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Possibility of No-Input Farming in Lowland Rice Fields in Japan from the Viewpoint of Sustaining Soil Fertility

Naoki Moritsuka

Abstract

In Japan, the area of low-input rice production is gradually increasing with a growing public interest in the quality and safety of our staple food. In an extreme case, rice has been grown over years without using any chemical fertilizers and agrochemicals. However, it is uncertain how much and how long such no-input farming can sustain rice yield and soil fertility. To better understand the sustainability of no-input rice farming in Japan, I briefly review previous results obtained from the long-term field experiments. The topics are (1) rice yield and soil fertility under no-input farming, (2) the environmental factors affecting rice growth and soil fertility under no-input farming, and (3) the dynamics of soil K under continuous rice cropping. The corresponding conclusions are as follows: (1) rice yield and soil fertility under no-input farming in Japan were influenced by various environmental and management factors operating at regional and field scales; (2) the input of K through irrigation and the high-clay content in soil were considered the key environmental factors that enable to sustain no-input farming; and (3) soil K depletion caused by long-term exhaustive cropping should be assessed by monitoring the decrease of soil nonexchangeable K rather than that of exchangeable K.

Keywords: irrigation effect, long-term field experiment, lowland rice, nonexchangeable potassium, soil sustainability

1. Introduction

It is generally considered that crop yield and soil fertility can be maintained by the adequate input of fertilizer elements to soil. However, in the case of irrigated paddy soil, there are several farmers' fields in Japan which have not received any fertilizers for more than a decade but sustained rice yield at around 400 g m^{-2}, i.e., about 80% of the conventionally fertilized fields [1–3].

The wonder of sustaining rice yield without fertilizer input may be explained by the unconscious input of nutrients to lowland fields through irrigation, rainfall, and biological nitrogen (N) fixation [4]. The advantage of lowland rice over upland rice can be found in the nutrient omission trials carried out throughout the country before chemical fertilizer was prevailed [5]. As shown in **Figure 1**, N was the most limiting element for both lowland and upland rice. For lowland rice, however,
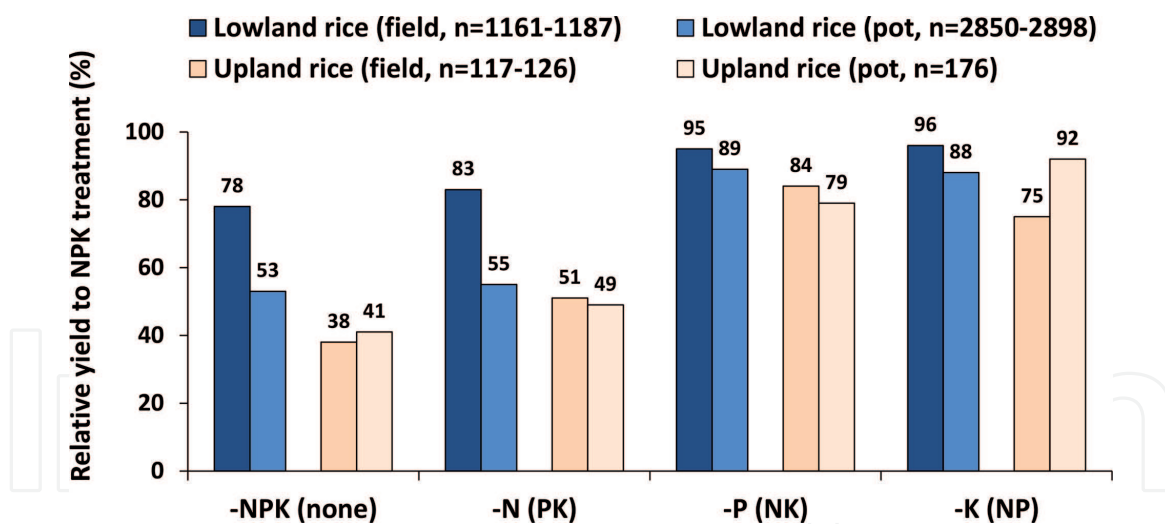
Figure 1.
Response of the yield of lowland rice and upland rice to the omission of N, P, and K fertilizers in Japan (adapted from [5]). Data obtained from the nutrient omission trials conducted under pot and field conditions since 1916 were summarized.
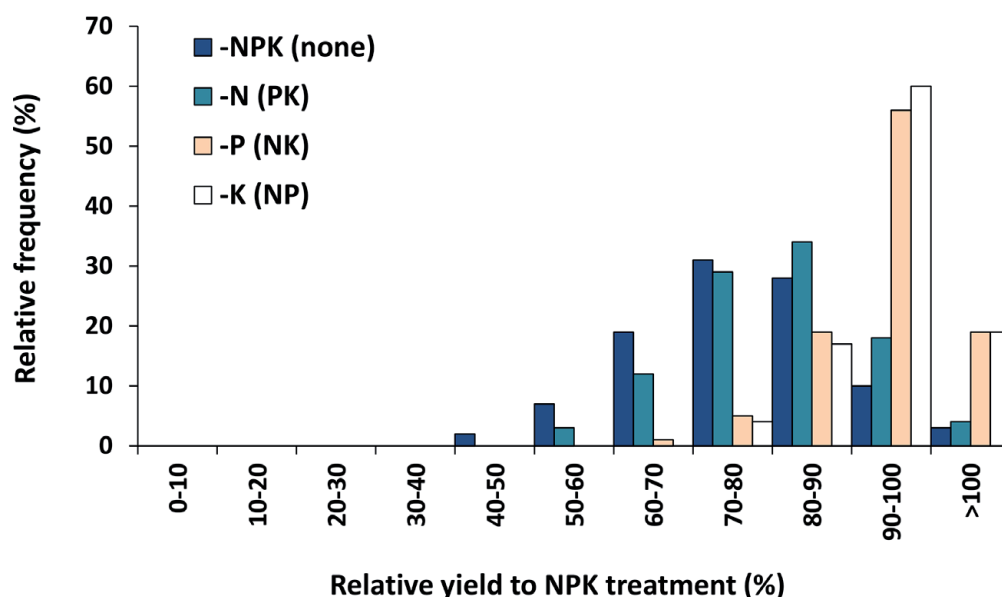

Figure 2.
Response of the yield of lowland rice to the omission of N, P, and K fertilizers in Japan (adapted from [5]). Data obtained from the nutrient omission trials conducted under field conditions (field-grown lowland rice in **Figure 1***) were summarized. The trials were 1097–1138 in number.*

the percentage of yield loss caused by the omission of fertilizers differed with the growth conditions; 22 and 47% under field and pot conditions, respectively. Such a discrepancy was not observed for upland rice. With a closer look at the response of lowland rice to the omission of potassium (K) and phosphorus (P) under field conditions, the omission of these elements also caused more than 10% decrease of the yield in more than 20% of the paddy fields surveyed (**Figure 2**). Accordingly, K or P began to limit rice yield in some of the paddy fields when N limitation was removed by the application of N fertilizer.

