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Research Article

Impact of water management on root morphology, growth and yield component of lowland rice varieties under the organic system of rice intensification

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Abstract : Water management is one of the keys to success in increasing rice production in paddy fields. Paddy rice production will decrease if the rice plants suffer from water stress, and conversely conventional cultivation is very wasteful of water. Local aromatic varieties have deeper rooting character than improved varieties making it more efficient in using water. The purpose of this study was to obtain more efficient and more productive aromatic local varieties in the use of irrigation water in the SRI organic cultivation system. This research was conducted in organic rice fields in Kebonagung village, Imogiri, Bantul with split plot design of 2 factors with 4 replications. Factor I: The mode of irrigation consists of (a) intermittent irrigation, and (b) continuous irrigation and Factor II: varieties consisting of (a) Mentikwangi, (b) Gabusan, (c) Sintanur and (d) IR64. The observation parameters included (1) root characters i.e. surface area of root, total length of root, and dry weight of root, (2) plant growth analysis i.e. specific leaf weight, net assimilation rate, plant growth rate, (3) and yield components i.e. weight 1000 grains, grain weight per hill, and grain weight per plot. The results showed that intermittent irrigation increased the surface area of root and the dry weight of root of Mentikwangi variety, and increased the specific leaf weight and weight of 1000 grains of IR64 variety, and increased the specific leaf weight and the net assimilation rate of Sintanur variety. Grain weight per hill and per plot showed no difference between intermittent irrigation and continuous irrigation. Grain weight per hill and per plot in intermittent irrigation achieved by Gabusan variety were 35.69 g and 14.28 kg respectively, while in continuous irrigation the grain weight achieved by Gabusan variety were 37.69 g and 15.08 kg respectively. In conclusion, there was no difference in yield between intermittent irrigation and continuous irrigation, so that the use of intermittent irrigation is more efficient in water use.

Keywords *: lowland rice, organic cultivation. root, SRI, water management*

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Introduction

Rice (*Oryza sativa* L.) is a major staple food for much of the world's population and the largest consumer of water in the agricultural sector (Thakur et al., 2014). World food security remains largely dependent on irrigated lowland rice, which is the main source of rice supply (Yang and Zhang, 2010). Fresh water for irrigation is becoming scarce because of population growth, increasing urban and industrial development, and the decreasing availability resulting from pollution and resource depletion (Chapagain et al., 2011 ; Thakur et al., 2011). Asia contributes more than 90% of the world's total rice production while using more than 90% of the total irrigation water (Khepar et al., 2000). Water is becoming increasingly scarce, and by 2025 the per capita available water resources in Asia are expected to decline by 15-45 percent compared with 1990 (Hassan et al., 2015). About 80% of the available water resources worldwide is used by the agricultural sector (Sujono, 2007), and of which irrigated rice makes the highest demand. Since rice is one of the biggest users of the world's developed fresh water resources (Tuong and Bouman, 2003), it takes 3-4 m^{-3} to produce 1 kilogram of rice, which is about 2 to 3 times higher than the amount required to produce 1 kilogram of cereals such as wheat or maize (Bouman et al., 2002). Mahmod et al. (2014) showed that rice uses around twice as much water; roughly 2,000 L to produce a single kilogram.

Water management is one of the keys to success in increasing rice production in paddy fields. Rice production will decrease if rice plants suffer from water stress. Common symptoms due to water stress include rolled rice leaves, leaf scorching, reduced rice tillers, dwarf plants, delayed flowering, and empty seeds (Subagyono et al., 2004). Accordingly, we should be thinking strategically about how to change this traditional irrigation method in rice production, and maintain rice cultivation with less water. Indonesian farmers should be able to enhance their rice production while improving soil and environmental quality, reduce demands on limited fresh water supplies (Rezaei and Nahvi, 2007). A water-saving rice cultivation method known as the System of Rice Intensification (SRI) has been introduced into Indonesia from Madagaskar. With SRI, rice productivity is reportedly increased by simultaneously modifying several agronomic and water management practices in rice cultivation (Stoop et al., 2002).

