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Management of inherent soil fertility of newly opened wetland rice field for sustainable rice farming in Indonesia

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Study on management of inherent soil fertility of newly opened wetland rice for sustainable rice farming in Indonesia was conducted in Bulungan District, from 2009 to 2010. The aims were to know the soil fertility status and properly manage its fertility status to improve rice yield and sustain rice farming. Six treatments were imposed including T0: farmers practices, T1: farmer practices + compost + dolomite, T2: NPK recommended rate, N and K were split two times, T3: NPK recommended rate, N and K were split three times, T4: NPK recommended rate, N and K were split three times + compost + dolomite and T5: NPK recommended rate, N and K were split two times + compost + dolomite. The residual effect of dolomite and compost applied in 2009 was continually assessed in 2010. The results indicated that inherent soil fertility was categorised poor with high level of iron and manganese. Application of 250 kg urea, 100 kg super phosphate-36 and 100 kg potassium chloride ha^{-1}, in which N and K fertilisers were split three times plus 2 tons dolomite and 2 tons compost ha^{-1} also the residual effect of dolomite and compost improved soil fertility, rice growth and biomass production.

Key words: Soil fertility, newly wetland rice, rice farming, dolomite, compost.

INTRODUCTION

Soil quality assessment including chemical, physical and biological properties has become a model to determine soil function. According to Doran and Parkin (1994) soil quality is defined as the capacity of the soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental productivity and promote plant and animal health. So far, Sharma et al. (2008) reported that in the past soil quality is understood as inherent soil capacity to supply essential plant nutrients.

Combining use of mineral and organic fertilisers (recycling rice straw, crop residues, compost and manure) are recommended to improve soil function (Fenning et al., 2005; Hasegawa et al., 2005; Khai et al., 2007; Yang et al., 2007; Sukristiyonubowo and Tuherkih, 2009).

In Indonesia over two third of total population depend on agricultural sector within which wetland rice play an important role in sustaining food security and building rural livelihood like providing job and income. However, agricultural practices particularly in rice farming, application of fertilizers rate and crop residue management differ among farmers within sub district, resulting variability in production and soil fertility properties.

Furthermore, the shrinking of agricultural land and harvest areas in Indonesia as well as in the countries producing rice due to; (a) increasing agricultural land conversion to non-agricultural purposes, (b) increasing water competition among agricultural sector and industrial as well as domestic purposes and (c) water pollution reducing total harvest areas leading to rice production (Anonymous, 2002; Bhagat et al., 1996; Bouman and Tuong, 2001; Sukristiyonubowo, 2007).

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Table 1. The detail treatment of the effect of NPK fertilization, dolomite and compost made of straw on soil chemical properties and rice yield of newly opened rice fields.

Code	Treatment	Urea (kg ha^{-1})	SP-36 (kg ha^{-1})	KCl (kg ha^{-1})	Dolomite (kg ha^{-1})	Compost (kg ha^{-1})
T0	Farmer Practices (as control)	100	100	-	-	-
T1	Farmer Practices + Compost + Dolomite	100	100	-	2000	2000
T2	NPK with recommendation rate	250	100	100	-	-
T3	NPK with recommendation rate (N and K were split 3 x)	250	100	100	-	2000
T4	NPK with recommendation rate + Compost + Dolomite (N and K were split 3x)	250	100	100	2000	2000
T5	NPK with recommendation rate + Compost + Dolomite	250	100	100	2000	2000

Hence, the Indonesian agricultural challenge ahead especially for rice is producing more rice with limited soil and water.

Highly weathered Indonesian soils, especially ultisols and oxisols are mainly granted for extending newly opened wetland rice field to meet rice growing demand in Indonesia, besides potential acid sulphate soils. Furthermore, these soils are acidic with low natural level of major plant nutrients, but having toxic levels of Al, Mn and Fe (Sudjadi, 1984). Theoretically, soils fertlity status can be effectively addressed with addition of mineral fertilisers.

However, for the smallholder farmers, for instance farmers living in transmigration areas the costs to purchase the fertilisers are problem. The chemical fertiliser in sufficient quantity is beyond the financial reach of smallholder farmers. 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., 1993; Sukristiyonubowo and Tuherkih, 2009). In addition, Whitbread et al. (2003), Sukristiyonubowo 2007, 2010 also reported that sustainable farming system requires stable soil fertility through balance fertilization and crop residue management.