These results contributed to predict the necessary amount and type of chemical fertilizers applied to paddy fields. **Figure 3** shows the temporal changes in the average rates of chemical fertilizer applied to paddy fields in Japan [6]. In 1950, N was applied at a higher rate than P and K. With time, the rates of P and K became comparable to the rate of N. This is probably because of the alleviation of N limitation and the use of compound fertilizer containing N and other nutrients. In 1970, more than 60% of
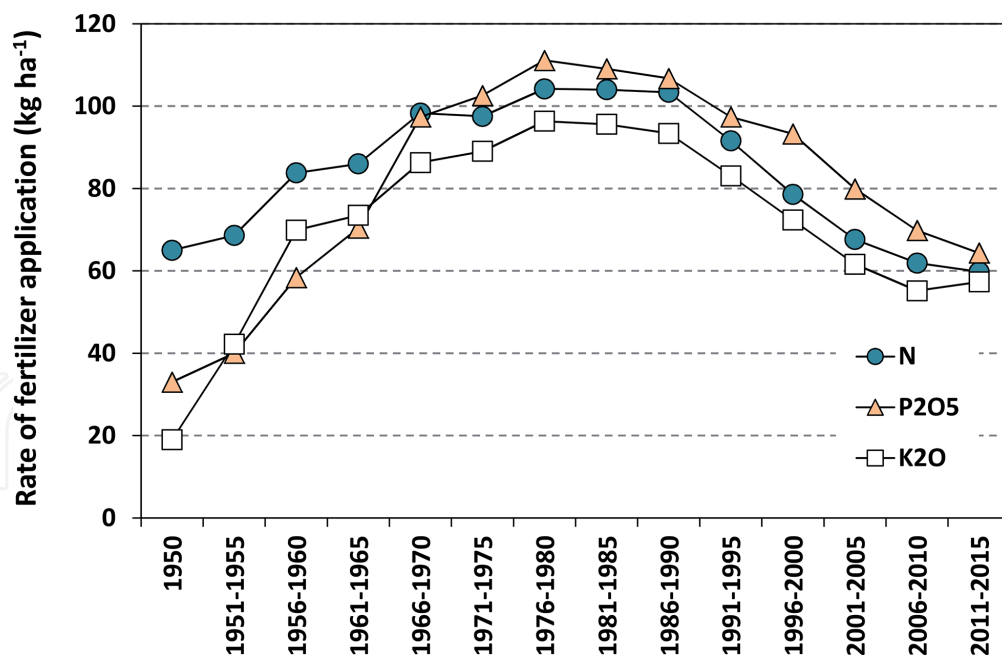
Figure 3.
Rates of chemical fertilizer application to paddy fields in Japan from 1950 to 2015. The values before 1970 were cited from FAO [6], and those after 1970 were cited from several volumes of Pocket Fertilizer Handbook published by the Association of Agriculture and Forestry Statistics, Tokyo.

N, P, and K were applied together in the form of compound fertilizer. The application rates of all nutrients increased rapidly by 1970 and reached a plateau around 1980. Then, the rates decreased from 1990 to 2015. The amount of N applied in 2011–2015 (60 kg ha^{-1}) became smaller than the amount of N applied in 1950 (65 kg ha^{-1}). This would be partly because the percentage of fertilizer N recovered by rice plants was significantly increased by the development of new techniques, e.g., side-dressing of polyolefin-coated urea that can supply N to rice roots according to crop demand. But a more plausible reason is the introduction of the *gentan* policy in 1970 for reducing rice production all over the country and the concomitant shift of the consumer preference to rice from the nutrition to the taste and safety. For example, recent Japanese consumers prefer low-protein rice that is less nutritious than high-protein rice, because cooked rice with high-protein content tends to become hard and nonsticky [7].

From these backgrounds, rice and other crops produced with reduced input of chemical fertilizers and agrochemicals have been attracting more attention by consumers. In 2001, the Japanese government established the guidelines for the certification of crops produced with chemical fertilizers and agrochemicals at less than 50% of the conventional dosage in each region. The area of production of such crops amounted to 0.12 million ha (2.6% of total arable land) in 2017. Organic farming, where chemical fertilizer is fully replaced with organic fertilizer, is also increasing gradually, although the area of organic-farming fields is still 0.5% of the total area of arable land in 2017. The most extreme way of farming is the production of crops without using any chemical fertilizers and agrochemicals. Such no-input farming is called *shizen nouhou* or *shizen saibai* in Japanese, and translated directly as natural farming [1] or nature farming [8]. The amount of rice produced by no-input farming was estimated to be only 0.04% of the national production in 1991 [9].

These histories clearly show that no-input farming in Japan has been developed as a result of the past high-input farming, and it does not represent various types of no-input farming systems in the world. Almost all no-input paddy fields in Japan had received chemical fertilizers and agrochemicals before no-input farming was introduced, and these fields are different from the absolutely no-input fields in other countries that have not received any chemicals since land reclamation.

Recently, no-input rice farming in Japan has been recognized as an economically feasible farming system. Due to the very limited availability, rice produced by no-input farming has been sold at twice or more the price of rice produced by conventional farming [10]. Besides the price of the products, the level of rice yield and its sustainability are also important for farmers [1]. Several researchers have compared rice yield among no-input paddy fields with different periods after introducing no-input farming [1–3]. However, most of the previous studies have used a space-for-time substitution approach instead of monitoring rice yield and soil fertility over years. Thus, it is uncertain how much and how long such no-input farming can sustain rice yield and soil fertility under various environmental conditions.

In order to better understand the sustainability of no-input rice farming in Japan, I briefly review previous results obtained from the long-term field experiments including our no-input trial. The main topics in this review are (1) rice yield and soil fertility under no-input farming, (2) the environmental factors affecting rice growth and soil fertility under no-input farming, and (3) the dynamics of soil K under no-input and high-input rice farming systems.

2. Rice yield and soil fertility under no-input farming

In 1990, Neera et al. [1] surveyed 542 no-input fields in 17 prefectures in Japan and compared rice yield with the average yield by conventional farming according to the corresponding municipal statistics. The sampling of rice plants was performed at one representative site in a paddy field at the rate of 30 hills per field [11]. On average of the surveyed fields, the period of no-input farming was 10.7 years, and the yield of brown rice by no-input farming (445 g m^{-2}) amounted to 87% of the yield by conventional farming (511 g m^{-2}). When the results were compared among different regions, the yield by no-input farming was significantly lower than the yield by conventional farming at six prefectures in Tohoku district located in northern Japan (**Figure 4**). The yield was relatively high in Tohoku district, and the average yield after no-input farming for 28–40 years amounted to 456 g m^{-2} (n = 19). On the other hand, the yield gap was not statistically significant at many prefectures in Kinki and Chugoku districts located in southern Japan except for
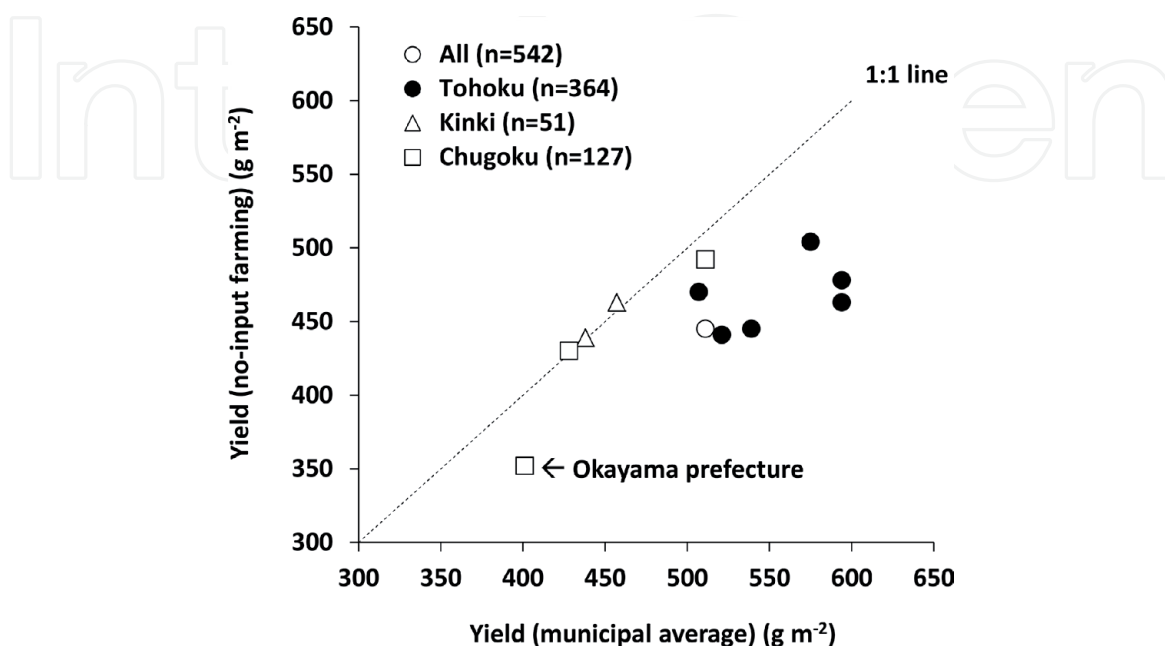

Figure 4.
Relationship between rice yields obtained from municipal statistics and from no-input farming (adapted from [1]).

