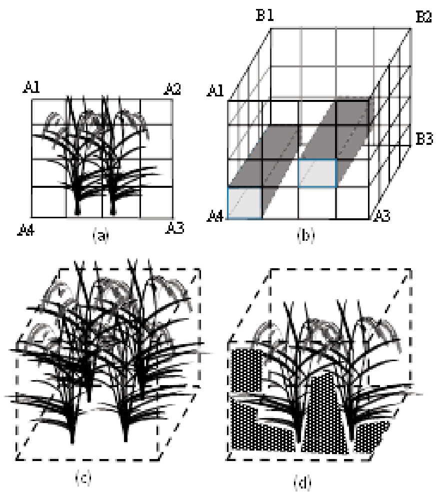

Figure 2. Steps to estimated free space around rice hills. (a) Two dimension hills projection used 10 cm×10 cm grids. (b) Three-dimension projection to estimated free space (shaded). (c) Three-dimension with eight rice hills. (d) Estimation of free space (shaded).

installed above rice hills and loaded gradually using weight until the panel reached height of 80 cm, 60 cm, 40 cm and 20 cm from soil level (Figure 1). Data was obtained from three replications. One measurement covered eight rice hills, and then was averaged. The height level was determined based on the preliminary study. WHC of rice hill at each height level was recorded at steady height and expressed in gram per hill. Hill and tiller damage was evaluated.

Rice plant was maintained according to local practice. NPK fertilizers were applied at rate of 300 $kg.ha^{-1}$ urea (46% N), 100 $kg.ha^{-1}$ SP-36 (36% P_2O_5) and 100 $kg.ha^{-1}$ KCl (60% K_2O). All phosphorus, all potassium, and two-thirds of nitrogen were applied at planting. The remaining one-thirds of N was applied at 3rd week after transplanting. Water level was maintained 10–15 cm in height from planting to maximum grain filling stage at 80 DAT; and it was reduced gradually until harvest.

Available space around rice plant canopy was estimated following the method of Li et al. (2017) with major modification. Briefly, the hills were captured using camera. Then by using computer, the space around rice hills was delineated to determine the filled and free spaces (Figure 2). Shaded space by rice culm or leaves was considered as filled space, otherwise, it was empty one. To avoid complexity in drawing, spaces between culm and leaves, and between leaves less than 2 cm were simply considered as filled space. Space occupied by a single leaf was considered empty. Thus, the accuracy of the estimation was limited by these assumptions.

Data was evaluated using ANOVA, and any significance was further evaluated using the least significant different (LSD) at level of confident of 5%.

RESULTS AND DISCUSSIONS

Plant characteristics

Ciherang variety in irrespective plant spacing produced 4–7 leaves with average of 4.4 leaves in each tiller. During the simulation time, most productive tillers had 2–4 green leaves and healthy culm, and the rice grains had fully developed irrespective of spacing treatments. On average, productive tiller from square spacing had 2.4 green leaves while double row spacing had 2.6 leaves, but they were statistically insignificant difference.

Plants from both square and double row spacing had similar height and stem diameter (Table 1). The plant from double row spacing had a higher number of tiller and productive tiller than that of the square one. The increasing number of tiller and productive tillers of rice planted in double row spacing has been reported (Erythrina and Zaini, 2014; Amanah et al., 2017; Ruminta et al., 2017).

Table 1. Ciherang variety properties from two plant spacing in 85 days after transplanting

Plant spacing	Total plant height (cm)^z	Plant height up to flag leaf (cm)	Stem diameter (cm)^y	Number of tiller per hill	
				Total	Productive
Square	69.3±4.4 a	85.7±4.0 a	0.36±0.03 a	10.3±1.9 b	9.6±1.3 b
Double row	70.2±4.9 a	86.8±6.1 a	0.40±0.03 a	15.5±2.7 a	14.3±2.1 a

Remarks: ^{z}From soil level to neck of panicle; ^{y}At 10 cm from soil level. Value followed by different alphabet was statistically different at LSD α=5%. Mean±SD