System of rice intensification (SRI) is a rice cultivation method that can provide higher yields with fewer inputs than conventional methods including irrigation water (Ferdinan and Harmailis, 2007). The provision of water in the SRI method is not carried out continuously but only for a certain period of time in order to keep the soil wet but the water is not stagnant (Thakur et al., 2014). SRI involves changes in certain management practices which provide better growing conditions for rice plants than traditional practices, particularly in the rhizosphere. SRI is a set of ideas and insights that emphasize the use of younger seedlings (<15-day-old) individually planted at wider spacing, together with the adoption of intermittent irrigation, organic fertilization and active soil aeration (Uphoff, 2007; Chapagain et al., 2011). SRI resulted in more vigorous growth of roots, reaching 13,004 cm/plant compared with non SRI results of 4,722 cm/plant. There was a 42% increase in grain yield when SRI methods were used. SRI practices reduced the need for irrigation water by 38.5% (Hameed et al. (2011). Rezaei and Nahvi (2007) showed that the SRI method could reduce water consumption and increase water productivity with no yield loss. Zhao et al. (2011) reported that uptake of N, P, K by rice plant during their growth stage was greater with SRI management compared to continuous flooding. Under SRI with intermittent irrigation, the ratio of N, P, and K in seed grain to total plant N, P, and K was 4.97, 2.00, and 3.01% higher, respectively, than with continuous irrigation. Moreover, under SRI management, internal use efficiency of N, P. and K was increased by 21.89; 19.34, and 16.96%, respectively, compared to rice plant under continuous flooding management. With SRI, irrigation water applications were reduced by 25.6% compared to continuous flooding. Thakur et al. (2014) showed that SRI practice produced 49% higher grain yields with 14% less water than the conventional transplanting system. Hassan et al. (2015) reported that the 3-day interval of irrigation consumed 50% as much water, as continuous flood, increased yield by 2% compared with continuous flood. Yang et al. (2004) reported that combined application of chemical fertilizers with farmyard, the root active absorption area, root oxidation ability of alpha-naphthylamine, and root surface phosphatase of rice plants by the continuous flooding decreased by 22, 28, and 35%, respectively, compared to the alternately flooded regime. Pascual and Wang (2017) showed that intermittent irrigation of three and seven-day interval produced water savings of 55% and 74 % compared with continuous flooding. Plant height and leaf area were greater in plants exposed to intermittent irrigation compared with those in continuous flooding.

The objective of this research was to obtain more efficient and more productive aromatic local varieties in the use of irrigation water in the SRI organic planting pattern.

Materials and Methods

The research has been conducted in rice fields in Kebonagung village, Imogiri sub-district, Bantul district, April 2016 - July 2016. This research was arranged in split plot design with two factors and four replications. The first factor was the method of water applications that consisted of intermittent and continuous irrigation. The second factor was the varieties that consisted of Mentikwangi, Gabusan, Sintanur, and IR64.

Before the experiment, an analysis of physical and soil chemistry was done including texture, volume weight, specific gravity, organic matter, total N (Kjeldahl method), available P (Bray method I), available K (Extraction of ammonium acetate), Cation Exchange Capacity (CEC) (NH4-acetate method (pH7), pH H_2O. Characteristic analysis of soil properties after experiments included N total, available P, available K, CEC, organic matter, pH H_2O. Analysis of organic fertilizer before use included water content, organic C, C/N ratio, organic matter (gravimetric), total N (wet destruction method), total P, total K, pH H_2O. First step was making an experimental plot with a length of 400 cm and a width of 400 cm. In the SRI method, irrigation was done intermittently at the beginning of the planting, the water supply was about 2 cm maximum.. Then let it dry until the soil conditions began to split and started again with maximum water application. For conventional methods, irrigation was by flooding system, height of flood was 5 cm from soil surface to full panicle formation. Two weeks before the harvest the land was left damp. Planting was done with spacing of 20 cm x 20 cm, and a population of 400 plants / plot. Fertilization is carried on with an organic fertilizer dose of 10 t/ ha. Weeding was done on the two-week and one-month-old plants. Control of pests and diseases was done by using organic pesticides made from jengkol extract, and harvest began when the seed shell on the top of the panicle has been clean and hard, and 80% of the seeds have brown straw.