Okayama prefecture. Furthermore, the coefficients of variation of yield by no-input farming were as large as 12–29% in each region displayed in **Figure** 4, and the number of surveyed fields in each region was relatively large (19–180). These results suggest that rice yield was also influenced by field-specific environmental and management factors. The lack of the yield gap in several prefectures might be due to the arbitrary selection of fertile fields for no-input farming, because it was contrasting to the results obtained from the nutrient omission trials (**Figure** 2). Thus, the authors emphasized that more research is needed to monitor the yield under no-input farming in combination with the yield under conventional farming and to elucidate the factors affecting rice yield under no-input farming.

Following this pioneering work, however, only a few researchers have attempted to identify the factors affecting rice yield under no-input farming. Hosoya and Sugiyama [2] surveyed 16 no-input fields in four prefectures (Aomori, Iwate, Miyagi, and Niigata) in northern Japan. The yield of brown rice in no-input fields was positively correlated with the number of panicles (r = 0.92, $p < 0.01$). The panicle number was positively correlated with the air temperature during the vegetative stage (r = 0.66, $p < 0.01$) and negatively correlated with the latitude of the location of each field (r = −0.60, $p < 0.05$). Tatara et al. [3] also examined 16 no-input fields in three prefectures (Fukui, Shiga, and Kyoto) located in the warmer part of Japan. The yield of rough rice was positively correlated with soil total N content (r = 0.76, $p < 0.01$) but was not significantly correlated with the content of mineralizable N in soil. These results imply that, in the case of northern Japan, the yield by no-input farming was limited by the low temperature during the vegetative stage. Thus, the rate of N mineralization from soil rather than soil total N was regarded as an important factor limiting the tiller (panicle) number and yield. In the case of southern Japan, on the other hand, soil total N content was regarded as the most important factor limiting rice yield. These interpretations are based on the assumption that rice growth was not limited by the vigorous growth of weeds in no-input fields, because much more labor is required to remove weeds mechanically without herbicides, and effective weeding is the biggest concern for rice farmers adopting organic farming or no-input farming [12].

Compared to rice yield, much less attention has been paid to soil fertility under no-input farming. When the results in the above two reports [3, 12] were combined, total N content in the surface soil showed a large variation among the fields (**Figure 5**), and the coefficient of variation became 47%. The content was similar to or higher than the national average (2.39 g kg^{-1}) in several fields with a no-input history for more than 5 years. The highest content was recorded in a field with no fertilizer input for 21 years. The soil in this field was classified as one of the Andosols, whereas the soil in all the other fields was classified as non-Andosols according to the digital soil map of Japan [13].

For other soil properties, Kuwamura [8] evaluated the characteristics of soil chemical properties under no-input farming by using a space-for-time substitution approach. An extensive survey was conducted by analyzing 654 soil samples collected from no-input paddy fields throughout Japan from 1992 to 1996. The period of no-input farming ranged from 0 to 49 years. The results were compared with the contemporary national soil inventory data (third survey from 1989 to 1993 in [14]). The average depth of a plow layer in no-input fields (18.5 cm) was larger than that in the conventional paddy fields (14.6 cm). The average content of total N in the surface soil (2.6 g kg^{-1}) was slightly higher than the national average (2.42 g kg^{-1}). On the other hand, the average content of mineralizable N in the surface soil (118 mg kg^{-1}) was slightly lower than the national average (145 mg kg^{-1}). The average content of available P (Truog P) in the surface soil (126 mgP$_2$O$_5$ kg^{-1}) was much lower than the national average (298 mgP$_2$O$_5$ kg^{-1}). When the soil samples were
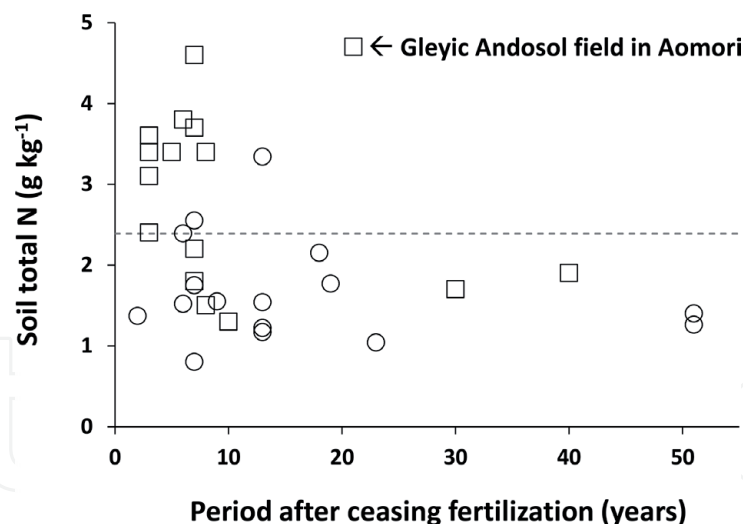
Figure 5.
Relationship between the period after ceasing fertilization to paddy fields and the content of total N in the surface soil (adapted from [3, 12]). The circular and rectangular plots are those reported by Tatara et al. [3] and Hosoya and Sugiyama [12], respectively. A dotted line in the figure indicates the average content in the surface paddy soil of Japan (2.39 g kg⁻¹) reported by MAFF [14].

limited to those classified as non-Andosols (n = 460), the concentration of available P was negatively correlated with the period of no-input farming (Spearman's $r = -0.42$, $p < 0.001$). This negative correlation was partly due to the presence of extremely high P soils in no-input fields with a short history, because the eight outliers with the available P content exceeding 600 mgP$_2$O$_5$ kg^{-1} were all sampled from the fields with a history of less than 20 years. Kuwamura [8] interpreted the results as follows: (1) soil available P was depleted by long-term no-input farming; (2) no-input fields with a short history had received more fertilizer-derived P before ceasing fertilization than those with a long history; and (3) no-input farmers with a long experience have managed their fields with lower return of plant residues such as rice straw. In contrast to available P, the concentration of mineralizable N in the non-Andosol samples was positively correlated with the period of no-input farming (Spearman's $r = 0.22$, $p < 0.001$), which implies that soil available N was not depleted by long-term no-input farming.

The above results were obtained from the one-time survey of no-input fields. Due to the lack of long-term monitoring data, it is difficult to make a simple conclusion. Nevertheless, it can be roughly concluded that rice yield and soil fertility in no-input paddy fields were influenced not only by the period of no-input farming but also by various environmental and management factors operating at regional and field scales.

3. Environmental factors affecting rice growth and soil fertility under no-input farming

In this section, I introduce our results obtained from a 5-year no-input trial [15]. To estimate the environmental factors that enable soil fertility to be maintained without fertilization, application of fertilizers to a paddy field at Kyoto University Farm in Takatsuki, Japan, was ceased in 2010. Both planted and unplanted plots were installed in the field (**Figure 6**). Then, changes in rice yield and soil fertility in the field were evaluated until 2015. Surface soil samples were collected from both planted and unplanted plots before transplanting and after harvesting of rice plants. At harvesting, rice straw was also removed from the field. The physico-chemical properties of the samples were monitored. Rice yield and the uptake of N

Figure 6.
Rice plants (cv. Hinohikari) at panicle initiation stage grown without fertilization in Kyoto University farm (right side). In the field with an area of 10 a, two unplanted plots were equipped next to the planted plots. The color of rice leaves in this field was yellower than the color in a fertilized field (left side), suggesting that N was the most limiting nutrient in the unfertilized field. The photograph was taken by the author on July 30, 2012, the third year after ceasing fertilization to this field.

and K by rice plants were also analyzed. The soil in this field was classified as non-Andosol (Gley lowland soil) according to Digital Soil Map of Japan [13]. The surface soil was relatively sandy (sand content higher than 60%) and had the following properties at the start of the experiment: $pH(H_2O)$—5.95; total C—20.2 g kg^{-1}; total N—1.99 g kg^{-1}; mineralizable N—156 mg kg^{-1}, available P (Bray no.2 P)—484 mgP kg^{-1}; and cation exchange capacity—10.4 $cmol_c$ kg^{-1}. As the soil was relatively rich in available P due to the long-term application of chemical fertilizers, we focused on the dynamics of N and K in this field.

