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著者	NANZYO Masami, TAKAHASHI Tadashi, KANNO Hitoshi
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Recent trends in the nutrient status of the paddy field soil in Japan and related topics

Masami NANZYO, Tadashi TAKAHASHI and Hitoshi KANNO

Graduate School of Agricultural Science, Tohoku University, Sendai, 981-8555, Japan
e-mail address of corresponding author: nanzyo@bios.tohoku.ac.jp

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Introduction

Paddy rice production is important for Asian people because rice is their traditional staple diet and it is a reliable crop for them. Rice shows second highest yield per ha next to maize (Kyuma, 2004) and sustainability of paddy rice production is excellent. In general, advantages and sustainability of paddy rice production are at least partly due to flooding and nutrient supply through irrigation water. Yield and quality of paddy rice are better than those of upland rice. In this paper, we review characteristics of the paddy field soils and recent trends in the nutrient status of Japanese paddy field soils, and then we discuss our recent research topics on N, P, S and Cd in the paddy field soil.

1. Characteristics of the paddy field soils

The conventionally tilled Ap horizon, 10-15 cm thick, of paddy field soils in Japan has many similarities even though soil classification names are different (Fig. 1). Soil classification names are determined using properties of soil horizons underlying the Ap horizon.

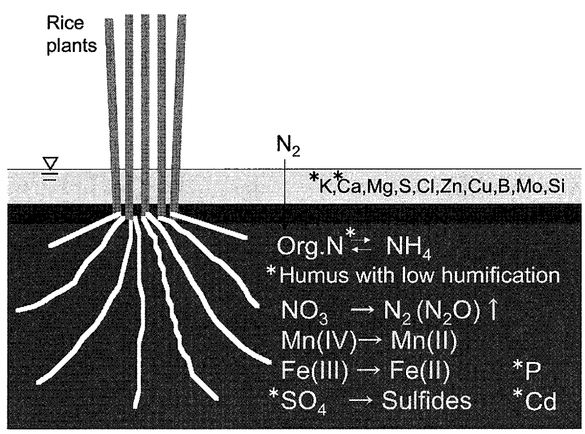

Fig. 1. Characteristics of the paddy field soil.

The Ap horizon is differentiated into two layers under flooded water during the rice-growing season. Upper 1 or 2 centimeters of the Ap horizon is kept oxidative due to O_2 diffusion through flooded water. Two thin layers, in millimeter scale, are often found at the very surface of the oxidative layer. The upper one is fine and the underlying one is relatively coarse due to sedimentation process of suspended soil particles after paddling (Saito and Kawaguchi, 1971). The Ap horizon below the oxidative layer is reduced during the rice-growing season. Manganese oxides, nitrate, iron oxides, sulfate, etc. are reduced, soil pH rises, organic N is partly mineralized, availability of P increases, and sulfides and carbonates of heavy metals may precipitate (Kyuma, 2004). Organic matter with low humification tends to accumulate in comparison with upland soils (Mitsuchi, 1974) due to restriction of O_2 supply.

On the other hand, morphological properties of subsoils are different due to many factors such as topography, groundwater level, drainage, soil texture, and so on. Paddy field soils are largely divided into two types that are endoaquic and anthraquic. The endoaquic type is found in the soil with high water table level. In this type, water percolation is slow and reductive elluviation of Fe from the Ap horizon and accumulation at the underlying horizon are relatively weak. Artificial drainage often improves rice production and harvest operations in the endoaquic paddy fields. Morphological properties of the Anthraquic type are formed due to artificial irrigation to the soils lacking inherited aquic conditions. In this type, subsoil is more or less kept oxidative, water percolation is relatively rapid, and reductive eluviation of Fe from Ap horizon and precipitation of Fe in the subsoil are intensive. Formation of iron mottles and soft Mn oxide masses is conspicuous.

2. Recent trends in nutrient status of Japanese paddy field soils

According to recent statistics (IRRI, 2006), rough rice production in Asia and in the world steeply increased during these 40 years (Fig. 2a). As the increases in the harvested area of the world have been quite gentle (Fig. 2b), it is due to the increase in yield (Fig. 2c) that the rough rice production increased. Regarding Japan, the rice production gradually decreased (Fig. 2a) and the harvested area has also been gradually decreased (Fig. 2b) due to production control that stated in 1970. Although rice yield often declined due to cold summer especially in the northern part of Japan, rice yield still tends to increase gently. These statistics suggest that the nutrient status in the paddy field soils is not deteriorating in Japan and also in the world. Thus, the rice production in the world appears highly sustainable.