The aims of the study were to know the inherent soil fertility status and its management to improve productivity and sustain rice under newly opened wetland rice field.

MATERIALS AND METHODS

To determine soil fertility status of newly opened wetland rice, soils samples were taken from the newly opened wetland rice of Bulungan District established in 2007. Composite samples of topsoil, 0 to 20 cm layers, were taken in March 2009, before land preparation. Eight composite samples were analysed. Every composite sample was randomly collected from ten sampling points mixed thoroughly to 1 kg as a composite sample. These samples were submitted to the Analytical Laboratory of the Indonesian Soil Research Institute at Laladon Bogor to determine chemical properties and texture. Soil chemical analyses included the measurement of pH (H_20 and KCl), organic matter (organic carbon and total nitrogen), phosphorus, potassium, base saturation and cation exchange capacity (CEC) as well as iron (Fe) and manganese (Mn) contents.

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 method, total P and available P were measured colorimetrically using HCl 25% and Olsen methods, respectively. The total potassium (K) was extracted using Chloride Acid 25% (HCl 25%) and subsequently determined by flame-spectrometry. The CEC was determined using an Ammonium Acetate 1 M, (pH 7.0) extraction and expressed in cmol$^+$ kg^{-1} soil. Base saturation was computed based on the sum of Ca^{++}, Mg^{++}, K^+, and Na^+ relative to CEC. Available iron (Fe) was measured using DTPA method (Soil Research Institute, 2009).

Field experiment was carried out in Panca Agung Village, Bulungan District in 2009 and 2010. Six treatments were tested including T0: farmers practices (as control), T1: farmer practices + straw compost + dolomite, T2: NPK with recommendation rate, in which N and K were split two times, T3: NPK with recommendation rate, in which N and K was split three times, T4: NPK with recommendation rate in which N and K were split three times + straw compost + dolomite and T5: NPK with recommendation rate in which N and K were split two times + straw compost + dolomite. They were arranged into randomized complete block design (RCBD) and replicated three times. The plot sizes were 5m x 5m with the distance among plot was 50 cm and between replication was 100 cm. NPK fertiliser used originated from single fertiliser namely urea, super phosphate-36 (SP-36) and potassium chloride (KCl). 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}, while the farmer practices rate was 100 kg urea and 100 kg SP-36 ha^{-1}. For the treatment T2 and T5, urea and KCl were applied two times, 50% at planting time and 50% at 21 days after transplanting (DAT). For the treatment T3 and T4, urea and KCl were split three times namely; 50% at planting time, 25% at 21 DAT and the last 25 % was given at 35 DAT. Dolomite as much as two tons ha^{-1} and rice straw compost of about two tons ha^{-1} were broadcasted a week before planting. The detail treatment is presented in Table 1.

In 2010, the residual effect of dolomite and compost was continually assessed, but the similar rates of mineral fertiliser in all treatments were still added. Like the previous experiment, for the treatment R2 and R5, urea and KCl were applied two times, namely 50% at planting time and 50% at 21 DAT, while for treatment R3 and R4 urea and KCl were split three times, 50% at planting time, 25% at 21 DAT and the last 25 % was added at 35 DAT.

Ciliwung rice variety was cultivated as plant indicator. Transplanting was conducted in the end of June 2009 and harvest in the beginning of October 2009. While for the residual experiment transplanting was conducted in the end of March 2010 and harvest in the beginning of July 2010. Twenty-one-day old seedlings were transplanted at about 25 x 25 cm plant and row spacing with about three seedlings per hill. Rice biomass productions including grains, straw and residues were observed. On a hectare basis, biomass productions were extrapolated from sampling areas of 1 x 1 m. These sampling units were randomly selected at every plot. Rice plants were cut about 10 to 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 immediately weighed at each sampling unit. Meanwhile, for rice growth parameter namely plant height and tiller number were monitored at 30 DAT, 60 DAT and at harvest. The common crop rotation is rice to rice fallow.

All data were statistically examined by analysis of variance (ANOVA) and computed using software SPSS program. Means were compared to Duncan Multiple Range Test with a 5% degree of confidence.

