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Review

Management of Acid Newly Opened Wetland Rice Fields

Sukristiyonubowo[1)] Heri Wibowo[1)], and Ai Dariah[1)].

[1]Indonesian Agency for Agricultural Research and Development, Soil Research Institute, Soil Fertility Division, Jln Tentara Pelajar 12 Bogor.

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Indonesia is one of the biggest producer and consumer of rice in the world. To meet the rice growing demand, Indonesia has conducted many efforts namely intensification and extensification including development of newly opened wetland rice fields. The soils allocated for development of newly opened wetland rice fields in Indonesia can be from dry and or/and wetland with mainly acid soil properties. Highly weathered soils, especially ultisols and oxisols are mainly granted for extending newly opened wetland rice areas originated from dry land, besides potential acid sulphate soil from wet land. These soils have low pH or acidic, low natural level of major plant nutrients, and they have Al, Mn and Fe in toxic levels. Application of 2 ton ha^{-1} year^{-1} dolomite, 2 ton ha^{-1} season^{-1} rice straw compost and mineral fertilizers (200 kg urea, 100 kg SP-36 and 100 kg KCl ha^{-1} season^{-1}) improve the soil chemical properties. Therefore, practically to manage these soils and to improve the rice yield, addition of organic matter, lime and mineral fertiliser should be applied together. With these applications the rice yield of 3,5 – 4,2 tons ha^{-1} season^{-1} can be reached.

Keyword: Newly opened rice field, Acid soil, dolomite, compost and mineral fertiliser

INTRODUCTION

It is estimated that more than 40% of the world's population use rice as a major source of calories and one of them is Indonesia. Indonesia is one of the biggest producer and consumer of rice in the world. More than half of total population depend on the agricultural sector and wetland rice plays an important role in sustaining food security and providing job and income. In Indonesia, agriculture plays an important role in the developing economy. It provides 46.3 % of the job opportunities, contributes for about 6.9 % to the total non-gas and petroleum export and for about 17.5 % to the Gross National Product (GNP). Therefore, rice is not only taking effect in social and economic aspects, but political life in Indonesia as well. The agricultural of Indonesian faces many problems including producing more rice with limited soil and water to meet rice growing demand. In addition, applications of fertilisers' rate and crop residue management differ among farmers within sub district, resulting variability in production and soil fertility properties. The shrinking of agricultural land in Indonesia due to: a) Increasing agricultural land conversion to non-agricultural purposes. According to Winoto (2005) and Irawan (2008) about 100 ha year^{-1} low land rice are converted to non agriculture purposes. b) Increasing water competition among agricultural sector and industrial as well as domestic purposes, c) Water pollution reducing total harvest areas are also agriculture challenge ahead to sustain rice security (Anonymous. 2002; Baghat *et al.,* 1996; Bouman and Tuong, 2001; Sukristiyonubowo. 2007; Sukristiyonubowo *et al.,* 2011a). Water scarcity is

*Corresponding Author's Email:sukristiyonuboworicky@yahoo.com; Tel: +6281226277259.

also due to lose or reducing in spring water and reducing in water debit (Kartiwa and Pawitan. 2009; Prastowo. 2001).

In the year 2025, the predicted Indonesian population will be about 270 million, increasing of 45 million people from the current figure of 225 million. This brings about an increasing food, water, and land demand. For unhusked rice alone annual consumption may increase by 30 %, representing about 17 million tons from the current 53 million tons annual consumption (Sukristiyonubowo. 2007; Agus *et al*. 2006).