Nation-wide soil test data of agricultural lands have been collected in Japan since 1960's (Oda et al., 1987; Obara, 2000; Nakai and Obara, 2003; Obara and Nakai, 2003). As a general view, little deterioration has been found in the paddy field soil during these 3 or 4 decades. Soil pH slightly rose (Fig. 3a), exchangeable Ca content (Fig. 3b), cation exchange capacity (Fig. 4a) and organic C content (Fig. 4b) were almost constant, exchangeable K content (Fig. 3c) and available N content (Fig. 4c) showed a slight increase, and available P content increased (Fig. 4d).

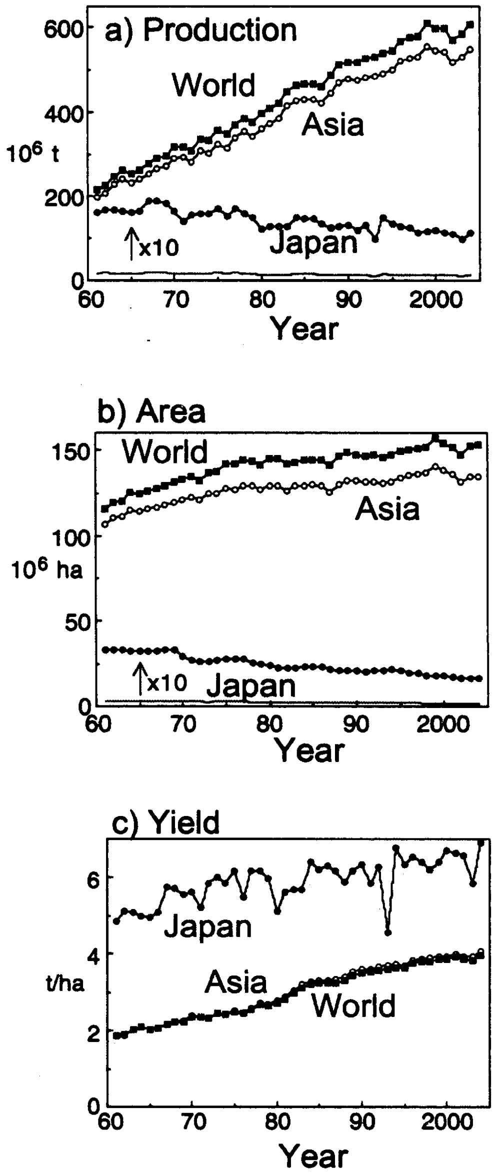

Fig. 2. Rough rice production (a), area (b) and yield (c). (IRRI, World rice statistics)

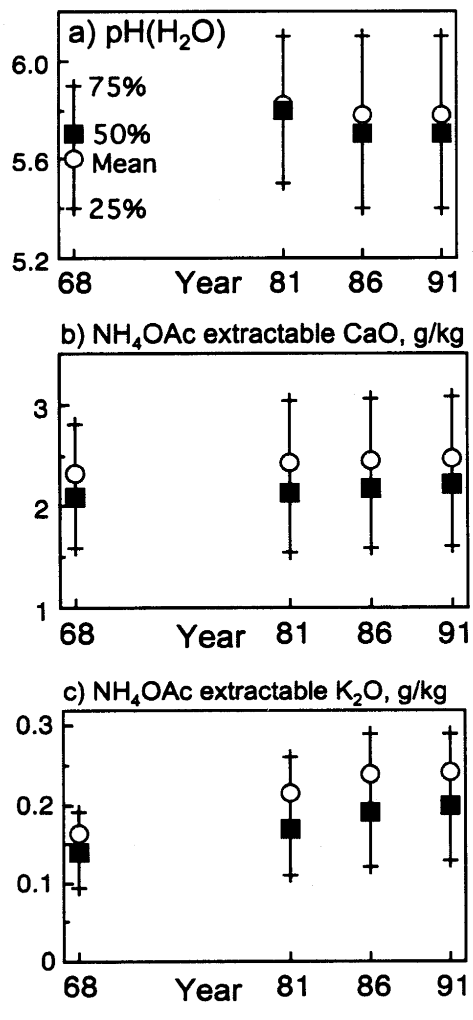

Fig. 3. Changes in pH (H_2O), exchangeable Ca and K.

The increase in exchangeable K content is probably due to recent changes in the method to harvest rice in Japan. Unlike N and P, a major part of K does not translocate to ear and remains in the straw. After widespread of combine harvester, straw is cut and returned to the paddy field soil. Thus, the present K input to the paddy field soil is more than before if the amount of K fertilizer application is the same as before. Slight increase in available N content may be due to application of rice straw and animal wastes.

