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APCBEE Procedia 4 (2012) 253 – 258

Procedia APCBEE

www.elsevier.com/locate/procedia

ICAAA 2012: July 23-24, 2012, Singapore

Effect of Water Management Improvement on Soil Nutrient Content, Iron and Aluminum Solubility at Tidal Low Land Area

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Abstract

Reclamation of tidal lowland at South Sumatra had been conducted since 1961. Land productivity at this area so far had still varied. The success of rice production at level of 6 ton/ha at Delta Telang I area (A/B Type) was not followed by rice production at other areas. The field study was conducted at two land typologies consisting of wet land at Delta Telang I and dry land at Delta Saleh. Improvement of water management was done by drainage system for wet land type (Telang I) and water retention in combination with leaching for dry land type (Saleh). The results showed that land at Delta Telang I, was belong to potential land whereas land at Delta Saleh was belong to acid sulphate land with pyrite layer at 60 cm depth and water table level at dry season was located more than 90 cm below soil surface resulting in phyrite layer oxidation and soil became very acid as well as an increase of iron solubility. Improvement effort of water management at tertiary level was capable to decrease the iron solubility from 78.68 ppm to 41.31 ppm at Delta Saleh and from 78.59 ppm to 39.24 ppm at Delta Telang I. On the other hand, land leaching had no effect on soil nutrients content. Improvement of water management had increased the average level of rice crop production from 3 ton/ha into 5 ton/ha at Delta Saleh.

Keywords: Tidal lowlands; water management, soil quality, acid sulfate soil

1. Introduction

Reclamation of tidal low land at South Sumatra had been conducted since 1961. Land productivity at this area so far had still vary. The success of rice production at level of 6 ton/ha at Delta Telang I area (A/B Type)

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doi:10.1016/j.apcbee.2012.11.043

was not followed by rice production at other areas which had average production of only 3.5 ton/ha even though water availability was sufficient during the first planting season, even at high typology land (Imanudin *et al,* 2007). According to Ismunadji *et al,* (1989), the main problem on acid suphate soil is availability of phyrite compound (Fe_2S). Oxidation of this compound produced acid soil, soluble metals and bases resulting in low fertility soil and disturbances for waters biota life due to drainage water from soil. If the previously oxidized soil experience reflooding, then ferro iron and hydrogen sulphide ions concentration will increase resulting in rice crop toxicity. The rate of these oxidation and reduction reactions are slow, but they can be several hundreds to several millions time faster with the aid of oxidation and reduction bacteria so that producing higher impact. Therefore, management of acid sulphate soil can be done by controlling the microorganisms involved in these oxidation and reduction processes. Some efforts to deter the activity of oxidation bacteria were bactericides application, oxygen supply cut off through flooding and addition of lime. From these three efforts, only water management approach that was practical and easily applied in the field (Imanudin *et al*., 2009).

The general impacts from phyrite oxidation were decreasing of soil pH and increasing of iron content. Land which experience Fe toxicity was usually distributed at tidal swamp area, peat land, low land, basin and newly cleared land with estimation area of 1 million ha (Ismunadji, 1990). Fe toxified land was also found at other countries such as Malaysia, Sri Lanka, India, Columbia, Senegal, and Siera Leone (Ponnamperuma, 1989). The decreasing yield of rice crop up to 90% at paddy field having high content of Fe was found at Yellow Red Podsolic land (Suhartini *et al*., 1992). Virmani (1977) reported that the decrease of rice crop yield at land having Fe toxicity was 70% for sensitive variety and 30% for tolerance variety. Some technologies to increase the rice crop yied at land having Fe toxicity were available such as through improvement of drainage, balance fertilizing, organic matter addition and liming (Ismunadji, 1990).

Based on the above potentials and constraints, it is important to conduct a field study in order to determine the effect of water management improvement efforts on the change of soil quality. Some of the observed soil quality indicators were iron content, aluminum content, nitrogen content, phosphorous content, potassium content and soil acidity level.

2. Methodology

The study was conducted at Reclaimed Tidal Lowland Area of Delta Saleh, Banyuasin District, South Sumatra Province. The representative area is consisted of one tertiary block within one secondary block for each sampling locations. The areas for field study of water management were at Primer 8 of Delta Telang I and Primer 10 of Delta Saleh. The field study period was from November 2005 to November 2009. Improvement of water management was conducted at two land typologies consisting of dry land and wet land. Its objectives were to guarantee water sufficiency for crop during growth period and to facilitate toxic elements leaching from the land due to phyrite oxidation. The applied treatments were shown in Table 1.

