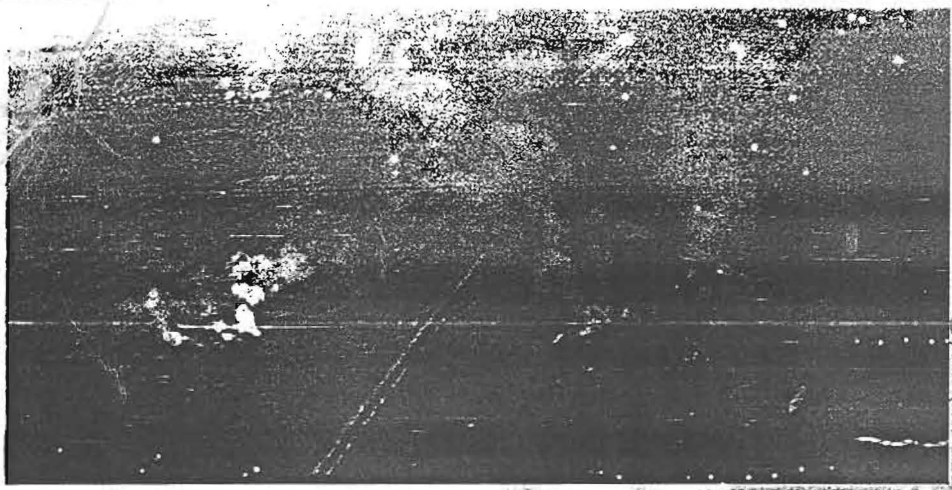
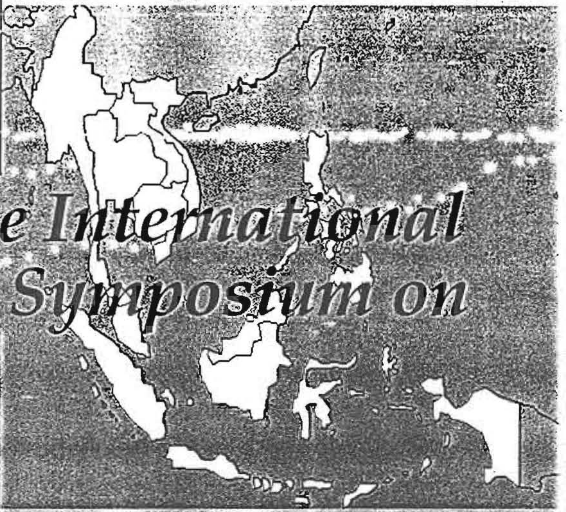
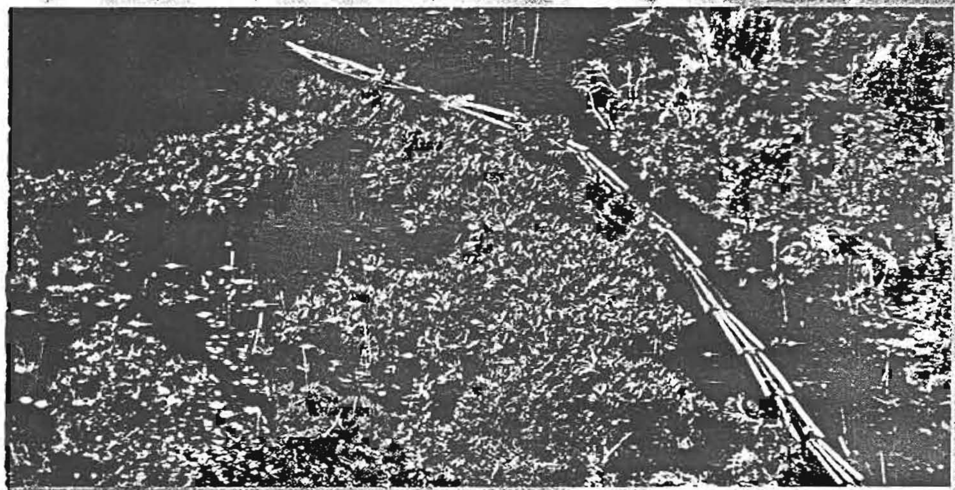




Proceedings of the International Symposium on



LAND MANAGEMENT AND BIODIVERSITY IN SOUTHEAST ASIA

September 17-20, 2002
Bali, Indonesia

ORGANIZED BY

Hokkaido University, Sapporo, JAPAN

&

Research Centre for Biology,
The Indonesian Institute of Sciences,
Bogor, INDONESIA

