The Nutritional Environment in Nonfertilized Rice Production and Its Effect on the Nutritional Quality of Brown Rice

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Abstract

The nonfertilized-nonchemical crop production (so-called nature farming) proposed by Mr. Mokichi Okada is a popular farming method in both Japan and worldwide. The farming method uses neither fertilizers nor chemicals but obtains comparable yields to those produced by conventional farming. Although the method was designed to utilize natural resources, the details of the mechanism are still unknown. This study was aimed to evaluate the nutritional environment on the basis of the measurement of the nutrients in the soil solution and to analyze the effect on the nutrient concentrations of brown rice. For this purpose, we selected 2 nonfertilized-nonchemical paddy fields (NN fields) and 1 experimental paddy field (Expt field) as a reference. One of the NN fields was cultivated for 6 years without fertilizer (6-year NN), and another was cultivated in this way for 59 years (59-year NN). In the Expt field, 3 types of fertilizer treatments (None, Basal and Conventional) were conducted. The NH_4^+ concentrations in the 6-year NN fields was lower than those in the fertilizer-applied plots (Basal and Conventional), but they were comparable to that in the None treatment. Conversely, NH_4^+ was not detectable in the 59-year NN field. Other nutrients were extremely different between the NN fields and Expt field, namely, the fertilizer treatments (Basal and Conventional) had little effect on the nutrient concentration of the soil solution. The P_2O_5 and K^+ levels in the Expt fields were notably higher than those in the NN field, whereas Ca^{2+} and Mg^{2+} showed an opposite trend. Significant interactions of the genotype by environment were observed for the nutrient concentrations in brown rice. The relatively low NH_4^+ and K^+ level in the soil solution in the NN fields tended to result for brown rice in low concentrations of those nutrients, which Japanese people tend to prefer. The relationship between the nutritional environment and the uptake and concentration of nutrients in brown rice should be studied further.

Keywords: rice, nonfertilized-nonchemical crop production, soil solution, nutritional quality of rice

Introduction

Agrochemicals such as fertilizers and pesticides largely increase agricultural production and support the huge population of the world. However, excess inputs of agrochemicals leak into the environment and cause various kinds of problems that pose threats to human life (Reichenberger et al. 2007). Organic farming or nature farming is derived from the reactions against such agrochemical agriculture.

The nonfertilized-nonchemical crop production proposed by Mr. Mokichi Okada is popular in both Japan and worldwide. This method of farming uses neither fertilizers nor chemicals but obtains comparable yields to those produced by conventional farming (Okumura, 2002). Okumura reported that the sources of some of the nitrogen were irrigation water and biological fixation but that the majority comes from soil. Although the method of farming was designed to utilize natural resources, the details of the mechanism are still unknown.

Because crop productivity is restricted by nutrients supplied through soil, an evaluation of the nutritional environment in the soil is quite important when discussing productivity. In general, the availability of nutrients for plants is evaluated by chemical analyses. However, the nutritional environment is quite influenced by the temperature, soil moisture and plant uptake and exudates, which suggests that periodic monitoring of the nutritional environment is required to analyze the plant response to nutrition and the nutrient availability (Boivin et al., 2002).

When plants take up nutrients from the soil, the procurement does not occur on the surface of the soil particles but through the liquid phase of the soil (soil solution). Nutrients in their ion forms, such as ammonium and potassium, move with the soil solution (mass flow) or by diffusion in the solution. Accordingly, nutritional analyses of the soil solution are suggested to evaluate the nutritional environment (Smethurst, 2000).

This study investigated nonfertilized-nonchemical fields and an experimental field as a reference. The soil solutions were sampled once every 2 weeks for the nutritional evaluation. Six representative rice cultivars were planted to evaluate any cultivar differences in nutrient uptake, dry matter production, yield and grain quality. This report focused on the changes in the nutrients in soil solution and the effect on the nutrient content of brown rice.