Table 2. Weight holding capacity (WHC) of Ciherang variety from square and double row spacing at different loading height from soil level

Plant spacing	WHC per hill (g)			
	80 cm	60 cm	40 cm	20 cm
Square	13.3±0.7 b	221.5±72.8 b	346.5±72.7 b	741.7±36.1 b
Double row	19.2±0.7 a	327.7±60.3 a	555.2±71.3 a	1149.2±118.4 a

Remark: Value followed by different alphabet was statistically different at LSD α=5%. Mean±SD

Hill and tiller strength

Weight holding capacity (WHC) increased from upper part of hill to the lower part, irrespective of spacing treatment (Table 2). For example, a hill was able to hold 13.3 g for square spacing and 19.2 g for double row spacing when plastic panel reached the height of 80 cm from soil level, and was able to hold 741.7 g and 1149.2 g respectively when the panel reached the height of 20 cm from soil level. Double-spaced plants produced stronger tiller, irrespective height from soil level. In average it hold 66.0 % ± 3.1 % more in weight than that of square spacing. Increasing WHC was more markedly at height of 80 cm and 60 cm, i.e., 69.3% and 67.6%, respectively, than at height of 40 cm (62.4%) and 20 cm (64.5%) although statistically they had no significant difference.

Increasing WHC from double-spaced hills was likely related to number of tiller and its' architecture. Double-spacing produced tiller of 33.5% and productive tiller per hill of 32.9% which was higher than square spacing (Table 1). The higher number of productive tiller at double-spaced planting system was inline with previous findings (Ikhwani, 2015; Magfiroh et al., 2017). It is probably that double-spacing leading all hills plays as the edge rows that commonly express superior growth in rice.

The presence of unproductive tiller presumably contributed to strength especially at hill base. It was confirmed within a treated plot that some hills with higher number of unproductive tillers had less severe damage than the hills without unproductive tiller. Table 3 shows that double row spacing stimulated growth of unproductive tillers, e.g., 33.3 % to 75.0% higher. It needs further verification on the contribution of unproductive tiller on hill strength.

There was difference on canopy width and space among spacing treatments (Table 3). In average, double-spaced hills had canopy width of 18.5% and free space of 12.5 % to 30.8% which was higher than the square one. It is probable that double-spaced hills received higher light intensity than those hills of square-spacing. The indication for double-spaced land receiving higher light intensity was confirmed by Rianto et al. (2019), where average weed investment around hills of double-spacing is higher than that around square-spacing. According to Restrepo and Garcés (2013) unshaded rice plants have about 33% higher photosynthetic rate than that of the shaded one. Unfortunately, light intensity and photosinthetic rate were not measured in present experiment.

Conversely, square-spacing had 13–37% denser canopy that might restrict the wind velocity, unlike hills of double-spacing that might have more aero-

Table 3. Canopy characteristics of Ciherang variety from different plant spacing

Plant spacing	Canopy width (cm)[z]	Empty space around plant canopy (%)[y]	Number of unproductive tiller (<20 cm)
Square	48–62 b	35–45 b	0–2 b
Double row	59–76 a	40–65 a	3–8 a

Remarks: [z]Measured from outer leaf or panicle projection. [y]Estimated using computer drawing. Value followed by different alphabet was statistically different at LSD α=5%.

Table 4. Average weight holding capacity (WHC) per tiller of Ciherang variety from square and double row plant spacing at different loading heighst from soil level

Plant spacing	WHC per tiller (g)[z]			
	80 cm	60 cm	40 cm	20 cm
Square	1.3±0.2 a	22.8±10.3 a	35.2±12.4 a	74.0±16.0 a
Double row	1.3±0.2 a	21.2±0.5 a	36.2±3.9 a	74.9±6.5 a

Remarks: [z]Including productive and unproductive tiller. Value followed by similar alphabet was statistically similar at LSD α=5%. Mean±SD.

dynamic in case of wind velocity. As the results, speare-spacing was prone to lodging. In steady wind, Hong et al. (2002) stated that wind speed decreases to upper half and the speed tends to increase from the lower half of the canopy towards the ground. From Table 3, it was expected that double-spaced hills had lower turbulence which resulted in less prone to strong wind impact. However, ifurther verification by using real wind simulator is needed.