ISBN4-9901827-0-7
9784990182700

COLLABORATING INSTITUTIONS:

- Hokkaido Institute of Technology
- Hokkaido University of Education
- Tokyo Univ. of Agriculture & Technology
- Kyoto University
- Shiga Prefecture University
- Kanazawa University
- Kansai University
- Tottori University
- Kagoshima University
- Palangka Raya University
- Bogor Agricultural University
- Bandung Institute of Technology
- Research Centre for Limnology, LIPI
- Research Centre for Geotechnology, LIPI

SUPPORTED BY

- BPPT - Agency for the Assessment and Development of Technology, Ministry of Research and Technology, Indonesia
- CIMTROP - Center for International Cooperation in Management of Tropical Peatland, Palangka Raya University
- EUTROP - European Union Natural Resource Functions of Tropical Peatlands Project
- JICA - Japan International Cooperation Agency, Biodiversity Conservation Project in Indonesia
- STRAPEAT - European Union Sustainable Management of Peatlands in Borneo Project

SPONSORED BY

Japan Society for the Promotion of Science (JSPS), JAPAN
&
Indonesian Institute of Sciences (LIPI), INDONESIA

PRINTED BY SUDA PRINTING CO., Ltd., Sapporo-JAPA

Utilization of Steel Slag in Wetland Rice Cultivation on Peat Soil

Suwarno
Department of Soil Science, Faculty of Agriculture, Bogor Agricultural University
Jalan Meranti, Kampus IPB Darmaga, Bogor, Indonesia
Telp.: 0251-629360; Fac.: 0251-629358; e-mail: soilipb@indo.net.id

ABSTRACT
An incubation experiment in laboratory using peat soil from Lagan, Jambi was conducted to study the effect of steel slag on chemical properties of peat soil. In addition, a pot experiment using the same peat soil was carried out to investigate combination effect of steel slag and NPK, saprodap, or standard fertilizers - urea, SP-36, and KCl - on growth and yield of wetland rice. Application of steel slag on peat soil significantly improved the availability of Si as well as increased soil pH and exchangeable Ca and Mg. On the other hand, it significantly decreased soil organic matter content, total N, and the availability of Fe, Mn, and Zn. Moreover, the effect of steel slag on the availability of Cu was not significant. Wetland rice grown on peat soil highly responded to steel slag application. The number of productive tiller, number of panicle, and weights of filled and total spikelets were significantly raised with steel slag application. Interaction of steel slag with NPK, saprodap, or standard fertilizers also had significant effect on those rice yield variables. In combination of steel slag and NPK fertilizer, steel slag 2.5 % produced the highest rice yield. However, in combination of steel slag and saprodap or standard fertilizers, the highest rice yield was achieved at dosage of steel slag 5.0 %. In general, combination of slag 2.5 % and NPK fertilizer produced the highest rice yield. Increasing the growth and yield of rice after application of steel slag was associated with increasing the availability of Si, soil pH, and exchangeable Ca and Mg as well as reducing toxic organic acids.

Key words: peat soil, steel slag, wetland rice

INTRODUCTION
Staple food of Indonesian people is rice, so rice is the most important crop in this country. Since 1960ís Indonesian Government have implemented various efforts to meet rapid increase of rice demand, such as intensification and expansion of rice land areas. These efforts succeeded in improving rice production and since 1984 Indonesia has successfully achieved self-sufficient level of rice production. However, the population grows so fast that the demand of rice keeps on increasing. Consequently, the rice production must be increased annually to maintain the self-sufficient level. Unfortunately, non-agricultural sectors are using up more and more arable lands. Therefore, the availability of fertile lands for rice is declining and rice lands are pushed onto infertile lands.

One infertile land potentially for expansion of wetland rice is peat soil, because these soils are flat and level, permanently water saturated - with cheap gravity drainage easily possible - and not yet occupied for agriculture or other purpose (Driessen, 1978). These soils are mainly distributed along the eastern coast of Sumatra, the southern and western coasts of Kalimantan, and the southern coast of West Irian (Driessen and Soepraptohardjo, 1974). They cover about 24 million hectares, corresponding to 12.6% of total land resources of Indonesia (Muljadi and Soepraptohardjo, 1975). Peat soils vary from extremely poor to very rich, depending on the kind and composition of the organic materials. In particular, they have low content of total silicon, and micronutrient deficiencies such as copper and zinc deficiencies occur frequently. Moreover, wetland rice on deep peat suffers from male sterility (Driessen, 1978).

