(Format No. 3)

SUMMARY OF DOCTORAL THESIS

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Title:

NUTRIENT DYNAMICS IN WATERSHEDS AND LOWLAND SAWAH IN JAVA ISLAND IN RELATION TO THE SUSTAINABILITY OF SAWAH FARMING SYSTEMS IN INDONESIA

ジャワ島の集水域および低地水田における養分動態とインドネシアの水田農業システムの持続可能性

Study on the nutrient dynamics in watersheds and lowland sawah in relation to the sustainability of sawah farming systems was conducted in Java Island, Indonesia. Recent stagnation and fluctuation of rice production in Indonesia raise concern on the issue of sustainability of rice production. The declining rice yields are strongly related to the soil quality degradation, particularly nutrient depletion. Nutrient depletion can be attributed to insufficient nutrient replenishment by human and natural fertilization. We investigated the soil fertility and nutrient balance in sawah under current rice farming systems in order to examine better management of sawah soils, through laboratory experiments and field surveys in two watersheds, Citarum and Kaligarang.

In the study of soil geochemical characteristics, we discuss the degree of rock weathering using the chemical index alteration (CIA) and the dynamic transport of major and trace elements. The results showed that the CIA values of soil samples ranging from 65.7 to 104.4, indicating that intermediate to extreme weathering had occurred. With such high weathering, mobile elements could easily be transported in lowland areas and might contribute to sustain rice production in lowland sawah. In addition, the parent material such as calcite-alkaline which was produce by volcanic eruptions in Citarum watershed has an abundance of minerals rich in bases. The parent material was the main indigenous nutrient source in sawah soils in Java. Trace elements ratio of trace element vs. trace element and major element shows similar trend in parent rock sample in upland and soils in lowland. This result suggested that the nutrient in lowland sawah in Citarum watershed was derived from the parent rocks in upper topographical position 100 km far from the lowland.

In the continuous rice cropping systems, large amount of N, P, K and Si (silica) were removed due to harvest. Unlike N, P and K, Si fertilizer is not applied in Indonesian sawah. So, we investigated Si availability and dynamics in soils of sawah, other land uses, and also in river and canal water in Citarum and Kaligarang watershed. As the result, the available Si content in sawah soil was found to be deficient at 2 sites and low at 10 sites out of 16 sites for rice plant growth investigated in the Citarum watershed. In the Kaligarang watershed, no sawah site was classified as deficient and 9 out of the 15 sawah sites were determined to be low. In the Citarum watershed, sawah soils developed from the accumulation of lake and clay sediment contained relatively little available Si, while sawah soils in the Kaligarang watershed that were mainly developed from tuff and volcanic ash contained relatively more available Si. In general, the Si content in river and canal water was higher in the Kaligarang watershed than in the Citarum watershed, and this appears to be affected by the type of parent material. In addition to the type of parent material, Si depletion occurring in three dams might also influence Si content in the lower stream of river or canal water in the Citarum watershed.

Regarding to the Si retention in the dams in Citarum watershed, the concentrations of dissolved Si (DSi) and other essential nutrients, as well as phytoplankton diversity and density, were monitored at several sites of the dams, rivers and canals from September 2006 to November 2007. As

the result, DSi concentration was highest in the upstream reaches, including the furthest upstream dam, (Saguling), and decreased downstream. Dams contributed to a decrease of approximately 49-58% in DSi concentrations. The DSi reduction is associated with rising diatom densities (P<0.05), which utilize Si in the construction of frustules. The lowest DSi concentration was measured in Jatiluhur reservoir where diatoms were very abundant. High NO_3-N and PO_4-P concentrations were also determined in the dams and were probably derived from drainage of industries and houses in upstream and feeding materials used for fish culture in the dams. This eutrophication might enhance the growth of phytoplankton including diatom, and result in retaining more DSi in its cell wall and depleting Si supply into sawah in lowland through irrigation water

Burning rice straw in sawah is common practice in Indonesia and is implicated in the loss of nutrients from sawah. We tried to quantitatively investigate the loss of nutrients in burning experiments of rice straw in the laboratory and field. Burning of rice straw at 300°C to 1000°C in the laboratory resulted in the loss from 85 to 100% for TC, 100% for TN, 0 to 5% for Si, 15 to 68% for K, 5 to 29% for P, 1 to 24% for Ca, 2 to 22% for Mg, 27 to 48% for Na, 1 to 16% for Fe, 0 to 26% for Mn, 6 to 42% for Zn and 6 to 20% for Cu. The greatly loss of K, Na, P and some micronutrients (Mn, Zn and Cu) were mainly due to their loss as particulate matter and also probably as gaseous compound during burning. Burning of rice straw with moisture contents about 10% and 30% in fields caused the loss of TC and TN by 99%, Si by 35 and 33%, K by 47 and 36%, P by 59 and 38%, Ca by 44 and 38%, Mg by 48 and 42%, Na by 61 and 55%, Fe by 32 and 31%, Mn by 60 and 44%, Zn by 59 and 56% and Cu by 29 and 28%, respectively. The loss of nutrients by burning in the field was significantly higher (P<0.05) than that observed at the burning temperature of 600°C or 1000°C in laboratory experiments for Si, P, Ca, Mg, Fe, Mn and Zn. This significant loss of the elements in the field was speculated to occur through the scattering of particulate matters during the burning of rice straw.

An assessment of nutrient balance in lowland sawah was conducted at four farmer fields in lowland sawah in Citarum watershed. Input parameters were counted as nutrient content derived from fertilizer, irrigation water, nitrogen fixation and returning straw, while outputs parameters were counted as the nutrient loss through harvest, drainage water and denitrification. As the results, N, P, Ca, Mg and Na showed positive balances, while K and Si showed negative. Continuous decrease of K and Si, and continuous increase of N, P and Ca may cause these nutrient deficiency or excess, and could be limiting factors for growth of the rice plant in Indonesian sawah soil.

The study of geochemical characteristics of sawah soils in Java Island showed that parent material rich in base cation which continuously supplied the nutrient into lowland sawah and could maintain sustainability of rice production. However, in the present intensive rice farming system, large amount of nutrient uptake through rice harvest has not been replenished by sufficient application of chemical fertilizer or organic matters, especially for K and Si. Therefore, further research should consider on how to manage and compensate the deficit of K and Si in sawah soil in Java. Besides that, maintaining the level of N, P, Ca and Mg in soil is also important in order to improved and sustain rice productivity.