Materials and Methods

The experiment was conducted in 2010. We used two types of paddy fields: one was operated under nonfertilized-nonchemical management by NPO Nonorganic, Nonchemical Crop Production Research Group (NN fields; Ogura, Uji city, Kyoto Prefecture, 34° 54' N, 135° 46' E), and the other was an experimental field in the Graduate School of Agriculture, Kyoto University (Expt field; Sakyo, Kyoto city, Kyoto Prefecture, 35° 02' N, 135° 47' E). The NN fields included 2 fields: one was cultivated for 6 years without fertilizer or agrochemicals (6-year NN), and the other was cultivated for 3 years without fertilizer or agrochemicals after the top-soil was converted using the soil of a field where nonfertilized-nonchemical management was conducted for 56 years. Thus, the soil of the converted field was used for a total of 59 years under nonfertilized-nonchemical management (59-year NN). The experimental year was the 7th and 60th year of cultivation, respectively. In the Expt field, 3 kinds of fertilizer treatments (None, Basal and Conventional) were conducted under pesticide application. The none treatment was conducted without fertilizer, whereas the Conventional and Basal treatments included the application of chemical fertilizer at a rate of N-P_2O_5-K_2O = 5-5-5 g m^{-2} as basal, and the Conventional treatment was top-dressed with fertilizer on the 22th of July and the 7th of August. The rate of each top-dress application was N-P_2O_5-K_2O = 2.5-2.5-2.5 g m^{-2}. Thus, the total application rate for the Conventional treatment was N-P_2O_5-K_2O = 10-10-10 g m^{-2}. The Basal treatment was designed to starve nutrients around the heading period.

Based on the results of a study conducted in the same field (Matsuyama et al., 2010), six representative rice cultivars were selected. Beniasahi (Japan) is a traditional japonica cultivar and has been self-seed-produced for the 59 years under the nonfertilized-nonchemical management, suggesting that the cultivar has adapted to these conditions (Okumura, 2002). Nipponbare (Japan) and Kasalath (India) are standard cultivars of japonica and indica, respectively (Kojima et al., 2005). Takanari (Japan) is a high-yielding indica cultivar and is promising for the production of rice flour and as a feed crop. B6144F-MR-6-0-0 (B6144F) was bred for upland cultivation in Indonesia (Atlin et al., 2006). Bei Khe (Cambodia) is a cultivar that produced the largest amount of dry matter in the experiment conducted by Matsuyama et al. (2010). The cultivars were sown on the 10th of May and transplanted to the Expt field on the 3rd of June and to the NN fields on the 8th of June. The transplanting density was 22.2 hill m^{-2}, with 1 plant hill^{-1}. The experiment was arranged in a randomized block design for each field.

A soil solution sampler (DIK-301B, Daiki Rika Kogyo Co., Ltd.) was placed at a 10 cm-depth in every Nipponbare and B6144F plot. The soil solution was sampled by a syringe aspiration method once every 2 weeks and the concentrations of NH_4^+, P, K, Mg and Ca in the solution were measured. The soil chemical properties were measured by a standard method. The brown rice grains at maturity and the above-ground biomass and leaves at heading were sampled, and its N, K and Mg concentrations were determined.

Results and Discussion

Evaluation of the nutritional environment determined on the basis of the soil solution

The three major soil solution nutrients, NH_4^+, P and K, were quite different among the fields and treatments (Fig. 1). The NH_4^+ concentration under the Basal and Conventional treatments in the Expt field was initially quite high due to the effect of the basal fertilizer, but it markedly decreased by 30 days after transplanting. The conventional treatment maintained a relatively higher NH_4^+ concentration due to the top-dress application of fertilizer, whereas the NH_4^+ concentration under the Basal treatment exhibited a lower level (almost 0 ppm) than the None treatment. The Basal treatment resulted in nitrogen starvation conditions, as was intended by the experimental design. In the NN fields, the NH_4^+ concentration in the 6-year NN field peaked at 60 days after transplanting and maintained levels of approximately 0.70 ppm and 0.25 ppm before and after the peak at 60 days, respectively. The NH_4^+ concentration in the 59-year NN field maintained levels of approximately 0.2 ppm and 0 ppm for 30 days after transplanting and thereafter, respectively.

