Water Productivity of Newly Developed Lowland Rice Field

Produktivitas Air dari Sawah Bukaan Baru

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Abstract. Newly developed wetland rice fields require more water because plough pan layer are not developed. Plough pan is established several years after the field development and its formation depends on the intensity of rice cultivation and the soil properties. Plot scale study was conducted on newly developed wetland rice field originated from upland in Pati village, North Kalimantan Province, Indonesia in 2013. The aim of this experiment was to study the water productivity of the newly developed wet land rice fields. Different water ponding treatments including water ponding layer of 5 cm as control (T0), ponding layer of 3 cm (T1) intermittent with two weeks wetting and one week drying (T2), and saturated condition with water layer of 0.5 cm (T3) were tested. Rice growth, rice grains yield and water productivity were evaluated. Water productivity was computed according to the ratio between rice grains yield and water input. Water input was predicted based on the difference between incoming and outgoing water. In this study water balance was not taken into account in calculating the water input. The results indicated that under saturated condition (T3), plant height and tiller number were significantly lower than the 5 cm ponding and also significantly lower than other treatments. Water productivity between 0.78 and 0.40 gram liter^{-1} were recorded under ponding water depth of 0.5 cm and intermittent ponding of 5 cm in the wet period.

Abstrak. Sawah bukaan baru membutuhkan banyak air karena lapisan tapak bajak belum terbentuk. Lapisan tapak bajak akan berkembang setelah beberapa tahun tergantung pada intensitas penanaman padi. Percobaan pada skala plot dilaksanakan pada sawah bukaan baru yang berasal dari lahan kering di Dusun Pati, Kabupaten Bulungan, Kalimantan Utara pada tahun 2013. Penelitian bertujuan untuk mempelajari produktivitas air pada sawah bukaan baru. Beberapa perlakuan tinggi genangan air diuji dalam penelitian ini meliputi tinggi genangan air 5 cm sebagai kontrol (T0), tinggi genangan air 3 cm (T1), *Intermitten* dengan dua minggu periode basah dan satu minggu periode kering (T2), dan macak-macak atau jenuh air dengan tinggi genangan air 0,5 cm (T3). Data yang diambil meliputi pertumbuhan tanaman padi, hasil gabah dan produktivitas air. Produktivitas air dihitung dengan perbandingan antara hasil gabah dengan air yang dibutuhkan, sedangkan air yang dibutuhkan dihitung berdasarkan selisih antara air yang masuk ke sawah dengan air yang keluar dari sawah. Hasil percobaan menunjukkan bahwa perlakuan macak-macak atau jenuh air dengan tinggi genangan 0,5 cm menghasilkan tinggi tanaman dan jumlah anakan padi yang secara nyata lebih rendah dibandingkan dengan perlakuan kontrol dengan tinggi genangan air 5 cm dan perlakuan lainnya, tetapi menghasilkan produktivitas air yang tertinggi yaitu 0,78 gram liter^{-1}. Produktivitas air yang memberi harapan yang menjanjikan pada sawah bukaan baru adalah antara 0,78 – 0,40 gram liter^{-1} dengan perlakuan macak-macak dengan tinggi genangan air 0,5 cm dan *intermitten* dengan tinggi genangan air 5 cm pada periode basah.

Introduction

In Indonesia, the great pressure of land resources currently has occurred in most areas in the provincial levels. This pressure happened due to population growth, industrialization and housing, agricultural land degradation, and growing demand of healthy or organic foods. In addition, waters are getting more limited and expensive because of increasing competition with industrial and domestic purposes and increasing water pollution. These are disturbing rice production, food security and rice self-sufficiency (Sukristiyonubowo 2007). Furthermore, water logging, salinization, ground water mining, deforestation and water pollution are

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increasing pressure water quality. Consequently, according to IWMI (2007) water used for irrigation is facing severe competition with industrial and household purposes. It has to need good water management not only to save water for avoiding push down of agriculture production, but also to have good water quality for domestic purposes like drinking water. Therefore, the great Indonesian agriculture challenge ahead is producing more rice with limited water and land (Sukristiyonubowo 2007; Sukristiyonubowo *et al.* 2011).

Rice is the major food crop that can be grown in standing water. In wetland rice, varying amount of water is needed from land preparation to ripening. In general, water in agriculture can be placed in social, ecological and political contexts as the water explicitly addresses multiple use, feedbacks and dynamic interactions between production systems, livelihood support and the environment (IWMI 2007).