Rice is the oldest and most important food crop in the world (Mikkelsen *et al.* 1995). About 90 % of the world rice area is in South and Southeast Asia, mainly in marine and fluvial lowlands. According to Bhagat *et al.* (1996) about 148 million hectares of wetlands are planted every year, taking into account two or three cropping seasons. About 90 % is produced and consumed in Asia. A fast population growth, increasing land demands for housing and industrial areas, and water pollution result in the shrinking of agricultural land, increasing fresh water scarcity, and decreasing rice production (Agus *et al.,* 2006; Bhagat *et al.,* 1996; Bouman and Tuong, 2001). Uphooff (2007) estimated that in year 2050 total available agricultures land is only one third of in year 1950. It has been reported also that in many Asian Countries, fresh water availability declined about 40 - 60 % per capita between 1955 and 1990. Good water control is still lacking in most parts of tropical Asia (Bhagat *et al.,* 1996; Bouman and Tuong, 2001). As in fact 75 % to 97 % of the total rice production comes from irrigated lowlands, the challenges ahead in rice growing areas are to save water and thus increase water productivity in conditions of limited land availability (BPS. 2003a; Bouman and Tuong, 2001).

To meet the rice growing demand, Indonesia has conducted many efforts namely intensification and extensification including development of newly opened wetland rice fields. In year 2014, Indonesia has targeted surplus in rice is about 10 millions. The soils allocated for development of newly opened wetland rice fields in Indonesia can be from dry land or/and wetland with mainly acid soil properties (Sukristiyonubowo et al. 2011a; 2011b).

Rice farming in newly opened wetland rice field should be intensified and handled more efficiently by using inputs without reducing biomass production and soil fertility. Therefore, it is interesting to review the management of newly opened wet land rice fields with pH lower than 6.00 or in acid soil properties.

Inherent Soil Fertility of newly opened wetland rice fields

In Indonesia, rice is not only a staple food, but also a source of income providing jobs for most villagers. Since the beginning of seventies through the First Long Term Development Program and it was executed through PELITA (*Pembangunan Lima Tahun* = Five Years Development Plan), increasing rice production has been one of the priorities of the Indonesian agricultural development. It is not only to meet the rice growing demand, but to improve farmer income and to support food security as well. Like other rice producing countries, to elevate rice and land productivities planting high yielding varieties and adding more mineral fertilisers are widely implemented and in 1984 Indonesia reached rice self-sufficiency. This achievement was mainly due to application of a system of high external inputs (Green Revolution technology) including high yielding rice varieties and agrochemicals, but this technology have no longer sustainable (Sukristiyonubowo. 2007).

To meet the rice increasing demand, highly weathered soils, especially ultisols and oxisols are mainly granted for extending newly opened wetland rice areas originated from dry land, besides potential acid sulphate soil from wet land. According to Sukristiyonubowo et al. (2011a; 2011b) these soils have low pH acidic, low natural level of major plant nutrients, and they have Al, Mn and Fe in toxic levels (Table 1).

While newly opened rice fields originated from wetland are dominated by acid sulphate soils. They are characterised by low pH, low major nutrient plant and has a high pyrite, in about 65 cm depth (Table 2)

Theoretically, these nutrients level of the soils can be effectively improved with mineral and organic fertilisers (Table 3). However, for the smallholder farmers for instance farmers living in transmigration areas the costs to purchase the mineral fertilisers are problem. Thus, the chemical fertiliser insufficient quantity is beyond the financial reach of smallholder farmers. So far, practically to increase and sustain crop production, proper management practices using more organic matter plus liming, and application of appropriate mineral fertiliser is often recommended (Sukristiyonubowo et al. 2011; 2012 ; Sukristiyonubowo and Tuherkih. 2009; Yan *et al.* 2007; Fageria and Baligar. 2001; Sukristiyonubowo *et al.* 1993). Sukristiyonubowo et al. (2011b) carried out research in Bulungan District, the results is fertiliser of N, P, and K with recommendation rate in which N and K are split three times + straw compost + dolomite is practically used to improve newly opened wetland rice fields. The recommendation rate is determined about 250 kg urea, 100 kg SP-36 and 100 kg KCl ha^{-1}, while the farmer practices rate is 100 kg urea and 100 kg SP-36 ha^{-1}. Urea and KCl are split three times namely 50 % at planting time, 25 % at 21 DAT and the last 25 % is given at 35 DAT. Dolomite as much as two tons ha^{-1} and rice straw compost of about two tons ha^{-1} are broadcasted a week before planting (Table3).