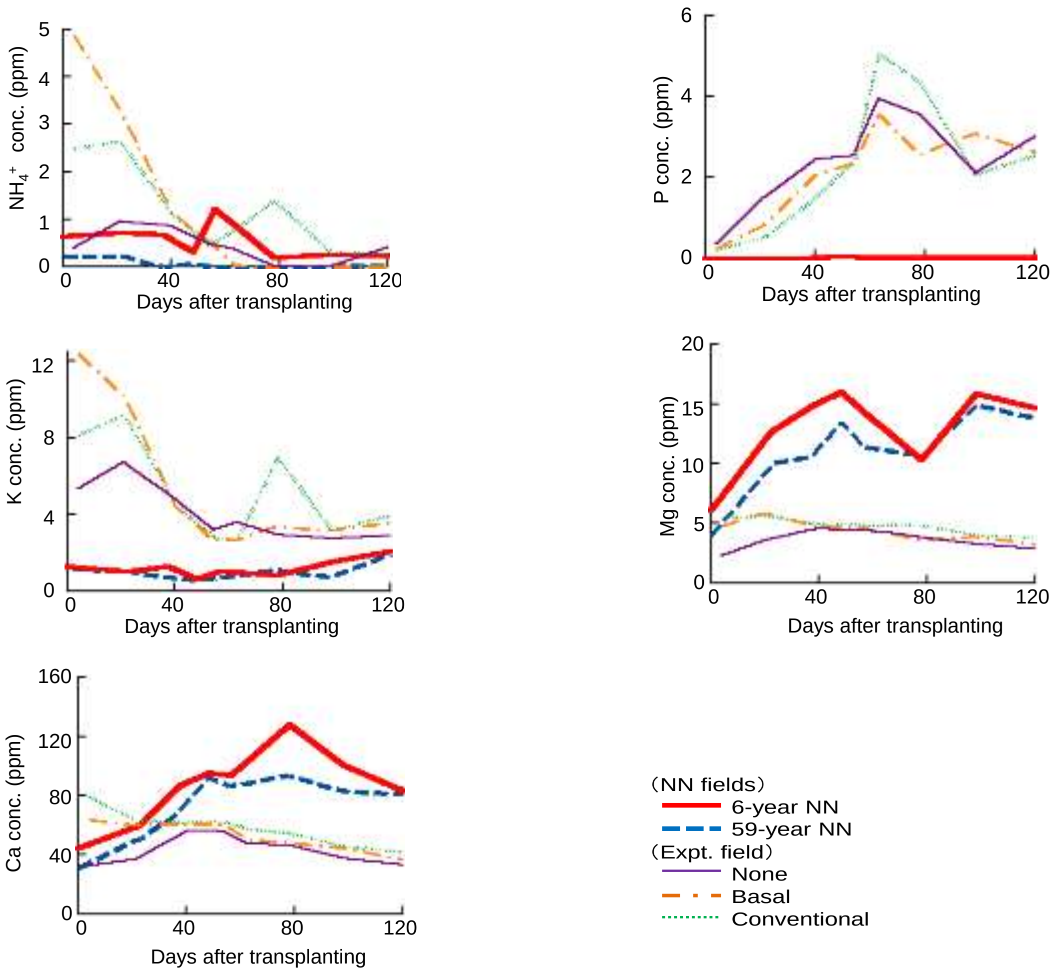


Figure 1. Change of nutrients concentration in soil solution.

The P concentration in the Expt field increased from the transplanting up to 70 days after transplanting, and differences among the fertilizer treatments were not obvious, suggesting that the annual P application accumulated P in the soil. Conversely, P was barely detectable in the NN fields. The difference in the P concentrations between the Expt and NN fields was corresponded to the soil chemical analysis (data not shown). Although the P concentration in the soil solution was negligible, the plants took up P from the soil (data not shown). Moreover, although the P concentration in the soil solution in the 6-year NN field was as low as that in the 59-year NN field, the P uptake by the plants in the 6 year-NN field was 1.6 times as large as that in the 59-year NN field. These data suggest that another indicator is required to evaluate the availability of P.