During the experimental period, the yield of unhulled rice was relatively stable; 630, 621, 618, 551, and 639 g m^{-2} from 2010 to 2014, respectively. On the other hand, the levels of mineralizable N, total N, and nonexchangeable K (boiling 1 mol L^{-1} HNO_3-extractable K minus exchangeable K) in the surface soil of both planted and unplanted plots began to significantly decrease after three cropping seasons (**Figure 7**). The amount of total N and boiling HNO_3-extractable K (exchangeable K plus nonexchangeable K) decreased from the surface soil (0–10 cm) of the unplanted plot during the 5 years was estimated to be 55 and 7.2 g m^{-2}, respectively, assuming a bulk density of 1.0 g cm^{-3}. On the other hand, the amount of N and K taken up by a single cropping of rice plants in 2012 was 8.3 and 11.5 g m^{-2}, respectively. Accordingly, N was lost from the unplanted plots with the magnitude comparable to the removal of N by rice plants. The results in **Figure 7** also indicated that the continuous removal of N and K from soil caused the significant depletions of mineralizable N and nonexchangeable K but not of more readily extractable fractions (NH_4^+-N and exchangeable K). By more frequent soil sampling and analysis conducted in 2012, it was revealed that the concentration of exchangeable K in soil decreased from transplanting to the maximum tillering stage and then recovered to the initial level from the booting stage to winter [15]. The reason for the lack of depletion of exchangeable K after continuous removal of K is discussed in the last section.

In 2013, the fourth year after ceasing fertilization, fertilizer trials with N or K application were conducted under both field and pot conditions to identify which element limited rice growth (**Figure 8**). Distilled water was used for irrigation in the pot experiment, whereas river or underground water was used for irrigation in the field experiment; total N and K concentration was measured at each irrigation event. The fertilizer trials demonstrated that the element limiting rice growth was K or N under pot or field conditions, respectively (**Figure 8**). To confirm this result, another nutrient omission trial was conducted in 2016 by using the surface soil collected after six harvests of rice without fertilization. Among the nutrients
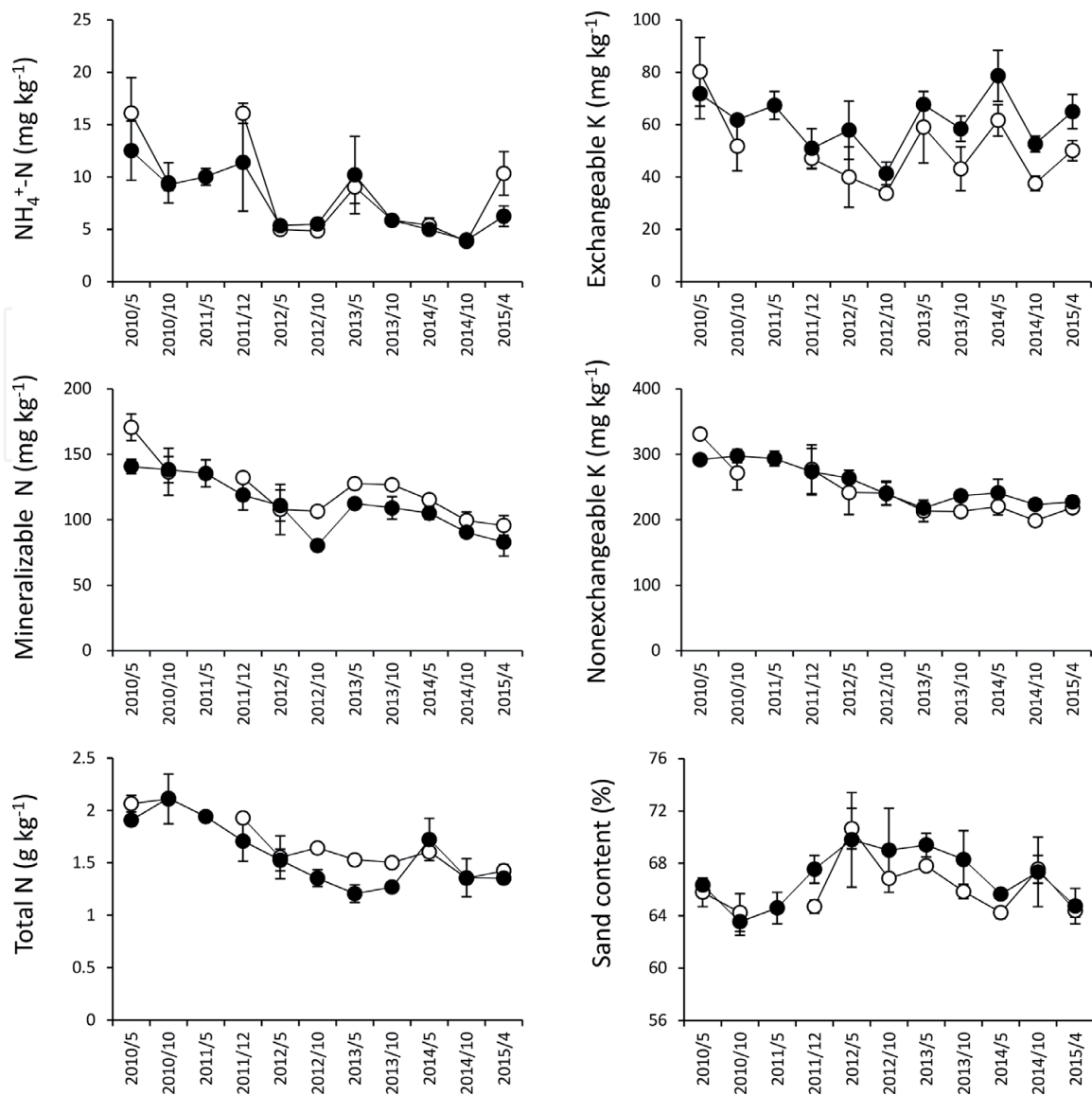
Figure 7.
Temporal changes of surface soil properties at planted (open circle) and unplanted (filled circle) plots in the unfertilized field (adapted from [15]). Error bars indicate the standard error of the mean (n = 2).

omitted (N, K, and Si), K was the most limiting nutrient when distilled water was used for irrigation (**Figure 9**). These results indicate that K, but not N, was the most limiting nutrient in the unfertilized soil and that the amount of K supplied by irrigation was sufficient to overcome the low K status of the unfertilized soil and meet plant demand. This should be the main reason why fertilizer responses were different between pot and field conditions. In other words, previous results on the nutrient omission trials (**Figures 1** and **2**) may have overestimated the ability of soil to supply nutrients to rice plants by allowing the external input of nutrients through irrigation.

In our field, the average concentration of K in irrigation water was 3.8 mg L^{-1} in 2013. If the amount of irrigation was assumed to be 1000 kg m^{-2}, the input of K to the field through irrigation becomes 3.8 g m^{-2}. This amount is slightly higher than the amount of K in rice panicles at maturity stage (3.0 g m^{-2} in our study). Thus, the input of K by irrigation may meet the plant's demand if rice straw is not removed from the fields and the irrigation water is rich in K (>2 mg L^{-1}).