Silicon is a beneficial mineral element for rice growth by maintaining erect leaves (Balasta *et al.*, 1988; Yoshida, Navasero, and Ramirez, 1969); promoting the growth, strong culms and roots, and early panicle formation; increasing the number of spikelets per panicle and percentage of matured grain (De Datta, 1981); decreasing transpiration rate (Matoh, Murata, and Takahashi, 1991); increasing the resistance to fungi, insects, and mites (Ishizuka and Hayakawa, 1951; Volk, Kahn, and Weintraub, 1958); diminishing the unfavorable action of nitrogen on the resistance to lodging, stem borer, and diseases such as blast (Idris, Hossain, and Chounhury, 1975; Ota, Kobayashi, and Kawaguchi, 1957) and alleviating Mn or Fe toxicity or both (Horiguchi, 1988; Okuda and Takahashi, 1962).

The most common material used as a source of Si for rice cultivation in many countries for example Japan, Korea, Taiwan, and China is steel slag containing calcium silicate, a by-product formed in the process of steel manufacturing (De Datta, 1981; Ma and Takahashi, 1993). At present, Indonesia produces annually about 350 000 tons of steel slag; however, it has not been used yet in agriculture. Besides has high content of Si, Indonesian steel slag also contains much Ca, Mg, and Fe as well as relatively high micronutrient (Suwarno and Goto, 1997a). It is necessary, therefore, to explore the effects of this slag on the growth and yield of wetland rice grown on peat soil.

The objectives of this experiment were: (i) to evaluate effects of steel slag on the chemical properties of peat soil and (ii) to evaluate effects of steel slag on growth and yield of wetland rice grown on the peat soil.

MATERIALS AND METHODS

Experiment I. Incubation experiment in laboratory using peat soil from Dendang, Jambi was carried out to evaluate effect of steel slag on chemical properties of peat soil. Peat soil equivalent to 10 g oven dry basis was placed in 200 ml of plastic bottle to which steel slag in size less than 2 mm in dosage of 0, 2.5, 5.0, 7.5, and 10 % of soil weight, respectively, was added and mixed thoroughly. The bottles were incubated for two months and then the chemical soil properties: pH, exchangeable Ca and Mg, available Si, Fe, Mn, Cu, and, Zn, total N and organic matter content were analyzed.

Experiment II. Pot experiment in greenhouse using the same peat soil was conducted to evaluate combination effect of steel slag and three kinds of fertilizer on growth and yield of wetland rice grown on peat soil. Each pot contained 2 kg oven dry basis of peat soil. Steel slag in size less than 2 mm was applied in three dosage levels: 0.2.5, and 5.0 % of soil weight and combined with three kinds of fertilizer: NPK (15-15-15), saprodap (16-20-0), and standard fertilizer (urea, SP-36, and KCl). These fertilizers were applied in dosage of 500 ppm N, 500 ppm P_2O_5 and 500 K_2O. Moreover, all pots were received 5 ppm Cu of $CuSO_4.5H_2O$ as basal fertilizer. Four plants of twenty one days-old of IR 64 rice variety were transplanted into all pots. This plant was harvested at maturity. Plant variables measured were numbers of productive tiller and panicle; weights of filled, unfilled, and total spikelets as well as percentage of filled spikelets.

To evaluate the effects of treatment, the data of soil chemical properties as well as plant growth and yield variables were analyzed by analysis of variance. Furthermore, the means of treatment were analyzed by w-Tukey Test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Effects of Steel Slag on Chemical Properties of Peat Soil

As shown in Table 1, soil pH, exchangeable Ca and Mg, and available Si were significantly increased after application of steel slag. The values of these variables were increased with increasing the amount of steel slag. On the other hand, organic matter content, total nitrogen, and available Fe and Zn were significantly decreased with application of steel slag. The magnitudes of these soil chemical properties were decreased as the amount of steel slag was increased. Available Mn was increased after application of steel slag; however, the availability of Mn was decreased as the amount of steel slag was increased from 2.5 % to 10 %. In addition, steel slag had no significant effect on available Cu.