Observation parameters of root characters were the total surface area of root, total length of root, and dry weight of root, growth analysis i.e specific leaf weight, net assimilation rate, crop growth rate, yield components i.e. weight of 1000 grains, grain yields per hill, and grain yields per plot. Data Analysis of the observational data was analysis of variance (ANOVA). If there was a difference between treatments then it was tested further by using Duncan's New Multiple Range Test (DMRT) at 5% level. To know the relationship of direct and indirect influence, regression and correlation analyses were done. Data were analyzed by computer device using SAS for window 9.0 program

Results and Discussion

Physical and chemical properties of the soil

Before the research, an analysis of the physical and chemical properties of paddy fields was done. The results of the analysis of physical and chemical properties of the soil before research in the field are presented in Table 1. The results of analysis of the physical and chemical properties of the soil indicate that the paddy fields belong to a turbid texture. The composition of the fraction of the soil texture composition is very influential on the ability of the soil to pass water, or the permeability of the soil.

The macro nutrient level in the rice field was quite good except for the low total N, each N total (%) 0, 18 (low), P available (ppm) 34.64 (high) and K available (me / 100 g) 0.60 (high)(Table 1). There was an increase in available P levels and available K after harvest, whereas total N and organic matter decreased (Table 2). The available P level in organic cultivation before the experiment was 34.64 ppm (high) but after the experiment it became 41.24 ppm (very high) (Table 2). This was because the P nutrient released by the fertilizer into the soil solution and the available nutrients in the soil solution were larger than that absorbed by the plant so that the residual nutrients left in the soil would be greater. Thus after the experiment was finished the P levels inside was greater than before the experiment was done.

Organic materials contribute very large negative charge content through carboxylic and phenolic groups so that organic matter is expected to increase the capacity of CEC (Pandey et al., 2013). The results of laboratory analysis show the CEC, C / N ratio can be used to predict the rate of mineralization of organic matter. The organic material will be mineralized if the C/N ratio is below the critical value of 25-30 and if above the critical value there will be immobilization of N (Atmojo, 2003).

Root characters of lowland rice fields

Root surface area

Root surface area represents the ability of roots to absorb water and nutrients, the more extensive the rooting zone, the wider the water absorption and nutrient zones. The result of data analysis shows that the root surface area was influenced by the interaction of the mode of irrigation with varieties (Table 4). Intermittent irrigation increased the root surface area of IR64 variety. In both continuous and intermittent irrigation, the root surface area of Mentikwangi as a local variety was greater than that of other varieties. Although intermittent irrigation increased the root surface area of the IR64 variety, the root surface area of the Mentikwangi variety with intermittent irrigation remained wider than the IR64 variety. In intermittent irrigation, when water is drained, rice plants try to lengthen the roots, because the roots are seeking water and nutrients to meet the metabolic needs.

Table 1. Soil analysis before research

Physical and chemical characters	**Bulk density (g/cm^3)**	**Gravity (g/cm^3)**	**pH H_2O**	**Texture**	**Organic matter (%)**	**Total N (%)**	**Available P (ppm)**	**Available K (me/100 g)**	**CEC (me/100 g)**
Value	1.14	2.09	6.25	Loam	7.17	0.18	34.64	0.60	23.73
praise	-	-	Neutral	-	high	Low	high	high	High

Table 2. Organic fertilizer analysis before research

Physical and chemical characters	**Water content (%)**	**Organic carbon (%)**	**C/N ratio**	**Organic matter (%)**	**Total N (%)**	**Total P (%)**	**Total K (%)**	**pH H_2O**
Value	54.11	24.72	13.68	50.11	1.81	0.23	0.17	7.60

Table 3. Organic fertilizer analysis after research

Chemical characters of soil	**Total N (%)**	**Available P (ppm)**	**Available K (me/100 g)**	**CEC (me/100 g)**	**Organic Matter (%)**	**pH H_2O**
Value	0.14	41.24	0.72	23.36	2.94	6.74
Praise	Low	Very high	High	High	Low	Neutral

Table 4. Surface area of root, total length of root, and dry weight of root as affected by mode of irrigation and varieties of lowland rice

