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Growth Inhibition of Rice by Water Drainage during Fallow at IRRI

Takuhito NOZOE[1,2,3]*, Reynaldo RODRIGUEZ[1] and Ruth AGBISIT[1]

[1] Crop, Soil and Water Science Division, International Rice Research Institute (IRRI)
(DAPO 7777, Metro Manila, Philippines)
[2] Crop Production and Environment Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)

Abstract

In a rice cultivation experiment at the International Rice Research Institute (IRRI), water drainage during the fallow period inhibited the growth of paddy rice, especially during the early stage of subsequent cultivation. This symptom became more prominent when rice straw was not applied, and when the amount of fertilizer applied was small. The application of a mixture of nitrogen, phosphorus, and potassium fertilizers reduced this inhibition. The amounts of phosphorus in the growth-inhibited rice and soil were smaller than those without growth inhibition. The findings suggest that one of the factors that inhibited rice growth was phosphorus deficiency. The inhibition was associated with high soil pH and low Fe(II) content in the problem soil. There was a negative correlation between soil pH and Fe(II) content. Water drainage during fallow decreased the amount of Fe(II) in the soil because Fe(II) was oxidized to Fe(III) under oxidative conditions. During the subsequent cultivation season, the amount of Fe(II) in the soil was low and the soil pH was high. The application of rice straw improved rice growth. The phosphorus deficiency of growth-inhibited rice was associated with a small amount of available phosphorus in soil presumably because of the high soil pH and the adsorptopn of phosphorus to Fe(III) oxides in the soil.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: ferrous iron, pH, phosphorus deficiency, the tropics

Introduction

In tropical Asia, irrigated lowland rice is the most important agricultural ecosystem. Double-cropping rice is the most common and effective method of cultivation in the tropics. Fallow periods of 2 to 3 months follow the rice cultivation in the wet season (WS) and in the dry season (DS). One of the characteristics of irrigated rice cultivation is the change in oxidation-reduction status of soil during the fallow and cultivation periods. The characteristic of soil in one fallow is different from that of the other because those fallows are present in WS (mainly October and November at Philippines) or DS (mainly April and May). During fallows, only weather conditions affect the oxidation-reduction status of the soil because the field is generally plowed and left without irrigation. It can be estimated that the soil in the fallow of WS is more reduced than that in the DS because of the high rainfall in the WS. Generally, soil drying during the fallow has beneficial effects on the following rice crop. For example, it avoids excessive reduction of soil and increases available soil nitrogen (N) due to the air-drying effect on ammonification[16]. Soil drying furthermore decreases organic acids that are toxins for rice growth[14,18].

It is generally accepted that soil management to maintain an oxidative status is preferable for rice cultivation. However, little research has been done on water management and rainfall during the fallow with regard to the following rice crop. As will be discussed below, water drainage during the fallow inhibited the rice growth. In this report, the mechanisms of the inhibition were analyzed.

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Present adress:
[3] National Agricultural Research Center for Hokkaido Region (Sapporo, Hokkaido 062–8555, Japan)
*Corresponding author: fax +81–11–859–2178; e-mail nozoe@affrc.go.jp

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Materials and methods

IRRI has conducted a long-term experiment since 1972. In this field (field name: L2), the same water, organic material, and fertilizer managements have been continued in each plot since the beginning of this experiment. During the 2001 WS and 2002 DS, shoot and soil were sampled periodically. In the 2001 DS, 2001 WS, 2002 DS, and 2002 WS, grain yields were analyzed. For the experiments on those seasons, pregerminated seeds of IR72 were sown on seedling trays to produce uniform seedlings. Fourteen-day-old seedlings were transplanted on 11 Jan 2001, 26 Jun 2001, 8 Jan 2002, and 27 Jun 2002 as 2001 DS, 2001 WS, 2002 DS, and 2002 WS cultivation, respectively. Spacing was at 20 × 20 cm with four seedlings per hill. Cultivation periods in the 2001 DS, 2001 WS, 2002 DS, and 2002 WS were 96, 91, 93, and 90 days, respectively. The field was irrigated with groundwater.