RESULTS AND DISCUSSION

Soil fertility of newly opened wetland rice fields

Originally, the land of about 30 ha was used to grow upland rice and cash crop, but since the last decade it was left out as the land productivity was considered low due to lack of water and lack of evidence of economic profitability. It was converted to wetland rice area in 2007, when the water from upper site (forest) was flew through pipes and collected to the agriculture water reservoir.

Chemical and physical soil properties of newly wetland rice fields of Panca Agung opened in 2007 are presented in Table 2. The texture of the soil varied from silty, clay, loam to clay, and classified into medium to fine textures. The pH of soils was acidic, varying between 4.62 and 4.70. The cation exchange capacities (CEC) values ranged between 5.81and 9.51 $cmol^+ kg^{-1}$ suggesting uniformity in clay mineralogy and low in organic matter contents. The CEC may be categorised as low. The levels of soil organic carbon (OC) and total nitrogen were very low, ranging from 0.71 to 1.29% and from 0.03 to 0.05 %, respectively. This may be due to the fact that in the past, all rice straw or crop residue was removed from the field to be used as cattle feed and/or was burnt. Sommerfeldt et al. (1988) and Clark et al. (1998) also observed higher soil organic matter (OM) levels in soils managed with animal manure and cover crops than in soils without such inputs.

Total P ranged from 31 to 58 mg P_2O_5 kg^{-1}. These values, observed in all newly opened rice field in Panca Agung, classified as very low. Furthermore, available P is also considered low, ranging between 1.09 and 2.69 mg P_2O_5 kg^{-1}. It can be suggested that application of recommended fertilisers rate as much as 100 kg SP-36 ha^{-1} $season^{-1}$ increase the availability of P. Total K extracted with HCL 25% is considered low, varying from 55 to 138 mg K_2O kg^{-1}. This also suggests that application of recommended fertilisers rate as much as 100 kg KCl ha^{-1} season $^{-1}$ will increase the total K in the soil. Clark et al. (1998), Rasmussen and Parton (1994) and Wander et al. (1994) also reported similar findings.

Base saturation is relatively low, varying between 16 and 39%. This is mainly due to the low concentrations of exchangeable Ca (1.04 to 1.83 $cmol^+ kg^{-1}$) and K (0.05 to 0.11 $cmol^+ kg^{-1}$). So far, exchangeable Mg concentrations are relatively low (0.21 to 0.27 $cmol^+ kg^{-1}$). Looking to the ratio of exchangeable calcium, magnesium and potassium percentage, the data also indicated an imbalanced ratio. In normal conditions, the ratio ranges from 60 to 65% of calcium, 10 to 15% of magnesium and 5 to 7% of potassium (Sukristiyonubowo, 2007). Looking at the iron (Fe) and manganese (Mn) concentrations, both elements are in toxic condition meaning that to minimize that problem application of organic matter as well as lime is must to enhance rice growth and yield. Therefore, it may be concluded that in general the chemical soil fertility is considered low due to low pH, organic matter content, available P and exchangeable potassium concentrations and very low to low P and K total. In addition, the soil properties variability was small as indicated by range of parameters values. Recommendation of agronomic practices to enhance rice yield of newly opened wetland rice include application of soil ameliorant like addition of manure, compost, lime, besides addition of mineral fertilisers.

Effect of lime, compost and mineral fertiliser on soil chemical properties

The influence of dolomite, compost made from rice straw, and NPK fertiliser on soil chemical properties is presented in Table 3. The results showed that in general addition of dolomite, compost and NPK fertiliser improved the total nitrogen (total N), available phosphorous (available P) measured with Bray I method, potential phosphorous (potential P) and potassium (potential K) extracted with Chloride Acid 25% (HCl 25%).

Furthermore, they also reduced Fe and Mn contents when they compared with control (farmer practices) and the original soil (taken in 2009 before land ploughing). So far, the increase in total N, potential P and K extracted with HCl 25%, available P measured with Bray I method in the treatments T3 and T4, where urea and KCl were split three times, was higher than other treatments. In addition, reduction in Fe and Mn concentration was also more than others. This shows that availability of plant nutrient especially nitrogen, phosphorous and potassium for rice growth and development when urea and KCl were split three times, was higher than other treatments.