In peat soil, steel slag reacted with H_2O containing CO_2, producing base cations (Ca^{2+}, Mg^{2+}, Na^{+}) and other cations in addition to base conjugate (hydroxide, silicate, and carbonate) and other anions, thus increased concentration of these cations and anions in soil solution. The Ca^{2+} and Mg^{2+} then replaced for exchangeable acidity (exchangeable Al and H) on adsorption sites. As a result, application of steel slag increased exchangeable Ca and Mg as well as increased available Si. This result was agreed to that obtained by Suwarno and Goto (1997b) on mineral soil.

At the same time, the hydroxide (OH^-) and silicate ($H_3SiO_3^-$) reacted with H^+, resulting in H_2O and H_4SiO_4. These processes reduced exchangeable H, which in turn increased soil pH value. Consequently, application of steel slag increased pH value of peat soil.

Increasing pH value of peat soil due to application of soil amendment increased decomposition of organic matter (Andriesse, 1997). During decomposition process, organic matter were attacked by microorganism, resulting in simple products such as carbon dioxide, water, ammonia, ammonium, nitrites, nitrates, elemental nitrogen, sulfides, sulfates, inorganic phosphates, and cations for examples Ca^{2+}, Mg^{2+}, and K^{+} (Brady, 1990). Increasing rate of decomposition increased the amount of decomposed organic matter, which in turn increased the amount of simple decomposition products. As a result, application of steel slag to peat soil - which increased pH soil pH - reduced organic matter content.

Total nitrogen is total of organic and inorganic nitrogen in the soil (Tan, 1996). During decomposition of organic matter, organic nitrogen is mineralized into inorganic nitrogen. Total nitrogen in the soil is constant during decomposition process if there is no release of gaseous nitrogen to the atmosphere. Result of nitrogen total analysis in

Table 1. Effects of Steel Slag on Chemical Properties of Peat Soil from Dendang, Jambi

No	Treatment	pH (H_2O)	Organic Matter	Total N	Exch.Ca	Exch.Mg	Available Si	Available Fe	Available Mn	Available Cu	Available Zn
			.........(%)........		....(cmol(+)kg^{-1})....		........................($mg\ kg^{-1}$)........................				
1	Slag 0 %	3.8 a	95.98 e	0.52 c	1.17 a	1.15 a	71 a	14.49 c	1.03 a	1.39	1.88 c
2	Slag 2.5 %	5.3 b	84.22 d	0.49 c	5.31 ab	5.20 a	224 ab	6.99 b	6.44 c	1.11	1.61 bc
3	Slag 5.0 %	6.2 c	76.22 c	0.41 abc	9.04 b	11.67 b	582 b	2.65 a	4.41 b	0.96	0.65 ab
4	Slag 7.5 %	6.7 d	60.40 b	0.35 ab	20.27 c	15.22 bc	1 695 b	2.20 a	2.08 a	0.93	0.46 a
5	Slag 10 %	6.8 e	52.04 a	0.33 a	23.81 c	16.90 c	2 128 c	1.93 a	1.59 a	0.88	0.44 a
	Tukey $_{0.05}$	0.3	5.15	0.12	7.24	4.78	416	1.93	1.53	NS	1.14
	Tukey $_{0.01}$	0.4	6.81	0.16	9.56	6.31	549	2.55	2.02	NS	1.50

Note: NS = Not significantly different
Means followed by the same letter were not significantly different by w-Tukey Test at 5 % level of difference.

Table 1 indicated that nitrogen total was decreased with application of steel slag. Ratio of C/N in steel slag treatments of 0, 2.5, 5, 7.5, and 10 % were 107.7, 101.5, 108.9, 98.4, and 91.9; respectively. This result indicated that in decomposition of organic matter there was released gaseous nitrogen to the atmosphere. The amount of gaseous nitrogen released to the atmosphere was increased with increasing the dosage of steel slag.