Mode of Irrigation	**Variety**	**Surface area of root (cm^2)**	**Total length of root (cm)**	**Dry weight of root (g)**
Intermittent Irrigation	Mentikwangi	861.75 b	656.03 a	36.25 a
	Gabusan	718.83 c	487.78 bd	25.85 bcd
	Sintanur	716.95 c	628.50 ab	32.70 ab
	IR64	700.73 c	429.93 cd	20.70 d
Continuous of Irrigation	Mentikwangi	1,026.35 a	564.65 abc	22.25 cd
	Gabusan	752.28 c	370.48 d	19.35 d
	Sintanur	659.78 cd	618.78 ab	31.70 abc
	IR64	569.33 d	405.88 d	16.78 d
Interaction		(+)	(+)	(+)
CV (%)		9.22	18.50	23.99

Note : The numbers in the same column followed by the same letter are not significantly different according to DMRT 5%.

Therefore, the roots will attempt to make a morphological adaptation, i.e. prolongation of roots, increase in root density as well as increase in the number and length of the root hairs (Costa et al., 2002). The morphological modification of the rooting system can increase the surface area of the roots in contact with the soil so that the surface area of nutrient uptake increases (Yang et al., 2004). There was no correlation between the root surface area and the total length of root (r = 0.25 ^{ns}) as well as the dry weight of root (r = 0.15 ^{ns}).

Total length of root

Measurement of the total length of root at the age of 9 weeks used area meter. The result of data analysis showed that the total length of root was influenced by the interaction mode of irrigation with varieties (Table 4.). The intermittent irrigation did not increase the total length of root. In continuous irrigation, the root of the Sintanur variety was longer than those of Gabusan and IR64 but not different from that of Mentikwangi, while in intermittent irrigation the root of Mentikwangi variety a local variety was longer than the roots of Gabusan and IR64. The roots of Mentikwangi variety in intermittent irrigation penetrated the ground soil up to 35 cm whereas in continuous irrigation only 25 cm, the roots of Gabusan and Sintanur varieties in intermittent irrigation could penetrate the ground soil up to 30 cm while in continuous irrigation they could only penetrate until a depth of 25 cm (Figure 2). This is because the roots will try to find water and nutrients to meet the metabolic needs, while water and nutrients in organic cultivation in a shallower layer of soil is still lacking. Yang et al. (2004) state that the amount of water and nutrients absorbed by plants is determined by the volume of soil contacting the roots. The volume of soil in contact with the roots depends on the number of branches of roots and the distance to which the roots develop both vertically and horizontally. Plants grown under continuous flooding produced shorter roots with decreased root length of 9% compared with those of intermittent irrigation. In addition, the root volume weight of intermittent irrigation was higher too. Greater root volume and longer roots are regarded as an adoption measure for plants to maximize water capture and access water at greater depths (Ascha, 2005 ; Kima et al., 2014).

Dry weight of root

The dry weight of the roots represents the growth of plant organs that are below the soil surface, which affects the development of the organs above it. Plants are considered to have a good rooting system if they have a good root dry weight/crowns ratio. The dry weight of the roots also represents the amount of assimilate that is distributed to the rooting system. The assimilate produced by the crowns of the plant will be circulated throughout the plant body through the carrier vessels. The result of data analysis showed that the dry weight of root was influenced by the interaction of an irrigation mode with varieties (Table 4).

The root dry weight of Mentikwangi variety in intermittent irrigation was more extensive than those of Gabusan and IR64 varieties but not different from that of Sintanur variety. In continuous irrigation, the root dry weight of Sintanur variety differed from those of Gabusan and IR64 varieties, but not different from that of Mentikwangi variety. The dry weight of root was higher under intermittent irrigation, which could indicate a strong water and nutrient absorption capacity translating into high grain production (Pascual and Wang, 2017). Thakur et al. (2011) in their study reported that the proportion of roots that were brown or black (non-functional and decayed) was found to be higher in continuously flooded plots compared with aerated rice fields. Pascual and Wang, 2017 added that roots of plants grown under continuous flooding regimes also showed a higher proportion of decayed or nonfunctional parts compared with those under intermittent irrigation. Continuous flooding caused the soil to become increasingly anaerobic with low redox potential causing adverse effects on root development and activity; moreover, plants grown under continually saturated or flooded soil produced a higher percentage of decayed roots. The total length of root is positively correlated (r = 0.60 **) with dry weight of root, meaning that the longer the root, the greater the dry weight.