Figure 10 shows the average K concentration in river water sampled from 225 rivers throughout Japan [16]. The sampling was carried out in 1940s and 1950s, when the eutrophication of river water was not a serious problem. The national average of the K concentration in river water was 1.20 mg L^{-1} with a large spatial variation
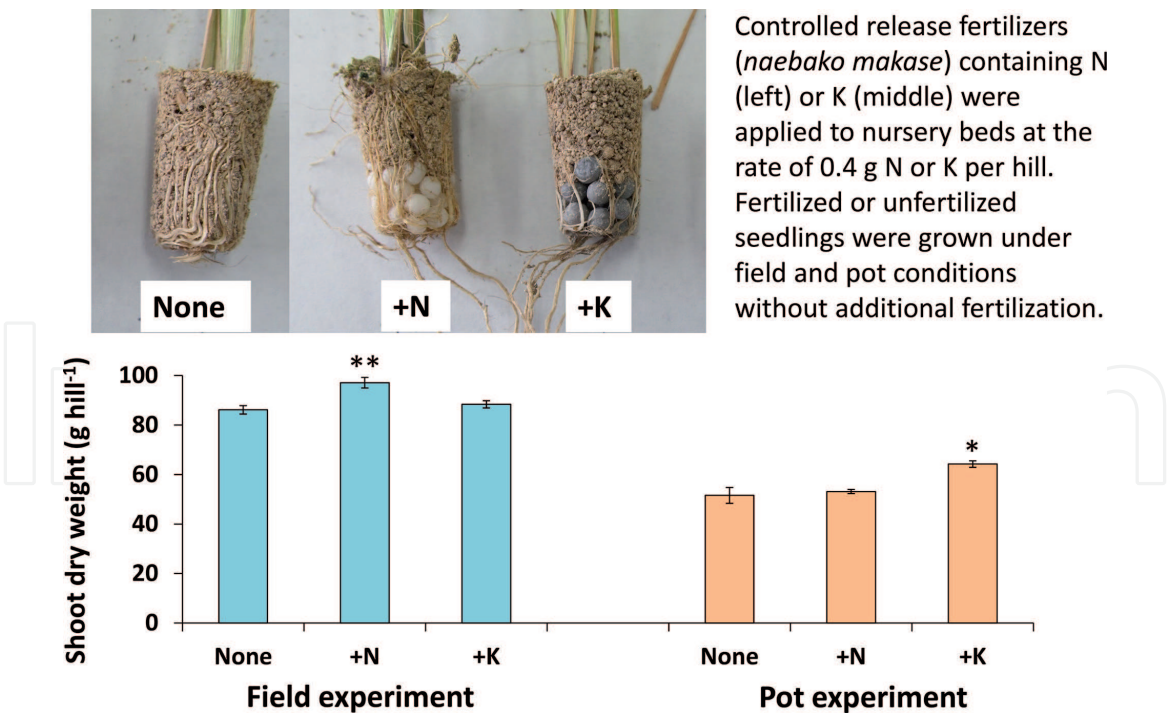
Controlled release fertilizers (*naebako makase*) containing N (left) or K (middle) were applied to nursery beds at the rate of 0.4 g N or K per hill. Fertilized or unfertilized seedlings were grown under field and pot conditions without additional fertilization.

Figure 8.
Dry matter weight of rice shoot (cv. Hinohikari) at maturity stage as influenced by the fertilizer application and growth conditions (adapted from [15]). Air-dry weight for field experiment and oven-dry weight for pot experiment. Error bars indicate the standard error of the mean (n = 60 for field experiment, n = 3 for pot experiment). In the pot experiment, distilled water was used for irrigation. **and * indicate significant difference from the unfertilized treatment at 1 and 5% (t-test), respectively.
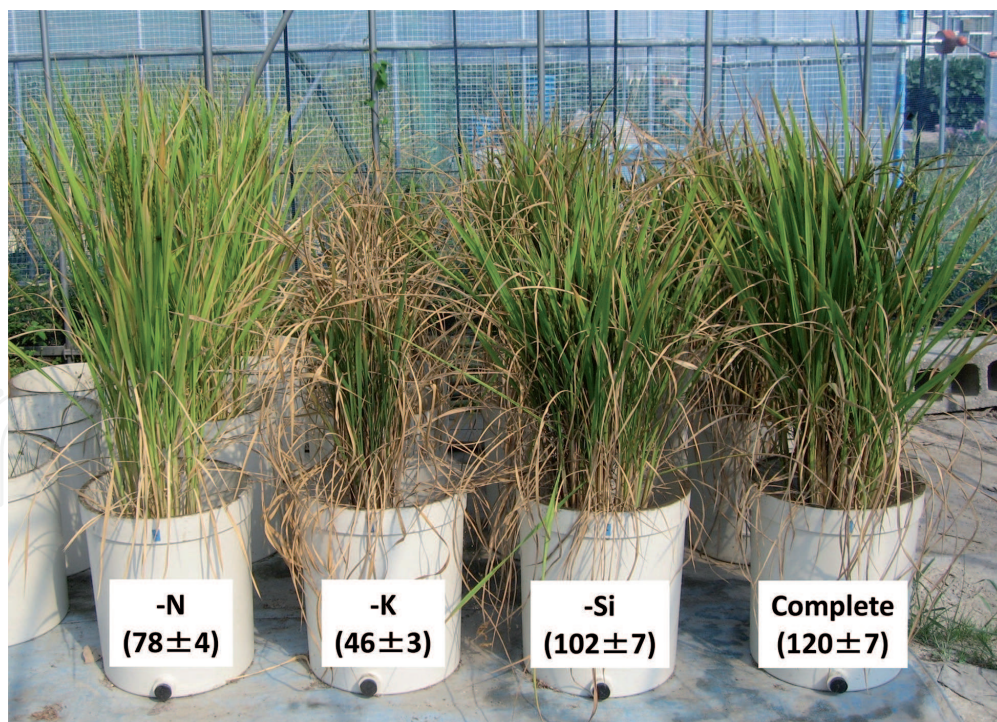

Figure 9.
Rice plants (cv. Hinohikari) at milk ripe stage grown in Takatsuki soil collected from the field without fertilizer application for 6 years (Moritsuka, unpublished). Distilled water was used for irrigation. The values indicate the average ± standard deviation of the shoot dry matter weight (g pot^{-1}, n = 3) for each fertilizer treatment. The photo was taken by the author on September 11, 2016.

(coefficient of variation = 57%). The concentration of K was higher than 2 mg L^{-1} in 24 rivers (10.7%), and 13 out of 24 rivers were located in Kyushu district in southern Japan. Several rivers originating from the Aso and Kirishima volcanic areas
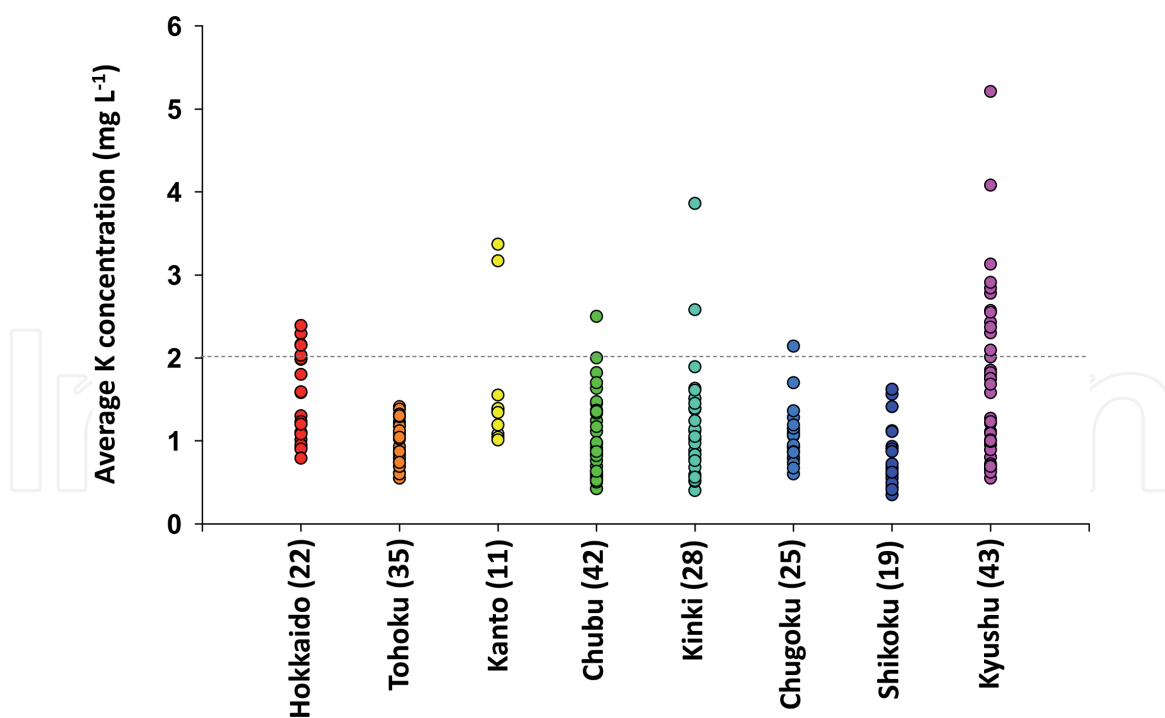
Figure 10.
Average K concentration in river water sampled from 225 rivers in Japan (adapted from [16]). The numbers in the parentheses below the figure indicate the number of rivers surveyed in each region of the country.
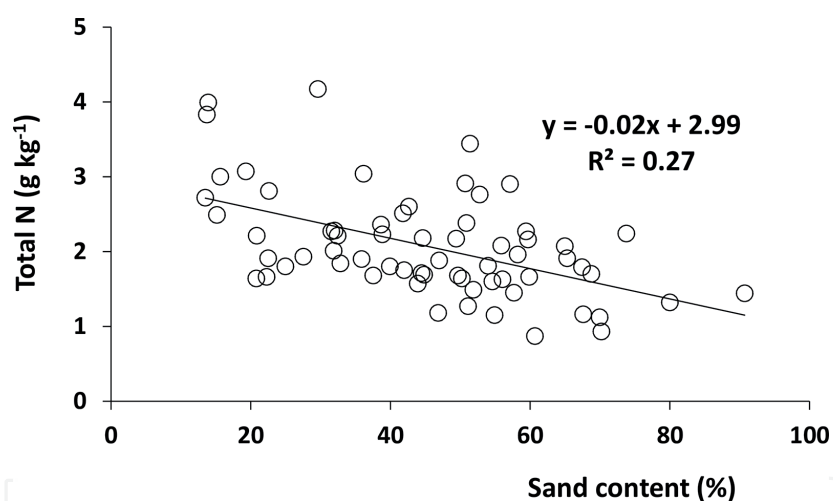