The K concentration was affected by the fertilizer application in the Expt field, but the effect was short-lived: the baseline concentrations under the Basal and Conventional treatments were similar to that under the None treatment. The K concentration in NN fields was one half of the basal concentration in the Expt field, and apparent differences were not observed between the 6-year and 59-year NN fields.

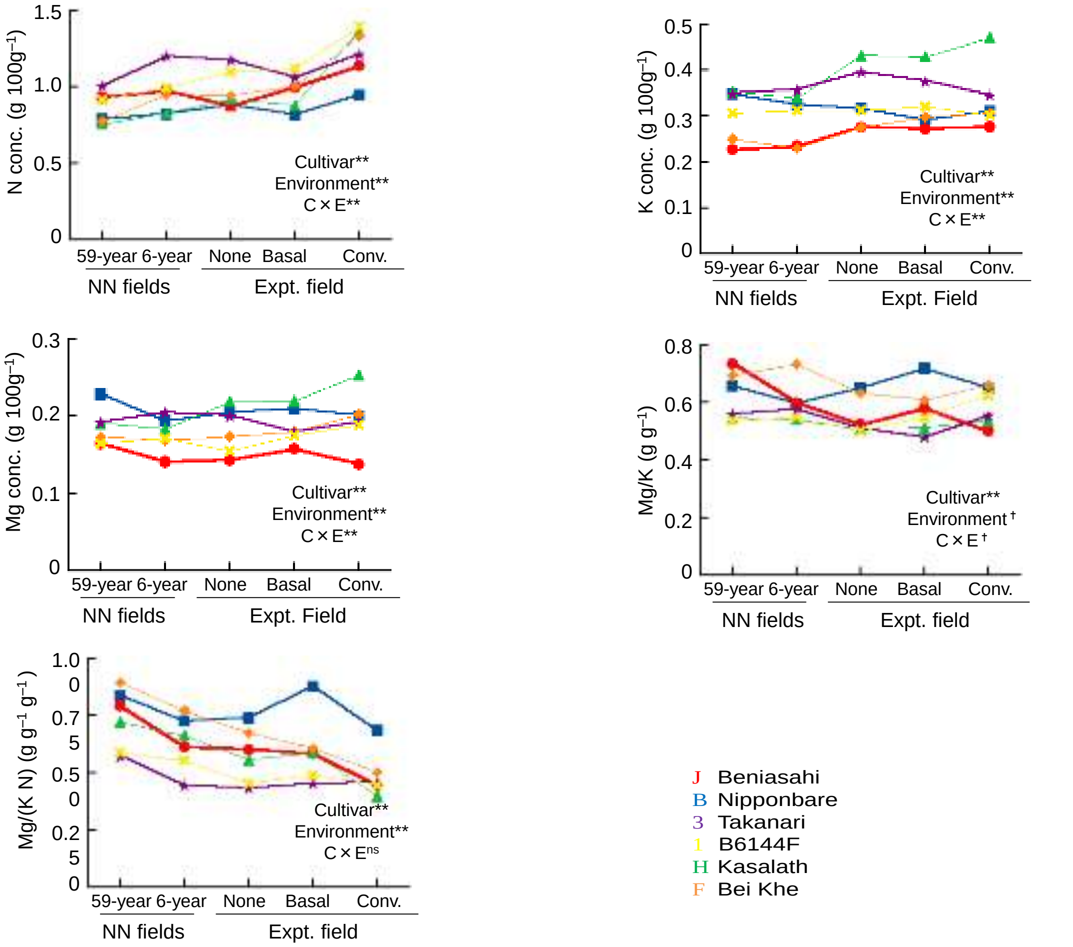
The Ca and Mg concentrations were different at transplanting among the fertilizer treatments in the Expt field, but the difference disappeared by 30 days after transplanting. The concentration gradually decreased with time, whereas the concentrations increased until 50 days after transplanting in the NN fields. The increase was repeated in a flood incubation using the soil sampled before transplanting (data not shown), suggesting that the trend shown in Fig. 1 is derived from the characteristics of the soil or the forms of Ca and Mg in the soil.