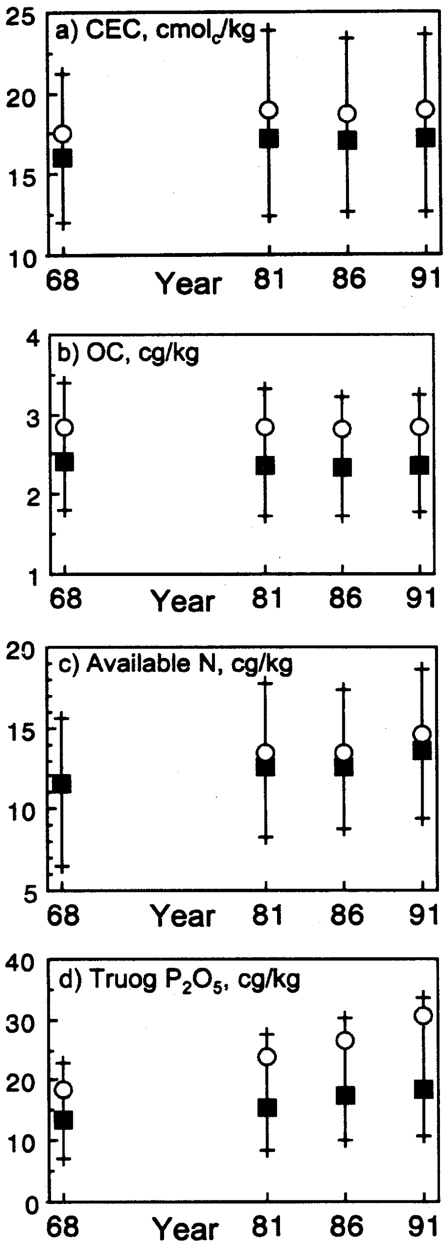

Fig. 4. Changes in CEC (a), Organic C content (b), available N content (c) and Truog P content (d).

The increase in available P is due to fixation of applied P in the soil although the rate of the increase is lower than those in upland and orchard soils.

Supply of nutrients such as Ca, Mg, K, S and micronutrients by irrigation water, increases in availability of Fe, Mn and P for rice plants under reducing conditions and microbial N fixation estimated as 20 to 40 kg ha^{-1} are the reasons for high sustainability of paddy rice production as well as lack of sick soil.

These statistics suggest our paddy rice fields are mostly in ordinary conditions. However, according to regional reports, organic C content is slightly decreasing in Hokkaido (Hashimoto, 2000; Goto et al., 2003) and Ishikawa prefecture (Kitada et al., 1999) due to reduction of organic matter application. Thus, careful management is indispensable to maintain soil fertility in adequate conditions.

Concentration of Si in the irrigation water is decreasing (Kumagai et al., 1998) and the factors involved may be an increase in irrigation canals made of concrete, absorption by diatom in the dam lakes and so on. This is an adverse trend for the recent paddy field soils as Si is beneficial for rice plants.

3. Increase in available N for rice after soy been cultivation

Due to overproduction of rice, shifting from rice to cultivation of other crops in the paddy fields started in 1970 in Japan. Soybean was one of the major crops shifted from rice. It is well known that available N content increases after soybean cultivation (Sumida and Kato, 2001; Sumida et al., 2005, Fig. 5) although the reason is not yet completely understood.

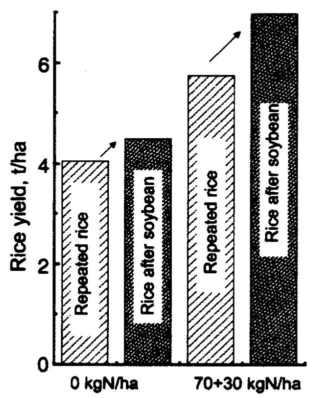

Fig. 5. Rice yield increases after soybean cultivation. Prepared after Sumida et al., (2005)

We determined available N content of the soil under soybean cultivation in pots every month using an incubation method and we found that the available N content of the soil increased during August (Maekawa et al., 2005). The increase in the available N content was confirmed also with rice plant cultivation. However, total N content did not significantly change. Other changes in soil properties were decreases in exchangeable K, Ca and Mg and available P contents.