Table 2. Chemical and physical soil properties of newly opened wetland rice in Tanjung Palas Utara Sub district, Bulungan District established in 2007 (Soils were sampled in March 2009).

Soil parameters	Unit	Value	Criteria
pH		4.62 to 4.70	Very acid
Organic matter			
C-organic	%	0.71 to 1.29	Very low
N Total	%	0.03 to 0.05	Very low
C/N ratio		20 to 26	
P Total (HCl 25%)	ppm	31 to 58	Very low
K Total (HCl 25%)	ppm	55 to 138	Low
P Bray I	ppm	1.09 to 2.69	Very low
CEC	cmol (+) kg^{-1}	5.81 to 9.53	Low
Base Saturation	%	16 to 39	Low
K	cmol (+) kg^{-1}	0.05 to 0.11	Very low
Ca	cmol (+) kg^{-1}	1.04 to 1.83	Very low
Mg	cmol (+) kg^{-1}	0.21 to 0.27	Low
Na	cmol (+) kg^{-1}	0.05 to 0.19	Low
Fe	ppm	170 to 210	High
Mn	ppm	50.40	High
Texture 1:			
Sand	%	6.1	Silty Clay Loam
Silt	%	64.8	
Clay	%	29.1	
Texture 2:			
Sand	%	1.3	Clay
Silt	%	18.3	
Clay	%	80.4	

Table 3. Effect of dolomite, compost and NPK fertiliser on soil chemical properties of newly opened wetland rice in Panca Agung Village, Bulungan District, East Kalimantan Province (soils were sampled at harvest time in October 2009).

Treatments	Chemical soil properties					
	N Total (%)	P HCl 25% (ppm P_2O_5)	K HCl 25% (ppm K_2O)	P Bray I (ppmP_2O_5)	Fe (ppm)	Mn (ppm)
Before experiment	0.05	58	31	1.09	170	50
T0	0.10	62	37	9.14	185	16.09
T1	0.12	171	29	7.40	183	17.46
T2	0.10	172	28	7.06	190	19.58
T3	0.14	149	39	9.63	157	16.80
T4	0.16	195	38	10.62	167	13.52
T5	0.14	154	31	9.25	171	18.31

T0: Farmer Practices (as control). T1: farmer practices + compost + dolomite. T2: NPK with recommendation rate. T3: NPK with recommendation rate (N and K were split 3 x). T4: NPK with recommendation rate + compost + dolomite (N and K were split 3x). T5: NPK with recommendation rate + compost + dolomite.

Besides, application of dolomite and compost to poor soil fertility was important. Combination of chemical fertilisers with compost and dolomite is important not only to improve nutrient supply, but also to minimise the

Table 4. Effect of dolomite, compost, and NPK fertiliser addition on rice plant growth of ciliwung variety at 30 DAT, 60 DAT and harvest cultivated at newly opened rice of Panca Agung site, Bulungan District.

Treatments	Plant height (cm)			Tiller number	
	30 DAT	60 DAT	Harvest	30 DAT	60 DAT
T0	39.50 ± 2.0 c	65.20 ± 4.2 c	87.67 ± 2.7 b	15.75 ± 0.3 bc	18.90 ± 2.2 b
T1	42.17 ± 3.2 bc	69.88 ± 4.5 bc	83.63 ± 2.5 b	13.72 ± 1.0 c	21.30 ± 2.3 ab
T2	45.67 ± 2.7 ab	71.10 ± 2.0 abc	90.20 ± 3.8 a	16.93 ± 0.1 ab	20.98 ± 1.0 ab
T3	47.50 ± 2.5 ab	74.73 ± 3.0 ab	90.47 ± 1.5 a	15.47 ± 0,1 bc	24.28 ± 3.0 a
T4	49.67 ± 4.2 a	76.38 ± 2.4 a	94.17 ± 1.8 a	18.57 ± 1.0 a	24.37 ± 2.0 a
T5	46.67 ± 2.7 ab	76.27 ± 3.1 a	89.72 ± 2.0 a	17.50 ± 2.5 ab	21.00 ± 2.0 ab
CV (%)	9.48	7.88	5.83	11.56	12.37

Note: The mean values in the same column followed by the same letter are not statistically different. T0: farmer practices (as control). T1: farmer practices + compost + dolomite, T2: NPK with recommendation rate. T3: NPK with recommendation rate (N and K were split 3 x). T4: NPK with recommendation rate + compost + dolomite (N and K were split 3x). T5: NPK with recommendation rate + compost + dolomite.

environmental damage.