Figure 11.
Relationship between the sand content and the total N content in soils frequently used for paddy fields (adapted from [15]). Among the data of agricultural surface soils in Japan reported by Sano et al. [17], those from soils classified as lowland paddy soils, Gley lowland soils, and Gray lowland soils (n = 65) were displayed.

in Kyushu district showed very high concentrations of both K and Si. These results suggest that, in some of the watersheds in Japan, the input of K by irrigation of river water can meet the plant's demand even without the application of K fertilizer.

In contrast to K, the national average of inorganic N (NH_4^+ and NO_3^-) concentration in river water was 0.28 mgN L^{-1} (coefficient of variation = 99%) [16]. The input of N by irrigation cannot meet the plant's demand unless river water is polluted by eutrophication. As shown in **Figure 5**, there was a large variation in total N content in no-input paddy soils even when an outlier classified as an Andosol was removed. Such a large variation may have originated from the capacity of soil clay particles to accumulate organic matter containing N. This is because a significant negative correlation was observed between the sand content and the total N content in agricultural surface soils frequently used for paddy fields (**Figure 11**) [17].

Summarizing the results of this section, the input of K through irrigation and high-clay content in soil were considered the key environmental factors that enable to continue no-input farming. These factors are indebted to geographical conditions. Furthermore, the accumulation of fertilizer-derived P in the surface soil before ceasing fertilization may be another important factor. As a result of the alleviation of K and P deficiencies in the field, N became the most limiting nutrient in our experimental field. Enhancing the biological N fixation by growing leguminous plants after rice harvest and returning the plant residue to soil before transplanting may help to alleviate the N limitation to rice growth.

4. Dynamics of soil K under no-input and high-input rice farming systems

In the last section, I focus on the dynamics of K in paddy soil. In our experimental field, the concentration of nonexchangeable K in soil decreased significantly by the no-input farming, whereas the concentration of exchangeable K in soil was relatively constant and tended to increase from harvest to next transplanting (**Figure 7**). In this section, these observations are compared with previous results.

Srinivasa Rao et al. [18] evaluated the long-term changes in soil K forms under rice-rice cropping system with different fertilizer management. The experiment was carried out at Hyderabad in India. Surface soils were collected four times over 20 years, and the samples were analyzed for the different forms of K, including nonexchangeable K (boiling 1 mol L^{-1} HNO$_3$-extractable K minus exchangeable K). **Figure 12** shows the temporal changes in the concentrations of soluble, exchangeable, and nonexchangeable K in surface paddy soil as influenced by different fertilizer treatments. Among the three K forms, nonexchangeable K showed the largest depletion over 20 years (**Figure 12**). The amount of HNO$_3$-extractable K decreased over 20 years was quantitatively comparable to the net output of K estimated from the total amount of crop removal and fertilization. Thus, continuous cropping of rice caused a significant depletion of nonexchangeable K, while the concentrations
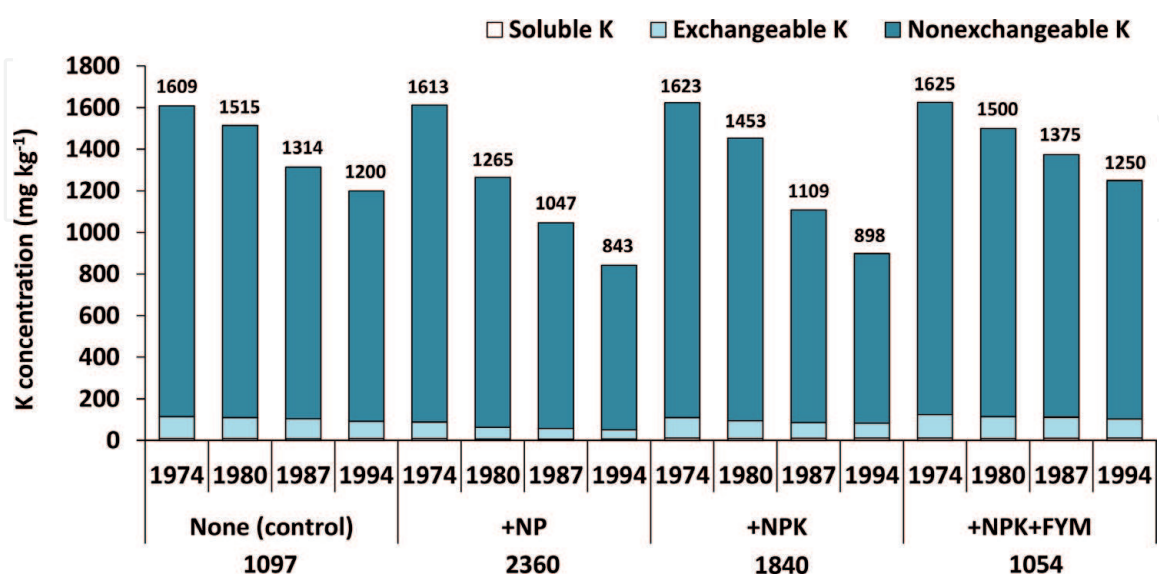
Figure 12.
Effect of 20 years of rice-rice cropping and fertilizer application on the concentrations of soluble, exchangeable, and nonexchangeable K in surface paddy soil (adapted from [18]). The values above each bar indicate the sum of all forms of K. The values in the bottom indicate the net output of K (crop removal minus fertilizer input) over 20 years (kg ha^{-1}). Inorganic fertilizers containing N, P, and K were applied at 115, 9, and 25 kg ha^{-1}, respectively, per cropping, and farmyard manure (FYM) was applied at 15 Mg ha^{-1} per year.

of more readily extractable K fractions were relatively constant. In a soil test, we usually measure the sum of soluble and exchangeable K by extracting soil with neutral 1 mol L^{-1} ammonium acetate. However, compared with nonexchangeable K, these K forms were much less sensitive to the long-term removal of K by rice plants. Based on these results, the authors concluded that the analysis of nonexchangeable K in soil should be added to a conventional soil test for better predicting K fertilizer requirements for long-term operation.

The results of Srinivasa Rao et al. [18] agree well with our results (**Figure 7**) and also with the results from an extensive survey by Khan et al. [19]. By reviewing previous results from the long-term field experiments in the world and comparing the net changes of exchangeable K in the surface soil at the beginning and end of the study period with the net inputs of K due to long-term fertilization and crop removal, Khan et al. [19] revealed that the changes in the soil exchangeable K pool during the study period were much smaller than the net input of K to the field estimated from the total amount of K added and removed (**Figure 13**). In the case of our field, the net decrease of soil exchangeable K during the 5-year experiment amounted to only 5.2% of the cumulative K removed by rice plants (**Figure 13**). From these results, the authors concluded that a one-time measurement of soil exchangeable K cannot account for the highly dynamic interchange of K between exchangeable and nonexchangeable pools. Khan et al. [19]) also reported that the concentration of exchangeable K in soil was increased significantly by air-drying soil samples to the soil moisture content below 50 g kg^{-1}, which is a conventional soil pretreatment required for sample homogenization.