3. Results And Discussions

3.1. Land Leaching Impact on Soil Quality Change

The dynamics of soil nutrients status is frequently affected by soil water status at root zone of crop. This condition is especially occured at reclaimed tidal swamp land. Analysis of some chemical soil properties showed the differences between dry season and wet season periods. Analysis results at dry season (Table 2) showed that C-organic values were vary from low to high status. The N-total values were in the range of low to medium, whereas phosphorus values were in the range of medium to high and potassium values were also low so that the soil fertility in general is relatively low. Soil quality problem was mainly due to high saturation level of aluminum having average value of more than 5 me/100g which mean that at least about 3 to 5 ton/ha of lime is needed to neutralize this aluminum. Iron concentration was within the threshold limit value because an analysis result of iron was in the range of 70 to 80 ppm. This low concentration of iron was due to improvement of water management. However, soil pH lower than 4 will produce disturbance toward crop physiology due to iron concentration. Results of soil analysis on A land typology at Delta Telang I showed that this area had relatively the same fertility level than that of Delta Saleh in terms of Nitrogen, Phosporus, Kalium and Iron status. The difference between these two areas was lied in aluminum saturation level, in which Delta Telang I had lower aluminum saturation level in the range of 1 to 2 me/100g. Moreover, soil at Delta Telang I had relatively high acidity with pH value of more than 4. Therefore, iron toxicity risk had not had significant effect on plant physiology.

Table 1. Treatments of water management at tertiary block.

Water requirement during each crop growth phase	Water management objectives	Field operation	
		A type land of Telang (wet)	C type land of Saleh (dry)
Soil tillage	Tillage: soil is below field saturation capacity Flooding : flooding depth 0 – 5 cm Leveling : flooding depth 5 cm	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide
Nursery	Soil is water saturated /no flooding	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide
Vegetative growth	Flooding depth 5 – 10 cm, water changing, water is flown out during fertilizing	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide	Tertiary gates is closed, retention of rainfall water
Reproductive gowth	Flooding depth 5 – 10 cm, water changing, water is flown out during fertilizing	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide	Tertiary gates is closed, retention of rainfall water
Maturation	Soil in field saturation condition	Tertiary gates is opened, drainage water is flown out during low tide, and water retention during high tide	Tertiary gates is closed, retention of rainfall water

Soil analysis after first planting season (wet season) was conducted to determine the change of soil nutrients status due to improvement of water management and land leaching process (see Table 3). No significant change was occurred on soil nutrients status, but significant change was occurred on soil pH and iron solubility. Average iron concentration was decreased from 78 ppm into 41 ppm. Slight decrease was occurred on aluminum solubility from average of 5 me/100g to 4 me/100g. These values implied that no physiology disturbance was occurred on rice crop. However, soil quality improvement still should be conducted by using lime addition in order to decrease the aluminum saturation. High aluminum saturation will inhibit the nutrients absorption by plants.

Iron toxicity on rice crop was due to high level of iron absorption (>300 ppm) which is caused by several soil factors such as high Fe, low pH (van Bremen and Moorman, 1978), nutrients deficiency and nutrients balance (Benckiser *et al*., 1982). Iron concentration in soil that can produce iron toxicity is depend on soil pH according to some studies. Fe in 100 ppm concentration and pH 3.7 as well as Fe in 300 ppm concentration and pH 5.0 can produce toxicity on crops (Tadano dan Yoshida, 1978). Fe element is micro nutrient for plant that is needed in minute quantity as activator of enzyme system, chlorophyl synthesis process as well as oxidation and reduction reactions in respiration. Fe deficiency will obstruct chlorophyl development mechanism as well as composing elements for specific enzymes and proteins (Brady, 1974). Micro elements such as Fe on acid soils can be in dissolved condition and available for crops in excessive amount and frequently can be toxic for crops. The critical threshold limit of Fe toxicity for crops according to Yoshida (1981) is 300 ppm.

Table 2. Changing status of soil nutrients content, aluminum and iron concentrations of acid sulphate soil at Delta Saleh and Telang I

Soil quality parameters	Unit	Saleh (high area)		Telang I (low area)	
		Dry	Wet	Dry	Wet
Soil pH		3.83	4.04	4.21	4.72
C- Organic	%	3.13	3.73	4.50	5.02
N-Total	%	0.24	0.25	0.37	0.37
P-Bray I	ppm	26.14	20.64	29.29	29.85
K-dd	me/100g	0.22	0.14	0.18	0.17
Al-dd	me/100g	5.33	4.45	2.10	1.61
Iron	ppm	78.68	41.31	78.59	39.24

Table 4 showed analysis results of soil nutrients during wet season at Delta Telang I (after first planting season). The C-organic content was relatively high, N-total value was medium, phosphorus value was relatively high, and potassium value was low. Soil fertility level in general was medium. The significant change was happened on iron concentration which was decreased from average of 79 ppm into 39 ppm due to effect of good water management through land leaching. The decrease in iron content was followed by decrease in aluminum content from average value of 2 me/100g to 1.5 me/100g. This condition had good impact on land quality improvement so that crop growth was normal without the physiological disturbance due to iron toxicity. Liming was not required for land at Delta Telang I because of low aluminum saturation.