Effect of dolomite, compost and NPK fertiliser on rice growth

The effect of dolomite, compost and NPK fertiliser addition on rice growth is presented in Table 4. At 30 DAT all treatments (T3 to T5) significantly increased the rice plant height. The T4 indicated the best treatment and significantly reached the highest rice plant height of about 49.67 ± 4.2 cm. The similar finding was observed at 60 day after transplanting. At 60 DAT, all treatments also improved rice plant height compared to control (Farmer Practices). So far, the treatment T4 also indicated the highest rice plant, meaning at this treatment nutrients supply, especially nitrogen and potassium for rice growth and development was more available. The highest rice plant was about 76.38 ± 2.4 cm (Table 4).

Furthermore, the similar results were also found at harvest time. Compared to farmer practices, all treatments, especially treatments T2 to T5 significantly increased the rice plant height. The highest rice plant was about 94.17 ± 1.8 cm, reached by T4. These data demonstrated that improvement of soil function were not only due to application of compost, dolomite and NPK fertiliser, but also the split application of N and K into three times providing more available nitrogen and potassium when they required by rice plant. Therefore, it can be said that application of NPK at recommendation rate in which N and K were split three times plus two tons ha^{-1} dolomite and two tons ha^{-1} not only improved soil function, but also rice plant height.

The similar phenomenon was also observed for the rice tiller number. At 30 DAT all treatments significantly enhanced the rice tiller number (Table 4). Interestingly, the best treatment was also showed by T4, reaching of rice tiller number as much as 18.57 ± 1.0. This data revealed that the time of fertilizer application is urgent, especially when the soil has low pH and high Fe, Al and Mn concentrations to supply more nutrients for rice growth and development.

Furthermore, at 60 DAT the similar finding was observed. The treatment T4 also indicated the highest rice tiller number of about 24.37 ± 2.0. This was significantly different with farmer practices. These data demonstrated that application of soil ameliorant and inorganic fertilisers are prerequisite for newly opened wetland rice fields to improve soil productivity. Therefore, it can be concluded that application of lime, compost and mineral fertiliser are must to improve soil function leading to enhance rice growth and yield.

Effect of dolomite, compost and NPK fertiliser on rice production

The effect of dolomite, compost and NPK fertiliser addition on rice biomass production is given in Table 5. As demonstrated in rice growth and development, compared to farmer practices, all treatments significantly enlarged the dry rice straw production. In addition to this, the treatment T4 showed the highest dry rice straw production, about 5.20 ± 0.4 t ha^{-1}. The similar results were observed for rice grain yield. All treatments significantly increased the rice grain yield, ranged between 3.09 and 4.29 t ha^{-1}. According to the farmers until one year after conversion to wetland rice areas, the rice yield was considered good, reaching 2.0 to 2.5 t ha^{-1}, afterward reduced to 1.0 to 1.5 t ha^{-1}.

It is interesting to note, the highest rice grain yield was about 4.29 ± 0.4 t ha^{-1} reached by T4, elevating yield about 1.78 t ha^{-1} or 71% compared to farmer practices (Table 5). The constant improvement of T4 to the soil function, rice growth and biomass production proved that is not only due to addition of compost, dolomite and mineral fertilisers, but also the way and time to apply the organic and especially inorganic fertilisers. The similar finding was reported by previous scientists (Clark et al., 1998; Fageria and Baligar, 2001; Yan et al., 2007;

Table 5. Effect of dolomite, compost, and NPK fertiliser addition on dry rice biomass production of Ciliwung variety cultivated at newly opened wetland rice of Panca Agung site, Bulungan District.