Generally, the newly opened wetland rice fields originated from dry land is planted with cash crops, upland rice or sleeping land with low in productivity (Sukristiyonubowo et al. 2011b). When they open to rice fields, in the first to two years, the rice yields are better,

Table 1. Soil chemical properties of newly opened wetland rice fields from dry lands Sei Gemuruh, Pesisir Selatan District (Sumatra Island), Semangga, Merauke District (Irian Island), Panca Agung, Bulungan District (Kalimantan Island) and Bualemo, Banggai District (Sulawesi Island) (Sources: Sukristiyonubowo Tunggul and M Husni. 2009; Sukristiyonubowo and M. Husni. 2010; Sukristiyonubowo and F. Jaffas. 2011; Sukristiyonubowo and M. Husni. 2012)

Parameter	Unit	Newly opened wetland rice fields originated from dry land			
		Sei Gemuruh-Pesisir Selatan	Semangga-Merauke	Panca Agung-Bulungan	Bualemo-Banggai
pH		4,5 – 4,9	3,9 – 5,3	4,62 – 4,70	4,66 – 6,49
Organic Matter:					
C-Organic	%	1.9 – 2,5	1,5 – 2,7	0.71 – 1.29	1,20 – 2,64
N Total	%	0,17 – 0.25	0,1 – 0,5	0.03 – 0.05	0,11 – 0,25
C/N ratio		15 - 18	5 - 17	20 - 26	8 - 13
P (HCl 25 %)	ppm	31,4 – 49,7	11,6 - 31,2	31 -58	24 – 29,2
K (HCl 25 %)	ppm	53 - 96	0,6 - 50,5	55 - 138	52 - 76
P Bray I	ppm	0,90 – 6,40	0,3 – 5,9	1.09 – 2.69	0,68 – 3,03
CEC	cmol (+) kg^{-1}	20 - 24	6 - 30	5.81 – 9.53	25,3 – 33,9
K	cmol (+) kg^{-1}	0.06 – 0.11	0,02 – 0,5	0.05 – 0.11	0,04 – 0,10
Ca	cmol (+) kg^{-1}			1.04 – 1.83	
Mg	cmol (+) kg^{-1}			0.21 – 0.27	
Fe	ppm	210 - 312	180 -230	170 - 210	170 - 225

Table 2. Soil chemical properties of newly opened fields originated from wet land in Tanjung Buka SP-2, Bulungan District (Kalimantan Island) and Toboali, South Bangka District(Sumatra Island) (Sources: Sukristiyonubowo et al. 2011. 2012; Sukristiyonubowo and M. Husni. 2012)

Parameter	Unit	Newly opened rice field originated from wetland			
		Tanjung Buka, Bulungan	Criteria	Toboali, Bangka Selatan	Criteria
pH		3,78 – 4.50	Very acid	4.52 – 5.20	Very acid
Organic Matter					
C-Organic	%	1.96 – 2.10	Low	0,84 – 1.08	Low
N Total	%	0,20 – 0.60	Low	0.09 – 0.15	Very low
C/N ratio		9.80		9 - 12	
P (HCl 25 %)	ppm	58 -79	Very Low	80 - 310	Low - medium
K (HCl 25 %)	ppm	129 - 176	Low	80 - 110	Low
P Bray I	ppm	11,6 - 19.6	Very Low	15.2 – 52.7	Low - medium
CEC	cmol (+) kg^{-1}	23 - 25	High	3.82 – 15.62	Low - medium
K	cmol (+) kg^{-1}	0.11 – 0.19	Very Low		
Ca	cmol (+) kg^{-1}	1.36 - 5,49	Low		
Mg	cmol (+) kg^{-1}	1,73 – 2.61	Low - medium		
Fe	ppm	251 - 270	High	270	high

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 (Sources: Sukristiyonubowo. 2001 b)

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

reaching about 2.0 – 2,5 tons ha^{-1}, but after that the rice yield decline finally achieve less than 1.0 ton ha^{-1} (Sukristiyonubowo, Tunggul and M. Husni. 2009; Sukristiyonubowo and M.Husni. 2010; Sukristiyonubowo and F. Jaffas. 2011; and Sukristiyonubowo and M. Husni. 2012). These due to low pH, low organic matter and low in N, P and K, but they have high in Fe and Al (Sukristiyonubowo et al. 2011b, 2012).