Water productivity can be defined as physical or economic output per unit water application or generally is defined as crop yield per cubic meter water consumption. It varies from region to region, from field to field depending upon cropping pattern and climate factors, irrigation technology, field water management and inputs (Cai and Rosegrant. 2003). The definition of water productivity is also scale dependent; therefore, it can be measured at plot, farm, watershed, regional and basin levels. According to Molden *et al.* (2003) water productivity also depends on the reability and quality of irrigation water applied in addition to over water delivery. It is reported that among cereals crops, rice consume more water and inefficient in using water. It is reported that water productivity of lowland rice in India range from 0.50 to 1.10 kg m^{-3} and in Philippines between 1.40 and 1.60 kg m^{-3} (Cai and Rosegrant 2003; Kijne *et al.* 2003;). Furthermore, Cai and Rosegrant (2003) reported that water productivity range from 0.15 to 0.60 kg m^{-3} and other cereals range from 0.20 to 2.40 kg m^{-3}. However, in general the water productivity in India, Philippine and Japan vary between 0.14 to 1.10 g kg $water^{-1}$ (Bhuiyan 1992; Bhuiyan *et al.* 1994; Bouman and Tuong 2001; Cabangon *et al.* 2002; Cai and Rosegrant 2003; Tabal *et al.* 2002; IWMI 2004). Furthermore, Anbumozhi *et al.* (1998) observed that water productivity in Vitric Andosol (Japan) is a bit better about 1.52 g rice per kg $water^{-1}$. Study in Iran found that water productivity of rice is about 0.42 kg m^{-3} (Montazar and Kosari 2008).

Nutrients-use efficiencies in flooded rice are often low because of high losses, resulting in groundwater contamination and high fertiliser cost for farmers. As a result, water management in newly developed wet rice field are required to increase water use efficiency in rice production. In order to quantify the water need on newly developed wetland rice field, ponding water depth including ponding water of 5 cm, 3 cm, saturated (*macak-macak)* and intermittent or alternate wetting and drying were studied. Ponding water layer of 5 cm depth is used as control as normally in rice field the farmers used to apply this depth. The importance of this study is to save water as water is getting scarce and more expensive. We do hope that the implementation of this study on water management of newly developed wetland rice would certainly contribute to improve wetland rice and save the water in Indonesia. This paper emphasized on the effect of ponding water depth on rice growth, rice yield and water productivity of newly developed wetland rice field.

Material and Method

Plot scale experiment was carried out in newly developed wetland rice at Pati Village, in Bulungan District, North Kalimantan Province, Indonesia in 2013. The site was relatively flat and developed two years ago in 2011. Soil samples were taken in February 2013 at 0-20 cm layer depth. These samples were submitted to the Analytical Laboratory of the Soil Research Institute at Bogor for analyses of chemical properties of the soils. Chemical analyses included the measurement of pH (H_20 and KCl), organic matter, phosphorus, and potassium, Organic matter was determined using the Walkley and Black method, pH (H_2O and KCl) was measured in a 1:5 soil-water suspension using a glass electrode, total P and soluble P were measured colorimetrically using HCl 25% and Olsen methods, respectively. The total K was extracted using HCl 25% and subsequently determined by flame-spectrometry. (Soil Research Institute 2009). From the chemical analysis, the soil was acidic with low natural level of major plant nutrients including N, P, and K, but having Al, Mn, and Fe in toxic levels (Table 1).

Table 1. Chemical soil properties of Pati Village, Bulungan District, North Kalimantan (soil samples were taken in February 2013 in 0-20 cm depth)

Tabel 1. Sifat kimia tanah dari tanah Dusun Pati, Kabupaten Bulungan, Propinsi kalimantan Utara (contoh tanah diambil pada bulan Februari 2013 pada kedalaman 0-20 cm)

Soil parameters	Value	Criteria
Soil pH (H_20)	4.88	Very acid
Soil pH (KCl)	4.38	Very acid
Organic matter:		
C-Organic (%)	2.50	Medium
N Total (%)	0.10	Medium
P Total extracted with HCl 25% (mg kg^{-1})	330	Medium
K Total extracted with HCl 25% (mg kg^{-1})	70	Low
Available K extracted with Morgan (mg kg^{-1})	190	Medium
Fe (ppm)	210	High
Mn (ppm)	50	High