The effect of nutrients in the soil solution on nutrient concentrations of brown rice

The N and K concentrations in brown rice almost reflected those in the soil solution: the concentrations of the brown rice in the NN fields tended to be lower than those in the Expt field. However, the Mg concentration of the brown rice in the 6-year NN field was lower than that under the Conventional treatment in the Expt field; thus, the concentrations of the brown rice did not reflect those in the soil solution. The interaction effects of the cultivar and the environment were significant for all of the nutrients, indicating that the plant responses to the nutritional environment were different among the cultivars.

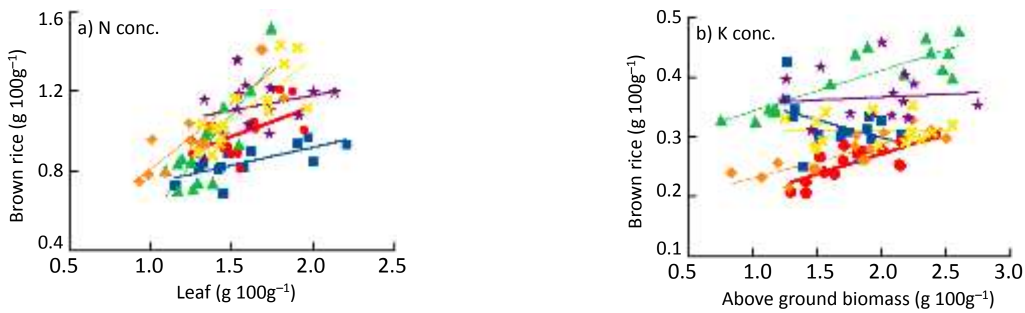
Previous studies report that the N concentration in brown rice is affected by that in the flag leaves at heading (Taira, 1997). The relationship in this study suggests that the indica cultivars are more affected than the japonica cultivars (Fig. 3). As available data atre inadequate for K and Mg, the relationship of the K and Mg concentrations of the brown rice was compared with that in the above-ground biomass at the heading stage. The relationships of the K concentration between the brown rice and the above-ground biomass were significant for the traditional varieties but not significant for the improved varieties. The relationships of the Mg concentration between the brown rice and the above-ground biomass were significant for the traditional indica cultivars but not significant for the other cultivars (data not shown). As shown in Fig. 3 these cultivar differences may be one of the causes of the significant interaction of the cultivar and the environment on the nutrient concentration in brown rice.

In terms of the nutrient concentration of brown rice, 1/N, Mg/K or Mg / (K N) were proposed as grain palatability indexes for Japan (Nakagawa et al., 2000). As mentioned above, the N and K concentrations of the brown rice in the NN fields tended to be lower than those in the Expt field, increasing the indexes in NN fields higher than those in the Expt field. However, as nitrogen starvation under the Basal treatment apparently decreased the N and K concentrations of the Nipponbare brown rice, the index for Nipponbare was the highest under the Basal treatment.



Results of ANOVA are shown in the figure: †, *, ** and ^{ns} indicates 10, 5, 1 % and non- significance, respectively.

Figure 2. Effect of cultivar and environment on nutrition concentration of brown rice (a, b and c), and grain palatability index (d and e).



		Slope	
		N conc.	P conc.
J	Beniasahi	0.30*	0.067**
B	Nipponbare	0.18**	ns
3	Takanari	ns	ns
1	B6144F	0.63**	ns
H	Kasalath	1.01**	0.068**
F	Bei Khe	0.66**	0.057**

Figure 3. (a) Relationship between N concentration in leaf at heading and that in brown rice at maturity. (b) Relationship between K concentration in above-ground biomass at heading and that in brown rice at maturity.

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-- back to Table of Content --