Table 3. Condition of soil nutrients status during wet season (After harvesting of first planting season on C typology land at Delta Saleh)

Observation numbers	Soil pH at dry condition	C-organic (%)	N-total (%)	P-Bray I (ppm)	Kalium (K-dd)	Aluminum Al-dd	Fe (ppm)
T1	3.97	3.47	0.7	36,.5	0.13	4.66	37.83
T2	4.23	2.71	0.21	35.25	0.13	3.68	42.51
T3	4.07	2.50	0.19	11.40	0.19	5.36	40.79
T4	4.34	3.07	0.23	24.00	0.13	3.76	42.32
T5	4.05	3.68	0.28	12.75	0.13	4.00	42.32
T6	4.07	5.86	0.39	14.25	0.10	3.56	40.95
T7	3.77	3.77	0.16	8.85	0.13	5.68	42.32
T8	3.79	3.79	0.25	22.50	0.19	4.92	41.42
Average	**4.04**	**3.73**	**0.25**	**20.64**	**0.14**	**4.45**	**41.31**

Iron toxicity phase on rice crop is consisted of two stages according to Ottow *et al*. (1989). The first stage is occurred at 7 days after flooding (stress due to seed transplanting). The roots are not capable to oxidize the excess amount of Ferro into ferric during flooding period. In other words, the excluding power mechanism of roots had not function properly yet. Therefore, excessive amount of ferro ions is absorbed by crop. The second stage was between primordial and flowering stages due to ineffective root mechanisms to exclude ferro because of increasing permeability of roots. However, Fe toxicity symptoms can be seen at each growth stage and it should be evaluated at maximum tillering stage and primordial stage (Suhartini, 2004).

Results of soil analysis showed that Al-dd soil was 8.1 me/100g on dry soil condition. It means that calcite lime of 8 ton/ha is required to neutralize the soil. Therefore, chemically soil remediation by using calcite lime is uneconomical measure. Water retention with proper operation of water gates in combination with land leaching for every ten days are an effective way to decrease Al and Fe solubilities within root zone of crops.

Table 4. Condition of soil nutrients status during wet season (After harvesting of first planting season on A typology land at Delta Telang I)

Observation numbers	Soil pH at dry condition	C-organic (%)	N-total (%)	P-Bray I (ppm)	Kalium (K-dd)	Aluminum Al-dd	Fe (ppm)
T1	4.89	6.44	0.45	31.50	0.15	1.60	39.86
T2	4.58	5.81	0.43	16.95	0.12	1.96	40.95
T3	4.61	5.53	0.39	23.70	0.14	1.64	41.34
T4	4.41	3.27	0.27	32.40	0.13	2.76	35.18
T5	4.47	3.79	0.27	33.15	0.26	2.56	39.94
T6	4.80	4.73	0.36	43.50	0.13	1.00	40.79
T7	4.74	5.53	0.39	19.20	0.13	1.20	40.56
T8	5.25	5.04	0.40	38.40	0.32	0.20	35.26
Average	**4.72**	**5.02**	**0.37**	**29.85**	**0.17**	**1.61**	**39.24**

Water gates were built at secondary channel in order to uplift water table level and to prevent the quick rainfall water loss. It had positive impact because these water gates were capable to retain rainfall water and to lift water table level. Current condition of water table level was frequently drop during seed tillering which results in decrease of crop production. The existence of water retention structures results in water table level which was located above the critical level zone. This produce better growth of rice crop and increase of crop production. In Saleh case, the farmer had conducted water retention only at tertiary channel that had less capability to maintain water table level. Improvement of water management had increased the average level of rice crop production from 3 ton/ha into 5 ton/ha at Delta Saleh.

4. Conclusion and Recommendation

Iron and aluminum solubility are soil quality problem at tidal swamp land area. The value of iron and aluminum solubility at dry land typology is higher than that of wet land typology. Improvement of water management, especially land leaching, is proved to be effective in decreasing the iron and aluminum solubility and had no significant difference in soil nutrients leaching so that soil nutrients availability is not affected by land leaching.

The main objective of water management at high area is water retention in combination with land leaching and channel flushing for every ten days. Intensive land drainage and high tide water retention are required for wet land typology such as at Delta Telang I area. Impact of water management improvement is the increase of crop production from average level of 2.5 ton/ha into 5 ton/ha on dry land typology at Delta Saleh area and from 4 ton/ha into 6-7 ton/ha on wet land typology at Delta Telang I area.

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