According to the farmers, the rice yield in this site was still good; in average about 2.0 t ha^{-1} $season^{-1}$, but this yield tend to decrease every season. This is also happening in Panca Agung Village in East Kalimantan (Sukristiyonubowo *et al*. 2011). This soil requires more mineral and organic fertilisers to improve nutrients level (Sukristiyonubowo *et al*. 2011; Sujadi 1984). Practically, to sustain crop production, proper management practices using more organic matter plus liming, and application of appropriate inorganic fertiliser is often proposed (Fageria and Baligar 2001; Yan *et al.* 2007; Sukristiyonubowo *et al.* 2011; Sukristiyonubowo and Tuherkih 2009; Sukristiyonubowo *et al*. 1993).

Four water ponding depths were tested namely T0: ponding water depth of 5 cm as control, T1: ponding water layer of 3 cm, T2: two weeks watering with ponding water of 5 cm followed by one a week drying (intermittent), and T3: ponding water layer of 0.5 cm locally called *macak-macak*. According to the farmers, water was applied from land preparation to the beginning of ripening phase. To control the ponding water depth, every plot was placed batch and staff gate. The treatments were arranged in Randomized Complete Block Design (RCBD) and replicated three times. Each plot size was 5 x 5 m with the distance among plot 50 cm and between replication 100 cm.

Urea, SP-36 and KCl were applied. Based on the direct measurement with Soil Test Kits, the recommendation rate was determined about 250 kg urea, 100 kg SP-36 and 100 kg KCl ha^{-1} $season^{-1}$. Urea and KCl were applied three times, 50% at planting time, 25 % at 21 days after planting (DAP) and the last 25 % was given at 42 DAP. SP-36 were applied two time, 50 % at planting time and 50 % at 21 DAP. Dolomite ($CaCO_3MgCO_3$) as much as 2 t ha^{-1} and rice straw compost of about 2 t ha^{-1} $season^{-1}$ were broadcasted a week before planting.

Twenty-one days old Ciherang rice variety, a national high yielding variety, was cultivated as plant indicator crop at spacing of 25 x 25 cm. Transplanting with three seedlings per hill was done in the end of March 2013 and harvesting in the beginning of August 2013. Rice biomass productions including rice grains, straw, and residues were assessed. On a hectare basis, they were extrapolated from sampling areas of 1 x 1 m. These sampling units were randomly selected at every plot. Rice plants were cut about 15 cm above the ground surface. The samples were manually separated into rice grains, rice straw, and rice residues. Rice residues included the roots and the part of the stem (stubble) left after cutting. Fresh weights of rice grain, rice straw, and rice residue were weighed for each sampling unit.

The parameters measured including (a) water discharge of incoming water from canal to the field or plot, (b) outgoing water from field or plot were observed using the *floating Method* with stop watch (Sukristiyonubowo 2007), (c) ponding water layers were measured from surface to the defined height according to the treatments by putting a small staff gate, and (d) rice growth and yield, as well as water productivity. Water productivity was predicted according to the ratio between rice grains yield and water input. Since the evapotranspiration was not measured, water input was computed according to the different between incoming water and outgoing water.

Results and Discussion

Effect of ponding water layer on rice growth

The effects of ponding water depth on plant height and tiller number of Ciherang variety are presented in Table 2 and 3.

In general, compared to the control or ponding water layer of 5 cm (T0 treatment), ponding water layer did not significantly increase rice plant height at 30 day after planting (DAP), 60 DAP and at harvest (Table 2). At 30 DAP, the ponding water of 0.5 cm locally called *macak-macak* (T4) was significantly lower than ponding water layer of 5 cm or Control (T0). Meanwhile at 60 DAP, there were no significantly different in rice plant height compared to control or ponding water of 5 cm (T0). It did not have any effect on rice plant height maybe because the amounts of nutrient coming from fertiliser and flooded were more than enough to support rice plant height. According to Ponnamperuma (1978), Tadano and Yoshida (1978)**,** Hardjowigeno and Rayes (2005) Widowati and Sukristiyonubowo (2012) flooding improve soil quality by increasing pH, activating microbial activities, increasing P and Ca availability, and decreasing Eh or potential redox.