Interestingly, WHC value per tiller did not show any significant difference among spacing treatments (Table 4). At the height of 20 cm to 60 cm from soil level, tillers from double row spacing had more uniform responses to weight treatment than those from square spacing; as expressed by lower standard deviation of WHC value in double row spacing. It means that determination using WHC value on the basis of number of tiller solely could be underestimated. Further analysis by excluding unproductive tiller revealed a sharp increase in WHC value for both spacing at the height of 20 cm to 40 cm from soil level (Figure 3). It was indicated that there was substantial contribution of unproductive tiller to WHC value in present experiment. On the other side, low WHC value at 80 cm in height was due to difficulty in loading treatment because it was nearly the same as the plant height. Table 1 shows that hills had 85.7 cm to 86.8 cm in height including flag leaf. It is interesting to evaluate hill strength using rice genotype with different height characteristics.

Hills damage and its implication

Loading treatment predominantly caused rice hills damage. A hill of square spacing required load of 741.7 g to complete damage/lodging while double-spaced hills required 1149.2 g (Table 2). However, the damage part of hill depends on the loading level (Table 5). In some cases, initially hills bended down before completely being lodged or broken. Loading up to 80 cm predominantly caused

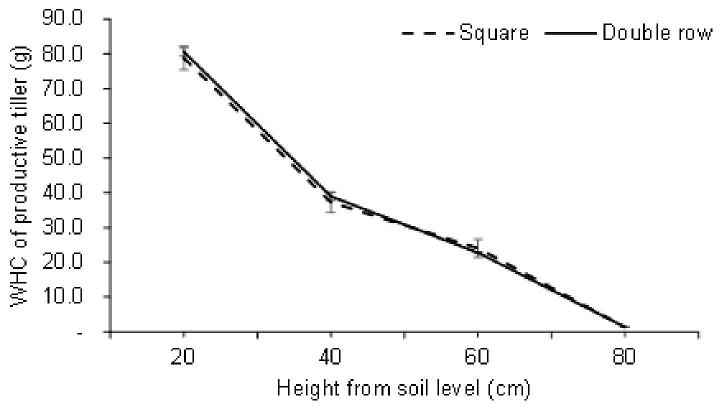

Figure 3. Weight holding capacity (WHC) of a productive tiller from square and double row spacing at different height from soil level. Mean ± SE

Table 5. The damage as the effect of loading at different height on Ciherang variety from square and double row spacing

Plant spacing	Loading height treatment from soil level			
	80 cm	60 cm	40 cm	20 cm
Square	Panicle	Panicle; 3rd and 4th internode from top	Panicle; 3rd, 4th and 5th internode from top	Panicle; 2nd, 3rd, 4th and 5th internode; 2nd and 3rd node; and internode close to soil level
Double row	Panicle	Panicle; 2nd and 3rd internode from top	Panicle; 3rd, 4th and 5th internode from top	Panicle; 2nd, 3rd, 4th and 5th internode; and internode close to soil level