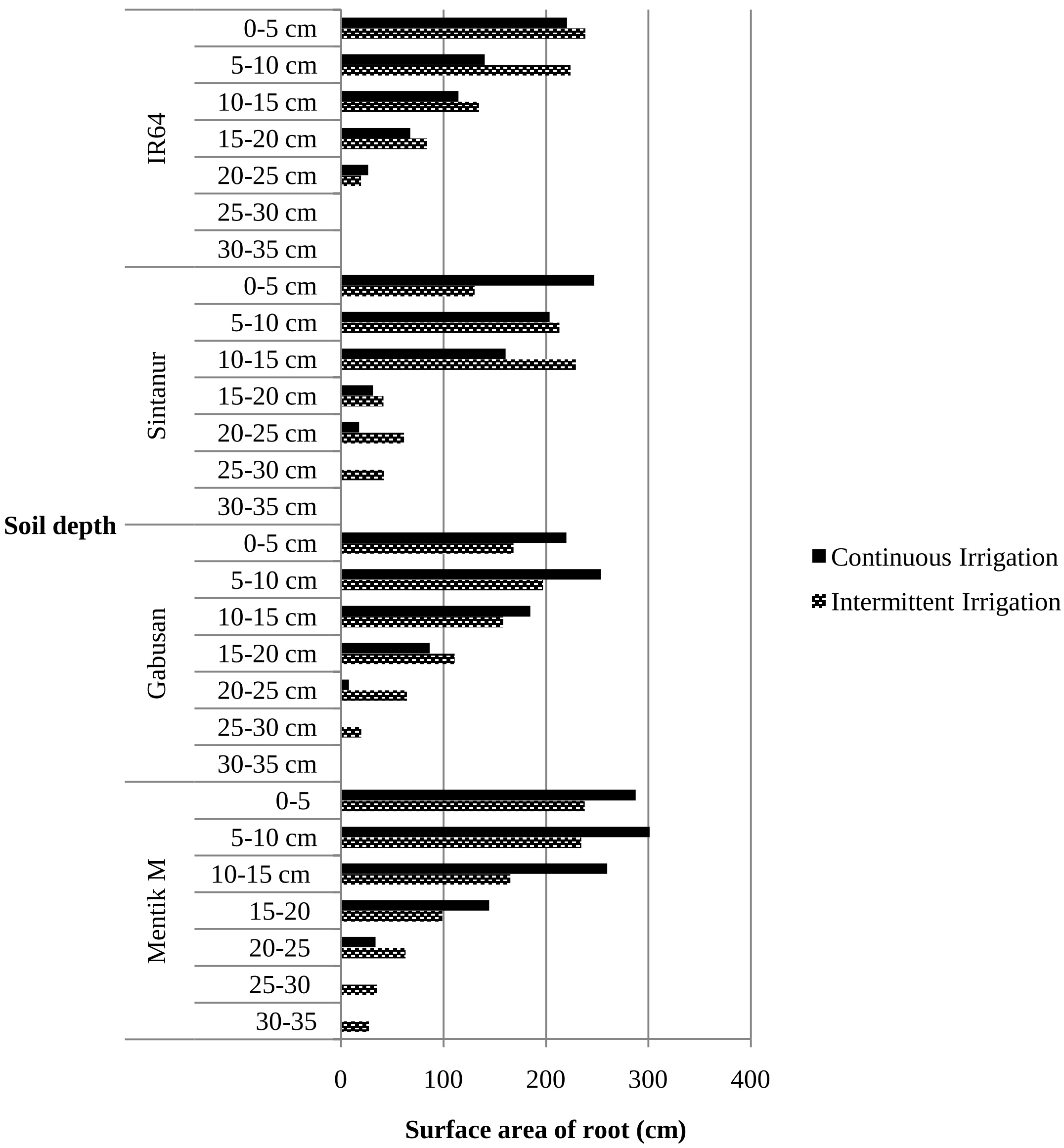

Figure 1. Distribution of the surface area of root four varieties with intermittent irrigation and continuous irrigation