The ponding water depth also did not improve the tiller number at 30, 60 DAP and at harvest compared to the control (T0). At the control or at the ponding water layer of 5 cm was significantly higher than other treatments (Table 3). Furthermore, the interactions between water depth and fertiliser enhanced the tiller number. According to Zen *et al.* (2002) at 0 cm water depth has a lower effective tillers and panicle per plant and significant increase with water depth up to 6 cm.

Effect of ponding water depth on rice yield and water productivity

Rice grains yield was significantly enhanced by the ponding water layers (Table 3). Depending on the treatments or ponding water layers, the rice grains yields varied from 3.18 to 3.91 t ha^{-1} $season^{-1}$ with the different in yields were about 0.57 to 0.73 t ha^{-1} $season^{-1}$. The highest

Table 2. Plant height of Ciherang variety planted on newly opened wetland rice at Pati Village, Bulungan District, North Kalimantan Province at 30, 60 DAP, and harvest

Tabel 2. Tinggi tanaman padi umur 30, 60, dan saat panen varietas Ciherang yang ditanam pada sawah bukaan baru di Dusun Pati, Kabupaten Bulungan, Propinsi Kalimantan Utara

Treatment	Plant height		
	30 DAP	60 DAP	Harvest
	……………………………. cm ……………………………..		
T0 : Ponding water layer of 5 cm as control	57.01 ± 1.72 b	88.26 ± 3.58 ab	106.65 ± 2.76 b
T1 : Ponding water layer of 3 cm	57.30 ± 3.23 b	89.72 ± 4.84 b	106.34 ± 2.58 ab
T2 : Intermittent (two weeks wet with ponding water layer of 5 cm and one week dry)	55.38 ± 3.35 ab	86.08 ± 4.70 a	105.41 ± 3.40 ab
T3 : *Macak-macak* with ponding water 0.5 cm	53.64 ± 4.28 a	85.26 ± 3.33 a	104.26 ± 2.90 a
CV (%)	5.87	4.77	

Note: DAP = Day after planting; The mean values in the same column followed by the same letter are not statistically different

Table 3. Tiller number of Ciherang variety planted on newly opened wetland rice of Pati Village, Bulungan District, North Kalimantan Province, at 30, 60 DAP, and harvest

Tabel 3. Jumlah anakan padi umur 30, 60 HST, dan saat panen varietas Ciherang yang ditanam pada sawah bukaan baru di Dusun Pati, Kabupaten Bulungan, Propinsi Kalimantan Utara

Treatment	Tiller number		
	30 DAP	60 DAP	Harvest*
T0 : Ponding water layer of 5 cm as control	10,77 ± 1.38 ab	14.87 ± 2.22 b	12.79 ± 1.29 c
T1 : Ponding water layer of 3 cm	11,04 ± 1.40 b	13.73 ± 1.53 ab	12.26 ± 1.32bc
T2 : Intermittent (two weeks wet with ponding water layer of 5 cm and one week dry)	10,10 ± 0.90 ab	14.15 ± 1.46 ab	11.82 ± 0.70 b
T3 : *Macak-macak* with ponding water 0.5 cm	9,83 ± 1.57 a	12.87 ± 12.87 a	10.87 ± 1.18 a
CV (%)	12.83	12.60	9.64

Note: DAP = Day after planting
*) At Harvest tiller number is also called number of spikelet
The mean values in the same column followed by the same letter are not statistically different

rice grains yield of 3.91 t ha^{-1} was indicated by the ponding water depth of 5 cm or control (T0). Compared to the ponding water of 0.5 cm or *macak-macak*, the T0 (the ponding water depth of 5 cm) was higher about 0.73 ton ha^{-1}. This probably was due to increasing tiller numbers and the number of spikelet as well as weigh of 1,000 filled rice grains in T0 treatment (Table 4).

The reason also due to in the *macak-macak* treatment (T3) too many weeds compared to other treatments. Thus, it was occurred the nutrient competition with weeds. Therefore, these findings proved that ponding water layer of rice cultivation can be managed depending on available irrigation water, and we can say that water ponding layer below 5 cm was still required in newly open wet land rice fields to save the water.

The calculation of water input during rice growth and development, started from land preparation to the beginning of ripening stage indicated that about 48 x 105 to 22 x 106 litter irrigation water was required to the rice field (Table 5).