In the case of Srinivasa Rao et al. [18], the application of farmyard manure in combination with chemical fertilizer contributed to recover the concentration of
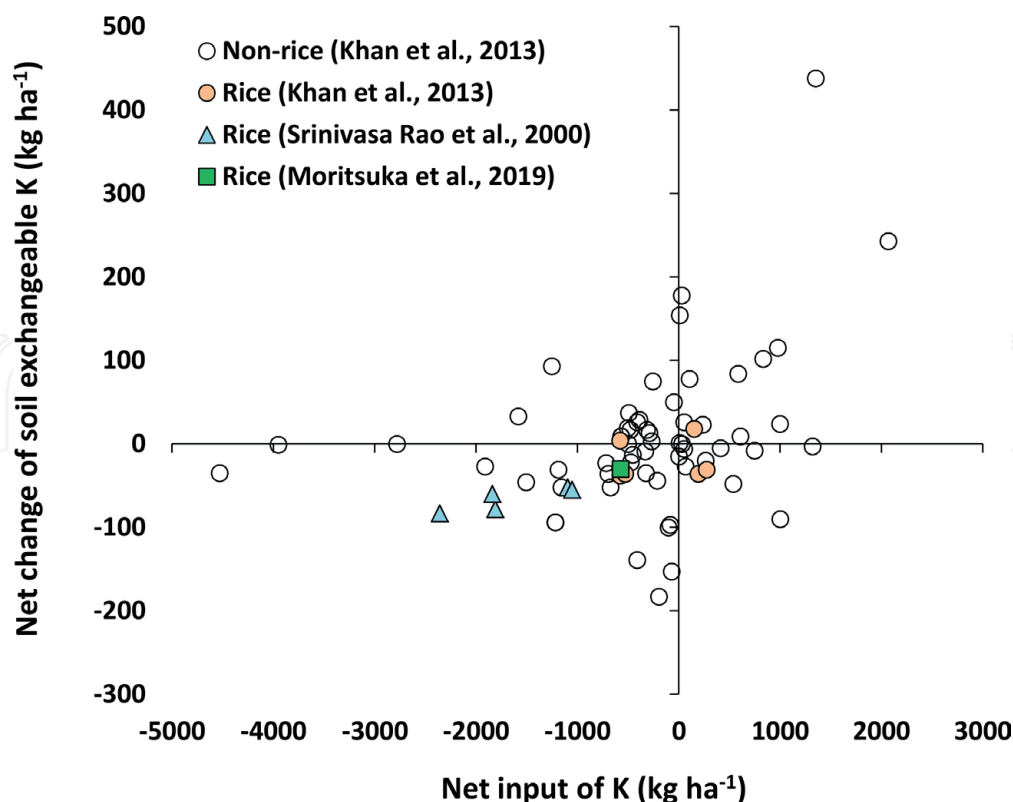

Figure 13.
Relationship between the net input of K due to long-term fertilization and crop removal and the net change of soil exchangeable K (adapted from [19]). Refer to the original papers [18, 19] for calculation methods. For our data, the net input of K was estimated from the extrapolation of crop K removal in 2012, and the net change of exchangeable K was calculated by assuming that soil depth and bulk density were 10 cm and 1.0 g cm^{-3}, respectively.

HNO$_3$-extractable K to some extent (**Figure 12**). However, a few researchers have reported contrasting results; the co-application of manure over long periods did not necessarily increase the concentration of nonexchangeable K in soil [20, 21]. For example, Kitajima et al. [20] evaluated the effect of long-term co-application of farmyard manure on the K forms in the surface soil at three locations in Japan. As shown in **Figure 14**, the co-application of farmyard manure increased the concentration of exchangeable K (including soluble K) but decreased the concentration of nonexchangeable K (boiling 1 mol L^{-1} HNO$_3$-extractable K minus exchangeable K) at all the locations. The authors suggested that farmyard manure accelerated the dissolution of K-bearing minerals in soil, by which nonexchangeable K was irreversibly transformed to exchangeable K. Regardless of the processes involved, the results in **Figure 14** cannot be explained by the dynamic equilibrium between the exchangeable K and the nonexchangeable K which operates to minimize the concentration changes of both K forms.

Yamashita et al. [22] recently reported that microbial biomass K in the surface paddy soil is detectable by the conventional fumigation-extraction approach and that the concentration of microbial biomass K was increased by the continuous application of compost to paddy fields. Combining these results with those by Khan et al. [19], it is plausible to consider that exchangeable K pool evaluated by using air-dried soil samples inevitably includes microbial biomass K. The increase of exchangeable K by the long-term application of farmyard manure (**Figure 14**) may be due to the contamination of microbial biomass K in the exchangeable K fraction. From these interpretations, the dynamics of soil K forms in the soil-plant-microbe systems are depicted in **Figure 15** by referring to the concept proposed by Asakawa and Yamashita [23]. The soundness and practical usefulness of this concept need to be evaluated in future experiments.

In summary, our results on soil K dynamics agreed well with previous results from long-term field experiments. Accordingly, it can be generally concluded that soil K depletion caused by long-term exhaustive cropping should be evaluated by monitoring the decrease of soil nonexchangeable K rather than that of exchangeable K. Furthermore, I hypothesized that the dynamics of soil microbial biomass K may cause the fluctuations of soil exchangeable K measured after air-drying pretreatment.
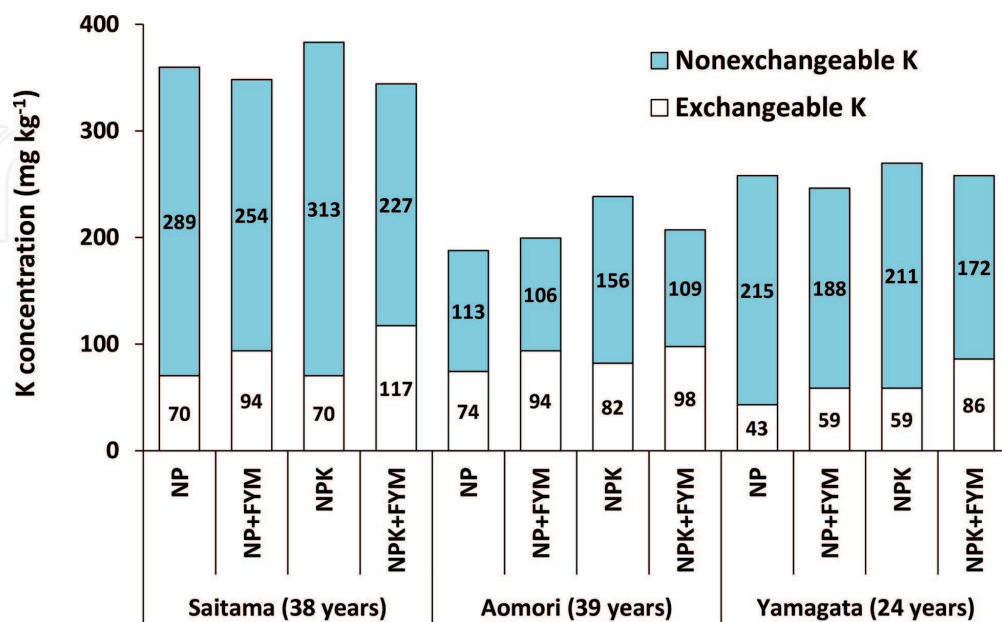