4. Mobility of P and K applied to the row side of rice seedlings

Machinery transplanting of rice seedling is now common in Japan and fertilizers (P, K and N) are automatically applied to the row side of the rice seedling using nozzles equipped with the rice transplanter. We determined vertical distribution of available P using the modified Bray P (II) method and exchangeable K content of the soils around the site of fertilizer application. High available P content was found at the site of the fertilizers application whereas distribution of the exchangeable K content was almost the same between the sites with and without K fertilizer application (Fig. 6, Akahane et al., 2006a). Thus, P moved little from the site of application. Although P availability in the paddy field soil increases under reducing conditions, the amount of P applied was still less than the P sorption capacity of the soils under reducing conditions (Nanzyo et al., 2004; Akahane et al., 2004). Localized P distribution in the Ap horizon soil was also confirmed by sampling horizontal soil sections after harvest (Fig. 7, Akahane et al., 2006a).

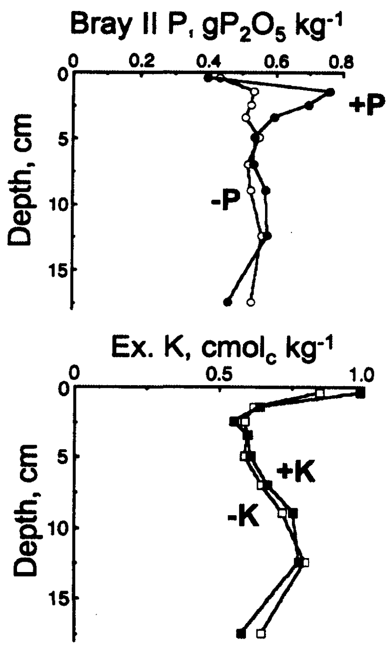

Fig. 6. Vertical distribution of Bray P(II) and exchangeable K at the sites with and without fertilizer application by a transplanting machine.

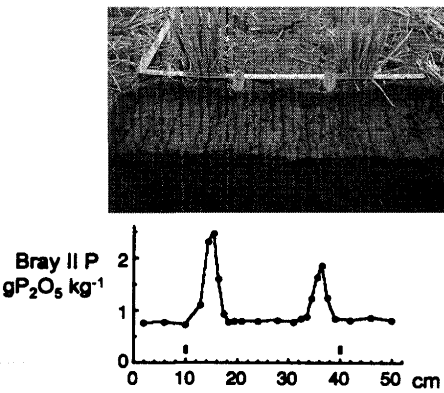

Fig. 7. Horizontal distribution of P applied to row side of rice seedlings.

Vertical distribution of P in the Ap horizon of the paddy field soil is also affected by biological activities. Labile inorganic P was partially converted to organic forms at the very surface of the soil and it was conspicuous in the no-till paddy rice field (Akanahe et al., 2006b).

5. S deficiency symptom of rice observed in the middle course plane of the Nihasama river

As sulfur is generally supplied as a solute in irrigation water and an accessory ingredient of N or P fertilizers, S deficiency was little observed so far. However, after Tsuji (2000) reported S deficiency of rice in Shiga prefecture, similar symptom was also recognized in the middle course plane of the Nihasama river, Miyagi prefecture. Lower leaves of rice plant started to show yellowish color at the growth stage of 5 leaves. Although the symptom resembles N deficiency, it was not ameliorated by an additional N application. It was with an enough application of $CaSO_4{\cdot}2H_2O$ that the symptom was ameliorated almost completely (Sasaki et al., 2006).

6. Partial removal of Cd from a contaminated soil by $CaCl_2$ washing

To ameliorate heavy metal contamination of paddy field soils, countermeasures such as removal of the contaminated soil and piling uncontaminated soil, simple piling of uncontaminated soil on the contaminated soil, removal of heavy metals using hyper-accumulator plants, washing the contaminated soils and so on were examined. Among these countermeasures, soil washing is one of the choices if the contaminated soil is washed and used on site. Washing does not take so long time as remediation by the hyper-accumulator plants. Mild washing procedure is desirable in order to keep the original soil properties and soil fertility as much as possible.

A Cd-contaminated soil was washed with 0.1 M $CaCl_2$ at pH 4. Content of Cd extractable in 0.1 M HCl reduced to almost a third. After thorough washing with water to remove excessive $CaCl_2$, pH was adjusted to about 7 using dolomite powder and rice plants were grown for 3 years using pots. Although removal of Cd is only two thirds, Cd content of the polished rice was kept below 0.2 mg kg^{-1} for at least 3 years whereas it was more than 0.5 mg kg^{-1} in the polished rice grown in the unwashed soil (Hayashi et al., 2006).

References

Akahane, I., M. Nanzyo and T. Takahashi (2004) Significance of hydrous Fe oxides in enhancing P sorption of soils with the addition of sodium hydrosulfite ($Na_2S_2O_4$). Soil Sci. Plant Nutr., 50 (8): 1317-1320.