Table 2. Chemical Composition of Steel Slag (Suwarno dan Goto, 1997a)

Composition	Unit	Content
Fe_2O_3	%	42.6
CaO	%	21.6
SiO_2	%	14.6
MgO	%	11.6
Al_2O_3	%	7.21
P_2O_5	%	0.37
MnO	%	1.55
K_2O	%	0.18
Na_2O	%	0.33
Neutralizing Value	%	67.6

Steel slag applied in this experiment contained total iron 42.6 of Fe_2O_3; however, application of this material to peat soil significantly decreased availability of iron. Although this steel slag contained very high total iron, result of mineral identification indicated that most of iron minerals was present as iron oxide mineral - wuestite, magnetite, and di-calsium ferrite (Suwarno and Goto, 1997a). According to Lindsay (1979), solubility of these minerals was extremely low in the pH range of soils and also affected by redox potential of soil. Consequently, those minerals did not affect the availability of iron in soil applied steel slag. Mineral containing iron in steel slag which could supply iron was apparently only forsterite feroan ($(Mg,Fe)_2SiO_4$) (Suwarno and Goto, 1997a). However, iron released from this mineral was precipitated as iron hydroxide with increasing soil pH after application of steel slag (Foth and Ellis, 1988; Lindsay, 1979). In addition, iron has high affinity to humic substances to form chelates (Tan, 1998). Formation of these chelates reduced available iron - amount of iron extracted with 0.05 N HCl - in peat soil.

The increase in soil pH might have shifted the equilibrium between soluble Mn^{2+} and insoluble MnO_2 toward insoluble MnO_2 (Adam, 1965), thus reduced available Mn. Moreover, Mn also could form chelates with humic substances (Tan, 1998). Formation of these chelates reduced the availability of Mn. On the other hand, reaction of steel slag in the peat soil also yielded Mn^{2+} ions, because this material contained 1.55 % of MnO_2 (Table 2). Apparently, the amount of Mn^{2+} produced by steel slag in this experiment was slightly higher than that of converted into MnO_2 and formed chelates with humic substances. As a results, available Mn was increased with application of steel slag; however, the availability of Mn was decreased with increasing the dosage of steel slag.

Available Zn significantly decreased with steel slag application, and the availability of Zn was decreased with increasing the dosage of steel slag. Availability of Zn in the soil was decreased with increasing soil pH (Lindsay, 1979). In addition, Zn could form chelates with humic substances resulted from decomposition of organic matter (Tan, 1998). Because application of steel slag increased soil pH and decomposition rate of organic matter, application of this material reduced availability of Zn in peat soil.

Table 3. Effects of Steel Slag Combined with Various Fertilizers on Growth and Yield of Wetland Rice Grown on Peat Soil from Dendang, Jambi

No	Treatment	Productive Tillers (no.pot^{-1})	Panicles (no. pot^{-1})	Weight of Spikelets ....(g pot^{-1}).................. Filled	Unfilled	Total	Percentage of Filled Spikelet (%)
1	Slag 0 % + NPK	0.0 a	0.0 a	0.00 a	0.00 a	0.00 a	-
2	Slag 0 % + Saprodap	0.0 a	0.0 a	0.00 a	0.00 a	0.00 a	-
3	Slag 0 % + Standard	4.3 ab	8.3 ab	3.55 ab	0.53 ab	4.08 ab	87.1
4	Slag 2.5 % + NPK	29.7 de	33.7 de	47.62 e	0.89 ab	48.51 e	98.2
5	Slag 2.5 % + Saprodap	18.0 cd	22.0 cd	7.71 ab	1.16 b	8.87 ab	87.4
6	Slag 2.5 % + Standard	14.0 bc	18.0 bc	22.93 cd	1.02 ab	23.95 cd	95.5
7	Slag 5.0 % + NPK	30.0 e	34.0 e	34.07 d	0.75 ab	34.83 d	97.8
8	Slag 5.0 % + Saprodap	16.7 c	20.7 c	15.03 bc	0.64 ab	15.66 bc	96.0
9	Slag 5.0 % + Standard	18.0 cd	22.0 cd	26.51 cd	0.75 ab	27.25 cd	97.2
	Tukey $_{0.05}$	11.8	11.7	12.00	1.12	12.07	
	Tukey $_{0.01}$	14.7	14.7	15.00	1.40	15.08	

Note: Means followed by the same letter were not significantly different by w-Tukey Test at 5 % level of difference.

Response of Wetland Rice to Combination of Steel Slag and NPK, Saprodap, or Standard Fertilizers

Growth of rice plant was very poor without application of steel slag. On treatments of steel slag 0 % + NPK fertilizer and steel slag 0 % + saprodap fertilizer, rice plant failed to produce panicle. As shown in Table 3, application of steel slag on peat soil significantly improved numbers of productive tiller and panicle as well as weights of filled and total spikelets. Combination of steel slag and NPK fertilizer produced higher numbers of productive tiller and panicle than combination of steel slag and saprodap or standard fertilizers. Weights of filled and total spikelets also higher with the former combination. In combination of steel slag and NPK fertilizer, steel slag 2.5 % produced the highest rice yield (weight of filled spikelets). However, in combination of steel slag and saprodap or standard fertilizers, the highest yield was achieved at dosage of steel slag 5 %. In general, among those combinations, combination of steel slag 2.5 % and NPK fertilizer produced the highest rice yield.