How to manage these soils and improve rice yield?

To manage these soils and to improve the rice yield, at least three ways should be applied together:

1. Addition of organic matters (compost, crop residues and returned rice straw)

To conserve natural resources, to protect the environment, and to reduce dependency on chemical fertilisers, organic farming is becoming a recent approach in modern agriculture systems. Moreover, the importance of organic sources including compost, rice straw, green manure and leguminous crops in improving soil chemical and physical properties have also received more attention in recent times (Clark *et al.,* 1998; Hasegawa *et al.,* 2005; Landa *et al.,* 1992; Mandal *et al.,* 2003; Sukristiyonubowo. 2007; Ray and Gupta, 2001; Whitbread *et al.,* 2000; Xu *et al*., 2006).

Crop residue is a fundamental natural resource for conserving and sustaining soil productivity. It supplies essential plant nutrients, improves physical and biological conditions of the soil, and prevents soil degradation (Aulakh *et al.,* 2001; Puget and Drinkwater, 2001; Jastrow *et al.,* 1998; Tisdale and Oades, 1979; Walter *et al.,* 1992). However, the nutrients present in roots often have been ignored in assessment of cropping systems. Most attention is paid to cover crops since they are considered to be a potential source of nitrogen for the following crops (Kumar and Goh, 2000; Thomsen, 1993; Harris and Hesterman, 1990). Now, it is observed that the contribution of plant nutrients from roots is important, ranging between 13 and 40 % of total plant N (Sukristiyonubowo *et al.,* 2010; Chaves *et al.,* 2004; Kumar and Goh, 2000). Planting of legume crops such as *Sesbania rostrata*, *Sesbania sesban* are also important to supplies N because these can do nitrogen fixation. Mandal *et al.* (2003) reported that application of green manure (*Sesbania rostrata*, *Sesbania aculeata*, and *Vigna radiata*) together with different rates of nitrogen fertiliser application increase the concentration of soil organic matter and total nitrogen, improve total pore space, water stable aggregates, hydraulic conductivity, and reduce bulk density. The results also show that the root length and yields are higher in green manure plots than in fallow plots, both for rice as well as for succeeding wheat crops.

Furthermore, it is also well documented that higher farm yard manure (FYM) levels significantly improve the number of roots $plant^{-1}$, length of roots, and rice yield (Bridgit and Potty, 2002). Similar results were also found in rice field managed with FYM and wheat straw under different water regimes (Yang *et al.,* 2004).

Research in terraced paddy field with application of returned rice straw also improve the rice yield in acid rice

Table 4. Biomass production as influenced by treatments in the WS 2003-04 (mean ± standard deviation)

	Biomass production (t ha^{-1} $season^{-1}$)		
Treatment	Rice grain	Rice straw	Rice residue
IT + RS	5.73 ± 0.62 a	7.50 ± 0.91 a	6.93 ± 1.17 a
I T	4.14 ± 0.57 b	6.25 ± 0.38 ab	4.67 ± 0.97 b
CFP + RS	3.82 ± 0.45 b	6.16 ± 0.77 ab	4.58 ± 1.39 b
CFP	3.19 ± 0.29 b	5.25 ± 0.63 b	4.57 ± 0.60 b
	(p = 0.001)	(p = 0.027)	(p = 0.006)

Note: The mean values in the same column followed by the same letter are not statistically different
p denotes significance of the effect (p – value ANOVA)

Table 5. Biomass production as influenced by treatments in the DS 2004 (mean ± standard deviation)