Treatments	Biomass production (t ha^{-1})			Increasing rice grain yield	
	Rice residue	Rice straw	Rice grain	t ha^{-1}	%
T0	2.76 ± 0.4 c	3.83 ± 0.4 b	2.51 ± 0.6 d	-	
T1	3.05 ± 0.4 bc	3.94 ± 0.7 b	2.97 ± 0.03 cd	0.46	18
T2	3.61 ± 0.2 ab	5.02 ± 0.5 a	3.09 ± 0.3 bc	0.58	23
T3	3.90 ± 0.2 a	4.64 ± 0.6 ab	3.68 ± 0.4 abc	1.17	47
T4	4.01 ± 0.1 a	5.20 ± 0.4 a	4.29 ± 0.4 a	1.78	71
T5	4.18 ± 0.3 a	5.24 ± 0.2 a	3.80 ± 0.3 ab	1.29	51
CV (%)	16.55	15.47	20.41		

The water content of dry rice grain was 12 to 14%. The mean values in the same column followed by the same letter are not statistically different.

Table 6. Residual effect of dolomite and compost on rice plant height of ciliwung variety at 30 DAT, 60 DAT and harvest cultivated at newly opened wetland rice of Panca Agung site, Bulungan District.

Treatments	Plant height (cm)			Tiller number		
	30 DAT	60 DAT	Harvest	30 DAT	60 DAT	Harvest
R0	39.50 ± 3.0 ^{c}	46.63 ± 7.1^{c}	72.30 ± 5.0 ^{c}	11.33 ± 1.3 ^{c}	14.35 ± 3.0 ^{b}	11.70 ± 0.9 ^{b}
R1	43.26 ± 2.9 ^{bc}	50.03 ± 4.6 ^{b}	74.70 ± 2.3 ^{bc}	11.15 ± 0.6 ^{c}	15.67 ± 0.4 ^{ab}	13.47 ± 0.5 ^{ab}
R2	47.33 ± 2.6 ^{ab}	68.77 ± 5.5 ^{a}	85.07 ± 4.1 ^{a}	13.60 ± 0.5 ^{b}	15.33 ± 1.0 ^{ab}	12.67 ± 0.7 ^{ab}
R3	49.83 ± 2.8 ^{ab}	66.37 ± 2.4 ^{a}	84.63 ± 3.4 ^{a}	13.80 ± 1.5 ^{b}	14.73 ± 1.9 ^{b}	13.57 ± 2.2 ^{ab}
R4	51.67 ± 6.9 ^{a}	70.33 ± 6.0 ^{a}	87.00 ± 7.7 ^{a}	17.83 ± 1.0 ^{a}	19.10 ± 3.8 ^{a}	14.70 ± 0.4 ^{a}
R5	47.12 ± 2.9 ^{ab}	64.80 ± 2.9 ^{ab}	83.70 ± 6.2 ^{ab}	14.50 ± 0.5 ^{b}	16.20 ± 0.6 ^{b}	14.27 ± 0.5 ^{a}
CV (%)	11.11	15.33	9.82	15.52	15.27	10.10

Note: The mean values in the same column followed by the same letter are not statistically different. R0: farmer practices (as control). R1: farmer practices + residue compost + residue dolomite. R2: NPK with recommendation rate. R3: NPK with recommendation rate (N and K were split 3 x). R4: NPK with recommendation rate + residue compost + residue dolomite (N and K were split 3x). R5: NPK with recommendation rate + residue compost + residue dolomite.

Rasmussen and Parton, 1994; Sukristiyonubowo et al., 1993; Sukristiyonubowo and Tuherkih, 2009; Wander et al., 1994).

Residual effect of dolomite and compost on rice growth

The residual effect of dolomite and compost on rice growth (rice plant height and rice tiller number) is given in Table 6. The results indicated that at 30 DAT, 60 DAT and at harvest time, the residue of dolomite and compost significantly improved the rice plant height. Compared to control, it increased about 9 to 31%, 7 to 51% and 3 to 21%, respectively (Table 6).

Interestingly, the highest rice plant in every observation (30 DAT, 60 DAT and at harvest) was also achieved by R4. This meant addition of 2 tons ha^{-1} dolomite and 2 tons ha^{-1} compost made from rice straw gave an effect up to two years maybe more in improving of soil fertility as well as rice growth. It can be concluded that dolomite and compost as much as two ton ha^{-1}, therefore can be applied at least every two years.

Furthermore, this was also found for rice tiller number. At 30 DAT, 60 DAT and at harvest time, the tiller numbers at treatments R1, R4 and R5 were significantly enhanced. Compared to farmer practices (R0), tiller numbers increased about 28 to 57%, 9 to 34 and 15 to 26%, respectively. The highest rice tiller number in every observation (30 DAT, 60 DAT and at harvest) was also achieved by R4.