Akahane, I., M. Nanzyo, T. Takahashi, O. Sekiguchi and M. Saigusa (2006a) Spacial distribution of phosphorus in the Ap horizon soils of paddy rice fields after rice harvest-effect of machinery localized fertilizer application at transplanting of rice seedlings-. Jpn. J. Soil Sci., Plant Nutr., 77: 171-177.

Akahane, I., N. Sasaki, M. Nanzyo, T. Takahashi, T. Tashiro, O. Sekiguchi and M. Saigusa (2006b) Relationship between vertical distributions of Bray 2 P content and organic P content in the Ap horizon of paddy rice fields. Soil Sci., Plant Nutr., 52: 654-661.

Goto, E., S. Miura, M. Nomura and O. Inatsu, (2003) The present condition of chemical properties of paddy soils in Hokkaido. Jpn. J. Soil Sci. Plant Nutr., 74: 475-484.

Hashimoto, H. (2000) Temporal changes of the soil chemical properties by the soil monitoring and some future problems of long-term monitoring. Pedologist, 44: 147-154.

Hayashi T., T. Kida, M. Nanzyo and T. Takahashi (2006) Effect of soil washing to ameliorate Cd contaminated soil and its persistence-rice cultivation using pots. Abstracts of the Annual Meeting, Jpn. Soc. Soil Sci. Plant Nutr., 52: 165.

Kitada, K., K. Morimasa, O. Miyakawa and N. Shioguchi (1999) Status and changes of physical and chemical properties of cultivated soil during a period of twenty years in Ishikawa Prefecture. Bull. Ishikawa Agric. Exp. Cent., 22: 49-73.

Kumagai, K., Y. Konno, J. Kuroda and M. Ueno (1998) Concentration of silic acid in irrigation water on Yamagata Prefecture. Jpn. J. Soil Sci. Plant Nutr., 69: 636-637.

Kyuma, K. (2004) Paddy Soil Science. Kyoto University Press, Kyoto, Japan. pp. 280.

Maekawa, R., K. Yoshizumi, M. Nanzyo and T. Takahashi (2005) Time-course of available N content in soil during soybean cultivation. Abstracts of the Annual Meeting, Jpn. Soc. Soil Sci. Plant Nutr., 51: 129.

Mitsuchi, M. (1974) Characters of humus formed under rice cultivation. Soil Sci. Plant Nutr., 20: 107-116.

Nakai, M. and H. Obara (2003) Monitoring of soil characteristics of arable lands in Japan. Jpn. J. Soil Sci. Plant Nutr., 74: 557-566.

Nanzyo, M., H. Kanno and S. Obara (2004) Effect of reducing conditions on P sorption of soils. Soil Sci. Plant Nutr., 50: 1028-1028.

Obara, H. (2000) Outline of the soil monitoring and soil quality of the arable land in Japan. Pedologist, 44: 134-142.

Obara, H. and M. Nakai (2003) Exchangeable bases and related soil properties of arable lands in Japan. Changes of soil characteristics in Japanese arable lands (I) Jpn. J. Soil Sci. Plant Nutr., 74: 615-622.

Oda, K., E. Miwa and A. Iwamoto (1987) Compact database for soil analysis data in Japan. Jpn. J. Soil Sci. Plant Nutr., 58: 112-131.

Saito, M. and K. Kawaguchi (1971) Coagulation properties of paddy field soil (No. 4) Structure of the plow layer in the paddy field. Jpn. J. Soil Sci.

Plant Nutr., 42: 95-96.
Sasaki, K., T. Hayashi, M. Nanzyo, H. Kanno, T. Takahashi, E. Hasegawa, M. Honna, Y. Aikawa and K. Yoshihara (2006) S deficiency symptom of rice and amelioration with $CaSO_4$ application. Program and abstracts of the 100th Anniversary of Tohoku University International Symposium "Frontiers in Rice Science-from gene to field-". pp. 38.
Sumida, H. and K. Kato (2001) Rice productivity of rotational paddy field converted from upland field cropped with soybean for 18 years. Tohoku Agric. Res., 54: 59-60.
Sumida, H., K. Kato and M. Nishida (2005) Depletion of soil fertility and crop productivity in succession of paddy rice-soybean rotation. Bull. Natl. Agric. Res. Cent. Tohoku Reg., 103: 39-52.
Tsuji, T. (2000) Studies on causes and measures for the growth disorder of early planting rice in the northern district of Shiga Prefecture (Part 1) Occurrence of initial growth disorder of rice plants supplemented with basal paste-like fertilizer, and effect of sulfate fertilizer application on the disorder. Jpn. J. Soil Sci. Plant Nutr., 71: 454-463.