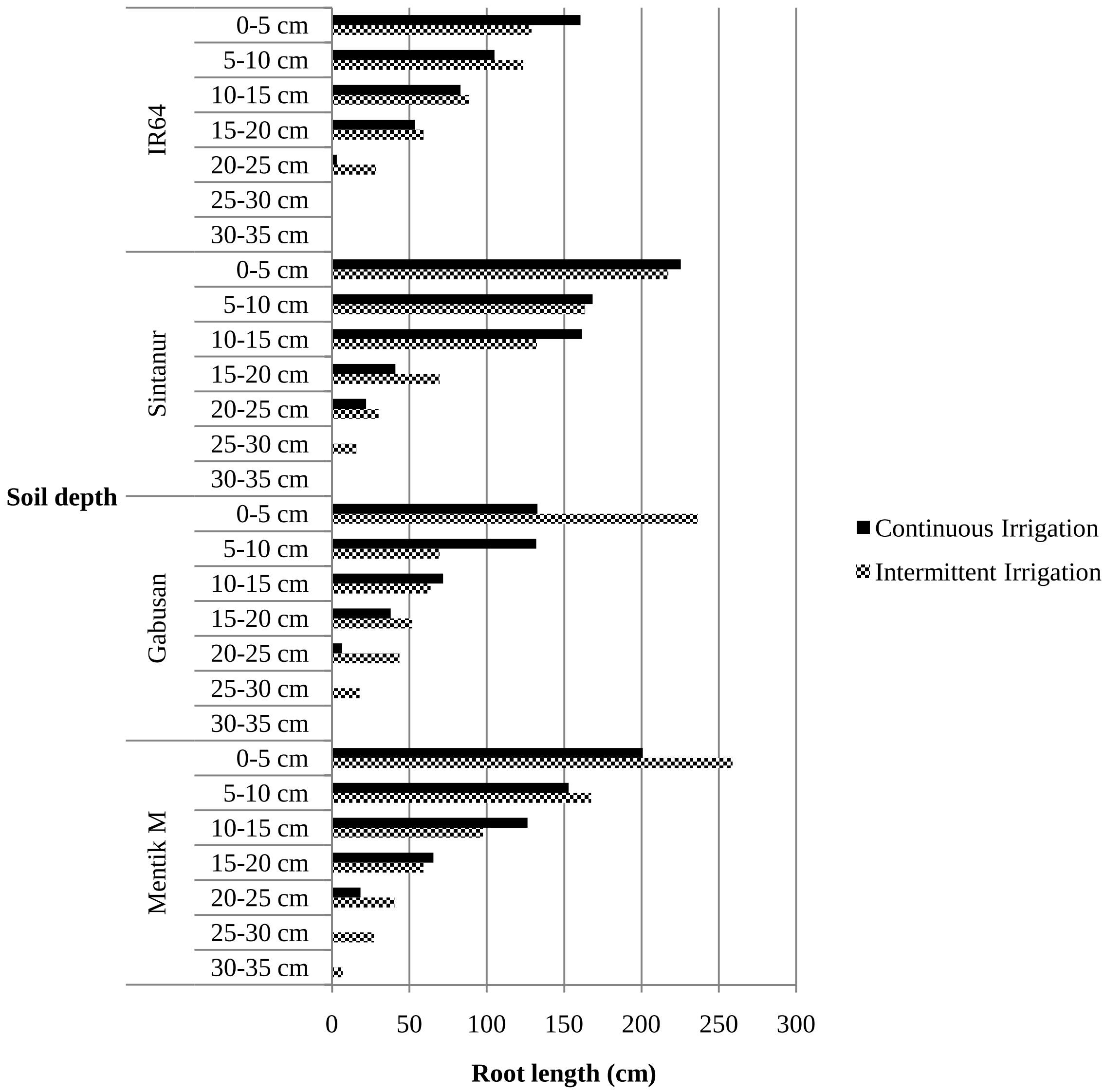

Figure 2. Distribution of the total root length of four varieties with intermittent irrigation and continuous irrigation