Residual effect of dolomite and compost on rice biomass production

Similar findings were also observed for rice biomass production. The residue of dolomite and compost significantly enhanced the rice biomass production including fresh rice residues, fresh rice straw and rice grain yields (Table 7). Compared to the farmer practices, no addition of dolomite and compost (R0), the residual effect of dolomite and compost at R1, R4 and R5 significantly improved the fresh rice residue, fresh rice straw and rice grain yields.

The best rice residue, rice straw and rice grain yield of

Table 7. Residual effect of dolomite and compost on rice biomass production of ciliwung variety at 30 DAT, 60 DAT and harvest cultivated at newly opened wetland rice of Panca Agung site, Bulungan District.

Treatments	Biomass production (t ha^{-1})		
	Fresh rice residue	**Fresh rice straw**	**Dry rice grain**
R0	3.54 ± 0.5 b	4.72 ± 0.7 c	1.90 ± 0.2 c
R1	4.46 ± 0.4 ab	6.38 ± 0.4 b	2.03 ± 0.3 c
R2	4.86 ± 0.6 ab	7.34 ± 0.8 ab	3.32 ± 0.2 ab
R3	5.04 ± 0.6 ab	6.96 ± 0.2 b	3.25 ± 0.1b
R4	5.84 ± 0.5 a	7.82 ± 0.6 a	3.74 ± 0.3 a
R5	5..79 ± 1.1 a	7.99 ± 1.1 a	3.53 ± 0.3 ab
CV (%)	19.97	18.45	25.96

Note: The water content of dry rice grain was about 12 to 14%. The mean values in the same column followed by the same letter are not statistically different. R0: farmer practices (as control). R1: farmer practices + residue compost + residue dolomite. R2: NPK with recommendation rate. R3: NPK with recommendation rate (N and K were split 3 x). R4: NPK with recommendation rate + residue compost + residue dolomite (N and K were split 3x). R5: NPK with recommendation rate + residue compost + residue dolomite.

about 5.84 ± 0.5, 7.82 ± 0.6, 3.74 ± 0.3 t ha^{-1} season^{-1} were achieved by R4. These data proved that application of NPK recommended rate (250 kg urea, 100 kg SP-36 and 100 kg KCl ha^{-1}, in which N and K were split 3x) at the residue of 2 tons ha^{-1} dolomite and 2 tons compost ha^{-1} are essential to continually improve poor inherent soil fertility, rice growth and rice biomass production of newly opened wetland rice filed.

Sustainable rice farming in indonesia

Based on the facts finding including on improvement of soil fertility, rice growth and rice biomass production, application of NPK at recommendation rate plus two tons dolomite and two tons compost is important to be socialized as newly opened wetland rice are done in many parts of Indonesia, especially in outer of Java and Bali islands. Application of this technology is not only to improve rice yield, but also to sustain rice farming and increase farmer's income.

Thus, to meet the rice growing demand, the Indonesian government not only open the wetland rice fields, but also enhance their productivity. Otherwise, the newly wetland will be left out and rice import will be happened. Increasing of rice yield will motivate the farmer to work hard to improve the rice yield. Therefore, scaling up of this technology or demonstration plot and training should also be conducted to open their farmer eyes and to change their cultural practices, as the farmers in transmigration came from Java and Bali islands. With these ways, sustainable rice farming under newly opened wetland rice fields leading poverty alleviation will be achieved.

Conclusion

Inherent soil fertility of newly opened wetland rice was categorised poor, with constrains low in pH, organic matter (soil organic carbon and total nitrogen), potential and available phosphorus, and potential potassium. In addition, it has high level of iron (Fe) and manganese (Mn).

Application of recommended fertiliser rate namely 250 kg urea, 100 kg SP-36 and 100 kg KCl ha^{-1}, in which N and K were split three times combined with 2 tons dolomite ha^{-1} and 2 tons compost made of rice straw ha^{-1} enhanced the soil fertility, rice growth and rice biomass production. Residue of 2 tons dolomite ha^{-1} and 2 tons compost ha^{-1} effectively increased soil function, rice growth and rice biomass production. Training and demonstration plot should be conducted to socialize this technology to sustain rice farming in Indonesia.

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