	Biomass production (t ha^{-1}-$season^{-1}$)		
Treatment	Rice grain	Rice straw	Rice residue
IT + RS	5.91 ± 0.33 a	6.37 ± 0.30 a	6.55 ± 0.21 a
I T	4.45 ± 0.59 b	5.52 ± 0.79 b	5.69 ± 0.68 ab
CFP + RS	4.12 ± 0.22 bc	5.33 ± 1.05 b	5.31 ± 0.88 ab
CFP	3.69 ± 0.07 c	5.10 ± 0.48 b	5.16 ± 0.71 b
	(p = 0.000)	(p = 0.026)	(p = 0.023)

Note:

1) The mean values in the same column followed by the same letter are not statistically different
2) p denotes significance of the effect (p – value ANOVA)
3) IT + RS: Improved Technology + Returned Rice straw
4) I T: Improved Technology
5) CFP + RS: Conventional Farmer Practices
6) CFP: Conventional Farmer Practices

field (initial soil pH: 4.52) in Wet and Dry Seasons (Table 4 and 5). The overall production of the IT + RS (Improved Technology + Rice straw) treatment is significantly superior over the other treatments ($p < 0.05$). The magnitudes of improvement are 79.7 %, 42.8 %, and 51.8 % over the conventional farmer practices (CFP) for rice grains, rice straw, and rice residues, respectively. Application of only 100-kg ha^{-1} $season^{-1}$ of Urea, TSP, and KCl, without returning rice straw (the IT treatment) do not significantly increase the biomass productions. This confirms the findings observed by Alice *et al.* (2003); Bridgit and Potty (2002); Mandal *et al.* (2003); Senapati *et al.* (2004), illustrating that incorporation of organic fertiliser is essential to improve soil fertility and rice yield.

In the DS 2004, the average biomass productions, including rice grain, rice straw, and rice residue, and their standard deviations are given in Table 5. As observed in the WS 2003-04, rice grain, rice straw, and rice residue productions in the IT + RS treatment in the DS 2004 are also significantly higher than for other treatments ($p < 0.05$). The biomass productions are about 5.91 ± 0.33; 6.37 ± 0.30; and 6.55 ± 0.21 t ha^{-1} for grain, straw and residue, respectively. They increase about 60 %, 25 %, and 26 % compared to grain, straw and residue yields in the CFP, respectively.

2. LIMING

Soil pH is a measure of the acidity or alkalinity in the soil. It is also called soil reaction. As the plant nutrients available at pH between 6.50 and 7.00, to improve the soil productivity and rice yield, the soil should be added lime. According to Sukristiyonubowo et al. 2011 to improve the soil pH, should be added lime at least 2 ton ha^{-1} $season^{-1}$, besides it is flooded/submerged. From the experiment done in Bulungan indicated that water pounding layer do not influence in plant height, but it is significantly increased the rice tiller number and grain yield of newly opened wet land rice field, beside improving the pH of the soil (Sukristiyonubowo et al. 2012). According to Ponnamperuma et al. (1966), within a few weeks after submergence, the pH of acid soils increases and the pH of sodic and calcareous soils decreases. The pH of most acid and alkaline soils converges between 6 and 7 after flooding.

3. Mineral Fertilisers

It is observed that even with a balanced use of NPK, optimal rice yield level could not be reached and maintained without proper application of organic matter. Many recent arguments showed up including other macro- and micro- nutrient deficiencies and deterioration of the soil physical ecosystem. Other studies concluded that since rice is also known as a silicon (Si) accumulator and could get benefits from silicon nutrition, incorporation of rice straw, one of the silicon sources, is highly recommended to cope the levelling off, to increase soil fertility and to improve yield (Sudhakar *et al.,* 2004; Takahashi, 1995; Yang *et al.,* 2004).

Alice *et al.* (2003) observed that application of 120-50-50 kg N P K ha^{-1} + Azola and 120-50-50 kg N P K ha^{-1} + Azospirillum showed the highest tiller production, 1000 grains weight, and rice grains yield. The lowest yield was found in the plot treated with only inorganic fertiliser. Another study revealed that incorporation of inter-cropped black gram along with application of Azotobacter and 5 tons ha^{-1} FYM (farm yard manure) significantly enhance rice grains yield (Senapati *et al.,* 2004).

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