The very poor rice growth on pots untreated steel slag might be associated with the very low soil pH value, the low exchangeable Ca and Mg, and the low available Si as well as the presence of toxic organic acids. At pH value less than 4.0, hydrogen ions had a significant influence on absorption of many inorganic ions (Jackson, 1967), so inhibit the growth of rice plant. The presence of toxic organic acids in peat soil is also the problem that has to be solved in utilizing of peat soil for wetland rice cultivation.

The low exchangeable Ca and Mg in this soil also restricted the growth of rice plant, therefore they had to be noticed in wetland rice cultivation on peat soil. According to De Datta (1981), the functions of Ca in rice plant are as: a constituent of cementing material of plant cells, an important constituent of calcium pectate, which strengthens the cell wall, maintainer of turgidity of cell walls, and promoter of normal root growth and development. The functions of Mg in rice plant are as: a constituent of chlorophyll molecule, a component of several essential enzymes, and functions similar to Ca.

Silicon has various beneficial effects in rice plant such as: promotes the growth, strengthens culms and roots, favors early panicle formation, increases number of spikelets per panicle and percentage of matured grains, increases the resistance to attack of fungi, insects, and mites, and deminishes the unfavorable action of nitrogen on the resistance of rice to diseases such as blast. Therefore, the low availability of Si has to be corrected in cultivation of wetland rice on peat soil.

Application of N, P, and K fertilizers as urea, SP-36, and KCl - called as standard fertilizers - only improve the availability of N, P, and K nutrients; therefore the growth of rice was poor. Application of steel slag to peat soil that increased soil pH, exchangeable Ca and Mg, and available Si as well as reduced toxic organic substances improved growth and yield of IR 64 rice variety. These results were agreed to that obtained by Snyder, Jones, and Gascho (1986). However, the increasing yield obtained in this experiment was far higher.

In this experiment, interaction effect of steel slag with NPK, saprodap, or standard fertilizers was significance. In combination with NPK fertilizer, steel slag 2.5 % produced higher rice yield than steel slag 5.0 %. On the other hand, in combination with saprodap or standard fertilizers, steel slag 5.0 % produced higher yield. Apparently, it was associated with the ability of the three kinds of fertilizer in supplying N, P, and K nutrients as well as condition resulted from their reactions in peat soil.

CONCLUSION

Application of steel slag on peat soil significantly improved the availability of Si as well as increased soil pH and exchangeable Ca and Mg. On the other hand, it significantly decreased soil organic matter content, total N, and the availability of Fe, Mn, and Zn. Wetland rice grown on peat soil highly responded to steel slag application. The numbers of productive tiller and panicle as well as weights of filled and total spikelets were significantly increased with steel slag application. Interaction of steel slag with NPK, saprodap, or standard fertilizers also had significant effect on those rice yield variables. In combination of steel slag and NPK fertilizer, steel slag 2.5 % produced the highest rice yield. However, in combination of steel slag and saprodap or standard fertilizers, the highest rice yield was achieved at dosage of steel slag 5.0 %. In general, combination of slag 2.5 % and NPK fertilizer produced the highest rice yield. Increasing the growth and yield of rice after application of steel slag was associated with increasing the availability of Si, soil pH, and exchangeable Ca and Mg as well as reducing toxic organic acids.

REFERENCES

Adam, F. 1965. Manganese. In C. A. Black et al. (eds.) Methods of Soils Analysis, Part 2. Chemical and Microbiological Properties, 1011-1018. Am. Soc. Agron., Inc. Publisher, Madison.

Andriesse, J. P. 1997. The Reclamation of Petaswamps and Peat in Indonesia. Center for Wetland Studies, Faculty of Agriculture, Bogor Agricultural University, Bogor.

Balasta, M. L. F. C., Perez, C. M., Juliano, B. O, Villareal, C. P, Lott, J. N. A., and Roxas, D. B. 1988. Effects of silica level on some properties of *Oryza sativa* straw and hull. *Can. J. Bot.* 67:2356-2363.