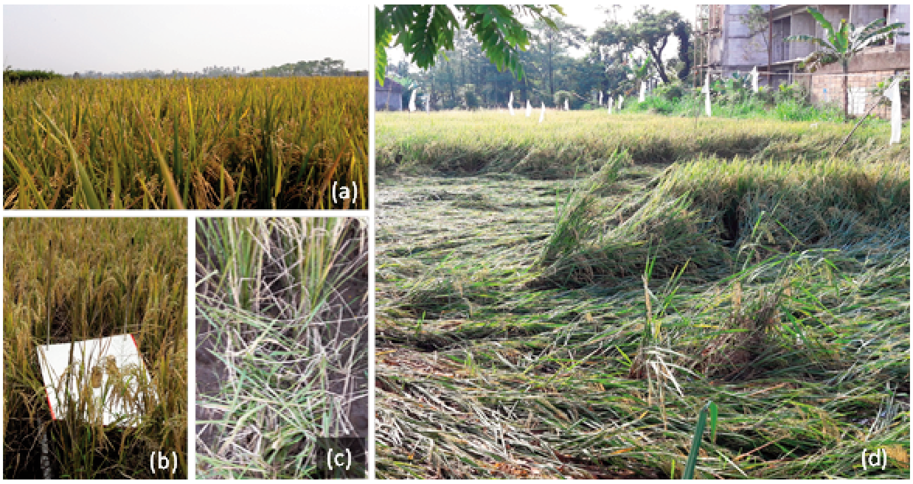

Figure 4. Rice hill before and after loading, and lodging by strong wind. (a) Hills before treatment. (b) Loading at 60 cm from soil level. (c) Straw breakage after loading up to 20 cm from soil level. (d) Inpari 30 got lodged after wind impact in Cilubang Village on 10 Nov, 2017.

minor panicle rupture. Additional loading up to height of 60 and 40 cm from soil level stimulated 2nd–5th internodes break accompanied by panicle damage. Breakage position of internode seemed random, but upper internodes tended to break earlier than the lower ones. Rice culm pointed from lower to upper part might be the reason why upper internodes were broken earlier at loading treatment. It is important to note that hills without unproductive tiller expressed more severe damage when plastic panel penetrated until 20 cm from soil level. Santosa et al. (2016) and Dulbari et al. (2018) pointed out that 0–20 cm or 0–40 cm from soil level is the most sensitive to strong wind impact. In the future, role of basal tiller strength should be further considered in rice genotype improvement, in addition to agronomic manipulation through application of silicate (Ahmad et al., 2013).

It is noted that hill damage after weight application contrasted to natural hill damaged by strong wind impact (Figure 4). Hills damage from loading treatment showed irregular pattern (Figure 4c) while it had particular pattern after natural wind impact (Figure 4d). Indeed, wind characteristic in the natural condition could be more complex than the simplification in the loading simulation. In the incident of rice lodging, wind pressure is likely the most important (Gan and Salim, 2014). In general, damage pattern from present simulation could be overestimated as the comparison to natural incident of lodging although such damage pattern has been observed by Santosa et al. (2016). Nevertheless, evaluation using WHC could be the initial screening tools for hill strength in reference to lodging tolerant genotype in the near future. Improvement tools on WHC measurement is needed.

According to the owner of rice field in Figure 4d, the Inpari 30 variety was planted in double row spacing. In the field, plant spacing might not be the only factor that determines lodging incidentas other causes have been mentioned by previous authors (Mochida et al., 2008; Hayashi et al., 2011; Selino and Jones, 2013; Tadrist et al., 2015; Barnard and Bauerle, 2016). Therefore, it is interesting to study rice canopy morphology that determines sturdiness under strong wind impact.

We speculated that in reference to strong wind adaptation, contribution of unproductive tiller and plant aerodynamic is important. Unproductive tiller mostly stay green at later stage of rice maturity, and could play as additional stake for the productive tillers from lodging at the weakest position to break, which was 0 cm to 40 cm from soil level. It was noted that most unproductive tillers sized 20 cm in height. In this preliminary finding, we speculated that the existence of high unproductive tillers under double row spacing became key factor in hill strength. Nevertheless, it is generally concluded that large number of unproductive tiller competes with final rice production (Wang et al., 2007; Badshah et al., 2014; Reuben et al., 2016). Therefore, it needs further evaluation by using larger number of rice genotypes to reveal the role of unproductive tiller andhill aerodynamic, and to figure out reasonable number of unproductive tiller.

CONCLUSIONS

Double row spacing improved hills strength by 62.4–69.3% (66.0±3.1% on average) than square spacing in Ciherang variety. Increasing the strength of double-spaced hills was related to number of tiller and free space around the hills. It was likely that presence of unproductive tiller contributed to enhance hill strength especially at the height of 0–40 cm from soil level. Thus, it is recommended to plant Ciherang variety using double row spacing to enhance hill strength against strong wind velocity. In the future, it is interesting to study effect of spacing on the hill strength using genotypes with different canopy morphology in order to develop better loging resistant.

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