Physiological traits and growth of organic lowland rice

Specific Leaf Weight (SLW)

Specific Leaf Weight (SLW) is an indicator of plant leaf thickness. The higher the value of SLW the thicker the leaves. The thicker leaves will have more cell numbers than those of thin leaves. High cell levels have the power to higher photosynthesis. The thick leaves cause the volume ratio to the leaf surface area to be high; therefore at the same network volume the surface area of the transpiration is lower. Under these circumstances, the transpiration rate is lower even though the total capacity remains high so that water usage is more efficient. The results of data analysis showed that the SLW (Table 5) was influenced by the interaction between system of irrigation and varieties. Intermittent irrigation increased the SLW of Sintanur variety. In continuous irrigation there was no difference of the SLW among the tested varieties, while in intermittent irrigation, the SLW of Sintanur variety was the highest and significantly different from those of the other varieties. SLW was positively correlated with the Net Assimilation Rate (NAR) (r = 0.85 **); the greater the SLW, the greater the NAR, and with the increase in SLW, the crop growth rate (r = 0.64 **) would increase too.

Net Assimilation rate (NAR)

The process of photosynthesis has an important role in the growth and development of plants. The process of photosynthesis that goes well will be followed by increased production of assimilates. The assimilates will be used in the metabolic processes within the plant. Net Assimilation Rate (NAR) is the production of dry matter per unit of leaf area per unit of time. This suggests that leaves and light are the determining factors in the formation of assimilation results. The wider the leaf and the more light that can be absorbed will determine the amount of assimilation results. NAR is greater when all leaves intercept light and are not shaded. This means that although the leaf area index (LAI) produced is high but due to shading in the crown below it, the number of leaves that can intercept is fewer, and consequently the NAR will decrease. The result of data analysis shows that the NAR was influenced by the interaction of the mode of irrigation with varieties. Intermittent irrigation increases the NAR of Sintanur variety. In continuous irrigation, the NAR of all tested varieties was not different, while in intermittent irrigation the NAR of Sintanur variety was the highest and different from those of the other varieties. The NAR significantly correlated positively with the Crop Growth Rate (CGR) (r = 0.47 **) which means that with the increased NAR, the CGR also increased.

Crop Growth Rate (CGR)

Crop Growth Rate (CGR) is the increase of plant weight per unit of land occupied by the plant within a certain time. The result of data analysis showed that CGR was influenced by the interaction of the mode of irrigation with varieties. Intermittent irrigation increases the CGR of all varieties i.e. Mentikwangi, Gabusan, Sintanur, and IR64. In continuous irrigation, the CGR of Sintanur variety was the highest and different from those of Gabusan and IR64 varieties, but not different from that of Mentikwangi. In intermittent irrigation, the CGR of Sintanur variety was the biggest and different from those of Gabusan and IR64 varieties, but not different from that of Mentikwangi variety. Lin et al. (2011) stated that intermittent irrigation produces a higher LAI than that in continuous irrigation. Continuous irrigation results in lower LAI, NAR, CGR and productive tillers. Thakur et al. (2011) reported that the higher value of CGR with aerated rice field by draining the flood water for some time as compared to continuous flooding is similar to this observation.

Table 5. Specific leaf weight, net assimilation rate, and crop growth rate as affected by mode of irrigation and varieties of lowland rice

Mode of Irrigation	**Variety**	**Specific Leaf Weight (x 10^{-5} g)**	**Net Assimilation rate (x 10^{-4}) (g/dm^2/week)**	**Crop Growth Rate (x 10^{-5}) (mg/cm^2/days)**
Intermittent Irrigation	Mentikwangi	2.453 bc	114 b	1967 ab
	Gabusan	1.768 bc	102 b	1351 cd
	Sintanur	6.090 a	222 a	2246 a
	IR64	2.662 b	86 b	1570 bc
Continuous Irrigation	Mentikwangi	1.358 bc	89 b	998 de
	Gabusan	1.066 c	54 b	781 e
	Sintanur	1.247 c	78 b	1292 cd
	IR64	1.219 c	46 b	710 e
Interaction		(+)	(+)	(+)
CV (%)		38.64	67.63	24.19