Brady, N. C. 1990. The Nature and Properties of Soils. 10th ed. Macmillan Publishing Company, New York.

De Datta, S. K. 1981. Principles and Practices of Rice Production. John Wiley & Sons, New York.

Driessen, P. M. 1978. Peat soils. In Soils and Rice, 763 - 779. IRRI, Los Banos.

Driessen, P. M. and Soepraptohardjo, M. 1974. Soils for Agricultural Expansion in Indonesia. Soil Res. Inst., Bogor.

Horiguchi, T. 1988. Mechanism of manganese toxicity and tolerance of plants IV. Effects of silicon on alleviation of manganese toxicity of rice plants. *Soil Sci. Plant Nutr.* 34:65-73.

Idris, M., Hossain, M. M., and Chounhury, F. A. 1975. The effect of silicon on lodging of rice in presence of added nitrogen. *Plant and Soil* **43**:691-695.

Ishizuka, Y. and Hayakawa, Y. 1951. Resistance of rice plants to the imochi (rice blast) disease in relation to their silica and magnesia contents. J. Sci. Soil and Manure, Japan 21:253-260. (In Japanese with English summary).

Jackson, W. A. 1967. Physiological effects of soil acidity. In R. W. Pearson and F. Adam (eds.), Soil Acidity and Liming, 43 - 124. Am. Soc. Agron., Inc., Madison.

Lindsay, W. L. 1979. Chemical Equilibria in Soils. John Wiley & Sons, New York.

Ma, J. F. and Takahashi, E. 1993. Interaction between calcium and silicon in water-culture rice plants. *Plant and Soil* **148**:107-113.

Matoh, T., Murata, S., and Takahashi, E. 1991. Effect of silicate application on photosynthesis of rice plants. *Jpn. J. Soil Sci. Plant Nutr.* **62**:248-251. (In Japanese with English summary).

Muljadi, D. and Soepraptohardjo, M. 1975. Masalah data luas dan penyebaran tanah-tanah kritis. Simposium pencegahan dan pemulihan tanah-tanah kritis dalam rangka pengembangan wilayah, Jakarta 27-29 Oktober 1975.

Okuda, A. and E. Takahashi. 1962. Nutritional potential role of silicon on plant. Part 5. Effect of silicon supply on the injuries of excessive amount of Fe^{2+}, Mn^{2+}, Cu^{2+}, AsO_3^{3-}, Al^{3+}, Co^{2+} in barley and rice plants. *J. Sci. Soil and Manure, Japan* **33**:1-8. (In Japanese).

Ota, M., Kobayashi, H., and Kawaguchi, Y. 1957. Effect of slag on paddy rice part 2. Influence of different nitrogen and slag levels on growth and composition of rice plant. *Soil and Plant Food* 3:104-107.

Snyder, G. H., Jones, D. B., and Gascho, G. J. 1986. Silicon fertilization of rice on Everglades Histosols. *Soil Sci. Soc. Am. J.* **50**:1259-1263.

Steel, R. G. D. and Torrie, J. H. 1980. Principles and Procedures of Statistics. 2nd ed. McGraw Hill, Inc., New York.

Suwarno and Goto, I. 1997a. Mineralogical and chemical properties of Indonesian electric furnace slag and its application effect as soil amendment. J. Agric. Sci. Tokyo Nogyo Daigaku (Tokyo Univ. Agric.) 42:151-162.

Suwarno and Goto, I. 1997b. Effects of Indonesian electric furnace slag on rice yield and chemical properties of soils. In T. Ando *et al.* (Eds.). Plant Nutrition for Sustainable Food Production and Environment, 803 - 804. Kluwer Academic Publisher, Dordrecht.

Tan, K. H. 1996. Soil Sampling, Preparation, and Analysis. Marcel Dekker Inc., New York.

Tan, K. H. 1998. Principles of Soil Chemistry. 3rd ed, Revised and Expanded. Marcel Dekker, Inc., New York.

Volk, R. J., Kahn, R. P., and Weintraub, R. L. 1958. Silicon content of the rice plant as a factor influencing its resistance to infection by the blast fungus, *Piricularia oryzae*. *Phytopathol.* **48**:179-184.

Yoshida, S., Navasero, S. A., Ramirez, and E. A. 1969. Effects of silica and nitrogen supply on some leaf characters of the rice plant. *Plant and Soil* **31**:48-56.