From Table 5, it was shown that water required for rice cultivation depending on the water ponding depth as well as the way of cultural practices. The deeper the water layers the higher the water requirement of rice crop. At the ponding water layer of 0.5 cm (T3), the irrigation water was the lowest, about $48x10^5$ litters, and it increased about 32 to 172 x 10^5 l $sesaon^{-1}$ with increasing ponding water layer (Table 5). According to Sukristiyonubowo *et al.* (2012), in the conventional rice cultivation normally with ponding water layer of 0-10 cm consume more irrigation water, with the average amount of water (50 x 10^6 l $season^{-1}$) followed by ponding water layer 0-7 cm (35 x 10^6 l $season^{-1}$). Meanwhile, maximum water saving was recorded with ponding water depth of 0.5 cm locally named *macak-macak* followed by intermittent with ponding water layer of 5 cm. The highest grains yield of about 3.91 t ha^{-1} was still observed at the water ponding layer of 5 cm (T0). This may be attributed probably to significant difference tiller number and number of filled spikelet as well as weight of 1,000 filled grains (Table 4).

Table 4. Weight of 1,000 filled grain of Ciherang variety at different ponding water layer planted at newly opened wet land rice

Tabel 4. Berat 1.000 butir gabah isi padi varietas Ciherang pada beberapa tinggi genangan air yang ditanam pada sawah bukaan baru

Treatment	Weight 1,000 filled rice grain
	gram
T0 : Ponding water layer of 5 cm as Control	27.75 ± 0.20 a
T1 : Ponding water layer of 3 cm	27.35 ± 0.18 a
T2 : Intermittent (two weeks wet with ponding water layer of 5 cm and one week dry)	27.16 ± 0.16 a
T3 : *Macak-macak* with ponding water 0.5 cm	26.78 ± 0.45 ab
CV (%)	0,01

Note: The mean values in the same column followed by the same letter are not statistically different

Table 5. Discharge of inlet and outlet, water input, rice grains and water productivity of Ciherang variety planted at newly opened wetland rice with different ponding water layer at Pati Village, Bulungan District, North Kalimantan Province

Tabel 5. Debit inlet dan outlet, kebutuhan air, produksi padi varietas Ciherang dan produktivitas air pada sawah bukaan baru dengan beberapa tinggi genangan di Dusun Pati, Kabupaten Bulungan, Provinsi Kalimantan Utara

Treatment	Discharge of inlet	Discharge of outlet	Water input	Rice grains	Water productivity
	……… l sec^{-1}	………	l season^{-1}	t ha^{-1}	gr liter^{-1}
T0 : Ponding water layer of 0 – 5 cm as Control	6.40	0.65	22 x 10^6	3.91 ± 0.47 b	0.18
T1 : Ponding water layer of 0 – 3 cm	3.85	0.60	13 x 10^6	3.75 ± 0.52 b	0.28
T2 : Intermittent (two weeks wet with ponding water layer of 0 – 5 cm and one week dry)	3.90	0.65	8 x 10^6	3.18 ± 0.64 a	0.40
T3 : *Macak-macak* with ponding water layer of 0.5 cm	3.15	1.30	48 x 10^5	3.79 ± 0.57 b	0.78
CV (%)				15.07	

In addition, at the intermittent treatment with ponding water of 5 cm when it wet (T2 treatment) indicated promising rice yield. However, it was good to be researched for future on water management in newly developed wetland rice field to save water as water for irrigation is getting scare.

Water productivity of newly developed wetland rice field ranged between 0.18 and 0.78 g litre^{-1} depending on the ponding water depth (Table 5). The promising water depths were at the ponding water layer of 0.5 cm (T0) and intermittent (T2) with the water productivity was 0.78 and 0.40 g litre $^{-1}$, respectively. These water depths will be the options to be demonstrated to save water for the future. These results were similar to rice producing countries (Bhuiyan, 1992; Bhuiyan *et al.* 1994; Bouman and Tuong, 2001; Cabangon *et al.* 2002; Cai and Rosegrant. 2003; Taball *et al.* 2002; IWMI, 2004).

Conclusions

Study on water productivity in newly developed wetland rice indicated that water ponding layer affected the tiller number, rice grain and water productivity. At the water depth of 5 cm, rice tiller number and grain yield were the highest among the tested treatments, but this trearment needs more water. The water productivity at the ponding water layer of 0.5 cm and intermittent irrigation indicated the best option to save water.

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