Note : The numbers in the same column followed by the same letter are not significantly different according to DMRT 5%

Yield and component of yields

Weight of 1000 grains

Weight of 1000 grains is the weight of 1000 grains of each plot. The results of data analysis showed that the weight of 1000 grains was influenced by the interaction of the mode of irrigation with varieties (Table 7). Intermittent irrigation increases the weight of 1000 grains of Mentikwangi, Sintanur and IR64 varieties. In continuous and intermittent irrigation, the weight of 1000 grains of Sintanur variety was the highest and different from that other of varieties. There was a negative correlation between the weight of 1000 grains, the grain weight per hill (r = -0.15) and per plot (r = -0.15).

Table 6. The correlation analysis between specific leaf weight, net assimilation rate, and crop growth rate

Growth character	Specific Leaf Weight (SLW)	Net Assimilation rate (NAR)	Crop Growth Rate (CGR)
SLW	**0**	0.85**	0.64**
NAR	0.85**	**0**	0.47**
CGR	0.64**	0.47**	**0**

Table 7. Weight 1000 grains, grains yields per hill, and grains yields per plot as affected by mode of irrigation and varieties of lowland rice

Mode of Irrigation	Variety	Weight 1000 grains (g)	Grain yields per hill (g)	Grains yields per plot (kg)
Intermittent Irrigation	Mentikwangi	23.94 c	35.56 a	14.23 a
	Gabusan	20.22 g	35.69 a	14.28 a
	Sintanur	30.32 a	33.94 a	13.58 a
	IR64	22.57 e	34.50 a	13.80 a
Continuous Irrigation	Mentikwangi	23.42 d	35.63 a	14.15 a
	Gabusan	20.04 g	37.69 a	15.08 a
	Sintanur	29.36 b	35.31 a	14.13 a
	IR64	21.84 f	34.00 a	13.60 a
Interaction		(+)	(-)	(-)
CV (%)		1.35	9.31	9.37

Note : The numbers in the same column followed by the same letter are not significantly different according to DMRT 5%

Grain yield per hill

Grain yield per hill is the weight of grains per hill. The result of data analysis showed that the grain yield per hill was not influenced by interaction of the mode of irrigation with varieties (Table 7). Intermittent irrigation did not decrease grain yield per hill of all tested varieties. In continuous and intermittent irrigation, the highest grain yield per hill was achieved by Gabusan variety as a local variety. Tadesse et al. (2013) reported that rice yield and yield components were depressed in response to prolonged flooding. The result of correlation analysis showed that the grain yield per hill was influenced by weight of 1000 grains (r = - 0.15 *), meaning that the greater the weight of 1000 grains the lower the weight of the grain yield per hill. Weight of 1000 grains indicates the size of quality, i.e. high grain yield are usually small sized but available in large quantities.

Grain yields per plot

The result of data analysis showed that the dry weight of grain at harvest per plot was not influenced by the interaction of the mode of irrigation with varieties (Table 7). Intermittent irrigation did not decrease grain weight per plot. In both intermittent and continuous irrigation, the grain weight per hill was achieved by Gabusan variety. Nyamai et al. (2012) precisely reported a 71% yield increase with alternate flooding and drying over continuous flooding and Lin et al. (2011) also reported a 10.5 to 11.3% grain yield increase under intermittent water application compared to continuous flooding. The result of correlation analysis showed that the grain weight per plot was positively correlated (r = 0.99 **) with the grain weight per hill, but negatively correlated with the weight of 1000 grains (r = - 0.15 *) (Table 8).

Table 8. The correlation analysis between weight 1000 grains, grain yields per hill, and grain yields per plot

Yield component	Weight 1000 grains	Grain weight per hill	Grain weight per plot
Weight 1000 grains	0	-0.15*	- 0,15*
Grain weight per hill	-0.15*	0	0.99**
Grain weight per plot	-0.15*	0.99**	0

Conclusion

It was observed that there was no difference in rice grain yield between intermittent irrigation and continuous irrigation, so that the use of intermittent irrigation is more efficient in water use.

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