Figure 14.
Effect of long-term co-application of farmyard manure (FYM) on the concentrations of exchangeable and nonexchangeable K in surface paddy soil (adapted from [20]). Animal dung manure had been applied at 11.3 Mg ha^{-1} at all sites. The experiments at Saitama (Konosu) and Aomori sites began in around 1930, and are the earliest fertilizer experiments in Japan. Soil sampling was carried out in December, 1968.
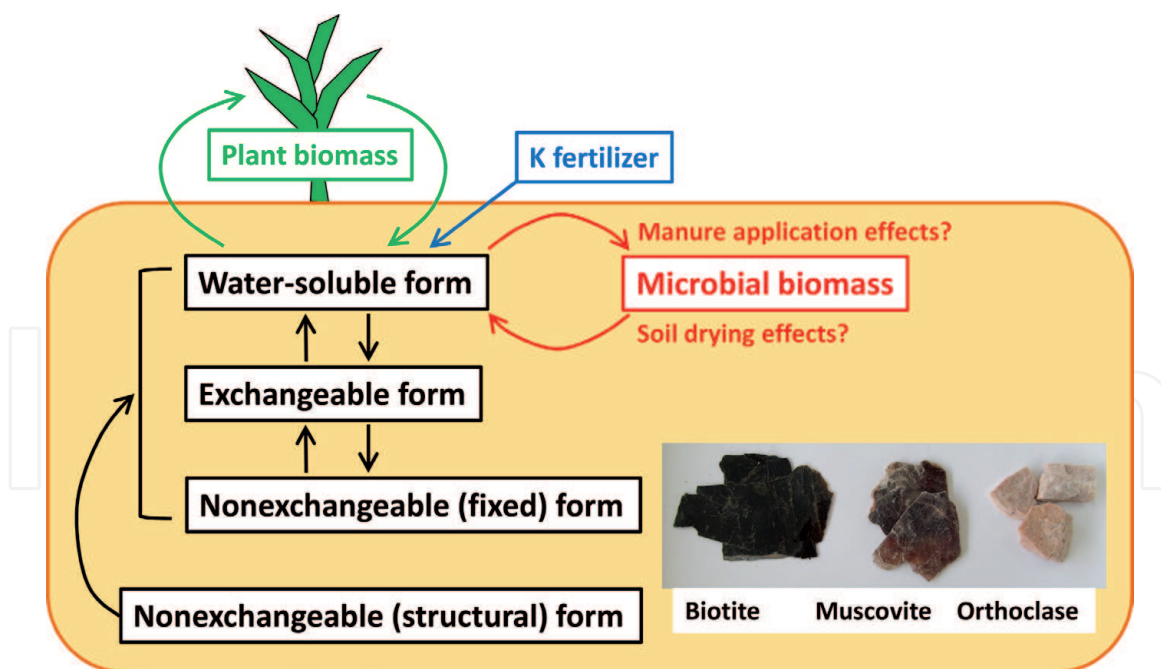
Figure 15.
Dynamics of K in the surface agricultural soil driven by crop plants, soil microbes, and fertilization (adapted from [23]). Both biotite and muscovite contain K in fixed form, and orthoclase contains K in structural form.

5. Conclusions

In this review, no-input rice farming in Japan was evaluated from the viewpoint of soil sustainability. It can be concluded that soil fertility under this farming system has been supported by various environmental and management factors, especially the input of K through irrigation, high-clay content in soil, and accumulation of fertilizer P applied previously to the soil. In the case of our no-input trial for 5 years, a significant depletion of mineralizable N and nonexchangeable K was observed after three cropping seasons, and rice growth was limited by soil K supply when the input of K by irrigation was restricted. These results highlight the importance of monitoring the dynamics of multiple soil nutrients for several years.

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References

[1] Neera P, Katano M, Hasegawa T. Comparison of rice yield after various years of cultivation by natural farming. Plant Production Science. 1999;**2**:58-64. DOI: 10.1626/pps.2.58

[2] Hosoya K, Sugiyama S. Factors contributing to yield variation among unfertilized paddy fields in northern Japan. Japanese Journal of Crop Science. 2016:266-273(in Japanese with English summary). DOI: 10.1626/jcs.85.266

[3] Tatara S, Homma K, Kuwata M, Kobayashi M, Shiraiwa T. Dynamics of Soil Nutrients and Uptake of Nutrients by Rice Plants in Long-Term no-Input Paddy Fields: Survey Results from 2014 to 2016 (in Japanese). 2017. Available from: http://muhiken.or.jp/wp/entrust/2016/

[4] Kyuma K. Paddy Soil Science. Kyoto: Kyoto University Press; 2004. 280 p

[5] Kawasaki I. Natural Supply of Three Major Elements from Arable Soils in Japan. Tokyo: Nippon Nogyo Kenkyusho; 1953. 19 p. (in Japanese)

[6] FAO. Crop Production Levels and Fertilizer Use. FAO Fertilizer and Plant Nutrition Bulletin No. 2. Rome: FAO; 1981. 69 p

[7] Ohtsubo K, Nakamura S. Evaluation of palatability of cooked rice. In: Li JQ, editor. Advances in International Rice Research. London: IntechOpen; 2017. pp. 91-110. DOI: 10.5772/66398

[8] Kuwamura T. Soil characteristics of nature-farming fields. Research Reports from Institute for Agro-Microbiology. 2005;**9**:7-25. (in Japanese with English summary)

[9] Neera P, Katano M, Hasegawa T. Rice culture under nature farming in Japan. Proceedings of Faculty of Agriculture, Kyushu Tokai University. 1992;**11**:67-74

[10] Sugiyama S. Scientific basis for obtaining rice yield at 480 g m^{-2} without applying fertilizers: Soil conditions suitable for causing biological N fixation. Gendai Nogyo. 2016;**95**(12):134-139. (in Japanese)

[11] Katano M. Rice Production by Natural Farming. Rice Morphology and Farmers' Practices. Rural Culture Association Japan: Tokyo; 1990. 246 p

[12] Hosoya K, Sugiyama S. Weed communities and their negative impact on rice yield in no-input paddy fields in the northern part of Japan. Biological Agriculture and Horticulture. 2017;**33**:215-224. DOI: 10.1080/01448765.2017.1299641

[13] NARO. Digital Soil Map of Japan (in Japanese). 2019. Available from: https://soil-inventory.dc.affrc.go.jp/

[14] MAFF. Summary on the National Soil Survey Programs in Japanese Agricultural Land from 1979 to 2003. Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries; 2008. 485 p (in Japanese)

[15] Moritsuka N, Izawa G, Matsuoka K, Katsura K. Annual changes in soil fertility after ceasing fertilization in an unfertilized paddy field and factors limiting rice growth in the field. Japanese Journal of Soil Science and Plant Nutrition. 2019;**90**:257-267 (in Japanese with English summary). DOI: 10.20710/dojo.90.4_257

[16] Kobayashi J. A chemical study on the average quality and characteristics of river waters of Japan. Nougaku Kenkyu (Research Institute for Bioresources, Okayama University). 1961;**48**:63-106 (in Japanese)

[17] Sano S, Yanai J, Kosaki T. Evaluation of soil nitrogen status in japanese agricultural lands with reference to

land use and soil types. Soil Science and Plant Nutrition. 2004;**50**:501-510. DOI: 10.1080/00380768.2004.10408506

[18] Srinivasa Rao C, Subba Rao A, Swarup A, Bansal SK, Rajagopal V. Monitoring the changes in soil potassium by extraction procedures and electroultrafiltration (EUF) in a Tropaquept under twenty years of rice-rice cropping. Nutrient Cycling in Agroecosystems. 2000;**56**:277-282. DOI: 10.1023/A:1009839704839

[19] Khan SA, Mulvaney RL, Ellsworth TR. The potassium paradox: Implications for soil fertility, crop production and human health. Renewable Agriculture and Food Systems. 2013;**29**:3-27. DOI: 10.1017/S1742170513000318

[20] Kitajima S, Kaneko J, Shiroshita T. The variations of cation status in paddy soils and cation absorption by rice plants with the application of potassic fertilizers. J. Journal of the Central Agricultural Experiment Station. 1975;**22**:105-177 (in Japanese with English summary)

[21] Sharma S, Chander G, Verma TS, Verma S. Soil potassium fractions in rice-wheat cropping system after twelve years of lantana residue incorporation in a northwest Himalayan acid Alfisol. Journal of Plant Nutrition. 2013;**36**:1809-1820. DOI: 10.1080/01904167.2013.815202

[22] Yamashita K, Honjo H, Nishida M, Kimura M, Asakawa S. Estimation of microbial biomass potassium in paddy field soil. Soil Science and Plant Nutrition. 2014;**60**:512-519. DOI: 10.1080/00380768.2014.919237

[23] Asakawa S, Yamashita K. Soil microbial biomass as a source of potassium to plants: Soil microbes bear not only nitrogen and phosphorus but also potassium in their bodies.

Kagaku to Seibutsu. 2017;**55**:444-445(in Japanese). DOI: 10.1271/kagakutoseibutsu.55.444