Eight plots (two for water management in fallow season × two for management of organic material × two for fertilizer management) were laid out in a randomized complete block design with four replications. The size of each plot was 5 × 6.5 m^2. Main plots were either not irrigated (W0) or irrigated (W1) during the fallow period. To analyze the effect of the application of organic materials, two plots were set up as subplots. All rice straw was removed from the field after harvesting of the previous crop (S0), or straw was spread and incorporated into the soil one month before transplanting (S1). The average amount of rice straw into the soil was approximately 150% of the grain yield. To analyze the effect of the amount of fertilizer, two plots were set up as sub-sub-plots. In F0, 50 kg ha^{-1} of nitrogen (N) was applied basally before puddling irrespective of season. Neither phosphorus (P) nor potassium (K) was applied. In F1, 150, 30, and 40 kg ha^{-1} of N, P_2O_5, and K_2O were applied in the DS. Those components in the WS were 80, 20, and 30 kg ha^{-1}, respectively. All fertilizers were applied basally before puddling.

Roots of collected plant samples were removed and shoot dry matter was weighed after drying. For the analysis, a part of the dried shoot was separated into leaf (leaf blade and sheath), stem, and panicle, which were ground. The amount of P in leaf was analyzed with the Infra Analyzer 405 (Braun+Lube, Norderstedt, Germany)[7]. In F0 plots, soil was sampled by a core sampler (5 cm diam.) and the soil 2 cm from the surface was removed. This soil sample was transferred to the laboratory immediately. Ferrous iron was extracted by acetate buffer (pH 2.8) and determined by a colorimetric method using *o*-phenanthriline[9]. The soil pH (H_2O) was determined by a standard method[19]. Before the application of fertilizer on 2002 WS, soil was sampled from each plot. After this sample was air-dried, the available P was determined by using the Olsen method[10].

Results

In the 2001 DS, 2001 WS, and 2002 DS, grain yields in the F1 plots were greater than those in the F0 plots because of high fertilizer application in the F1 plots (Fig. 1). In all cropping seasons of current experiments, grain yields in the W0S0F0 plots were significantly lower

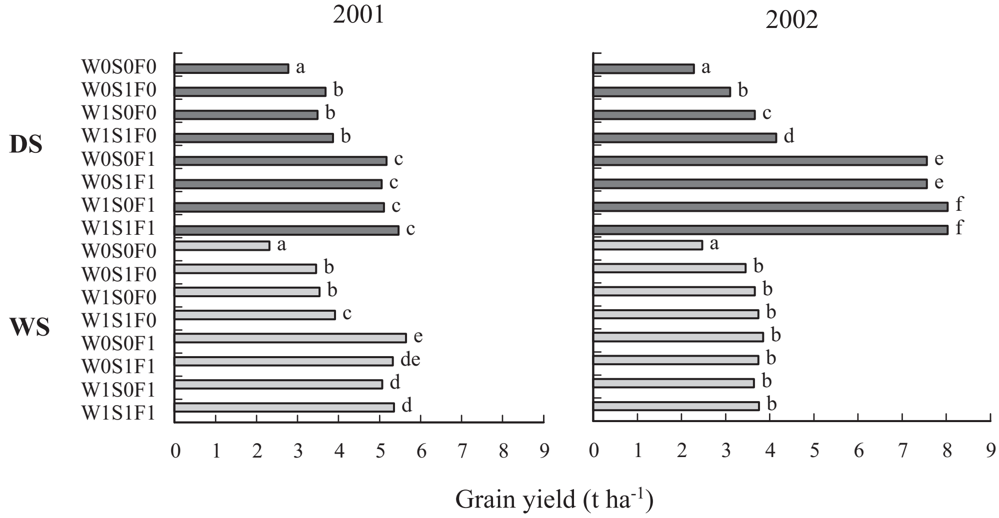

Fig. 1. Grain yield

Data were converted to grain yield at 14% water content. Symbols with different letters denote a significant difference at the 5% level by Duncan's protected LSD.

W0: Dried fallow, W1: Flooded fallow, S0: No straw, S1: With straw, F0: Low input of N, F1: Full NPK supply.

than those in other F0 plots. While, in the F1 plots, the yields in W0S0F1 plots were not smaller than other F1 plots.

Fig. 2 shows the development in dry weight during the 2001 WS and 2002 DS. In both seasons, the dry weights in the F1 plots were greater than those in the F0 plots, and those in the W0S0F0 plots tended to be smaller than those in other F0 plots. To analyze this growth inhibition in W0S0F0 plots, the changes in dry weight in F0 plots were re-plotted in Fig. 3 on the basis of the data

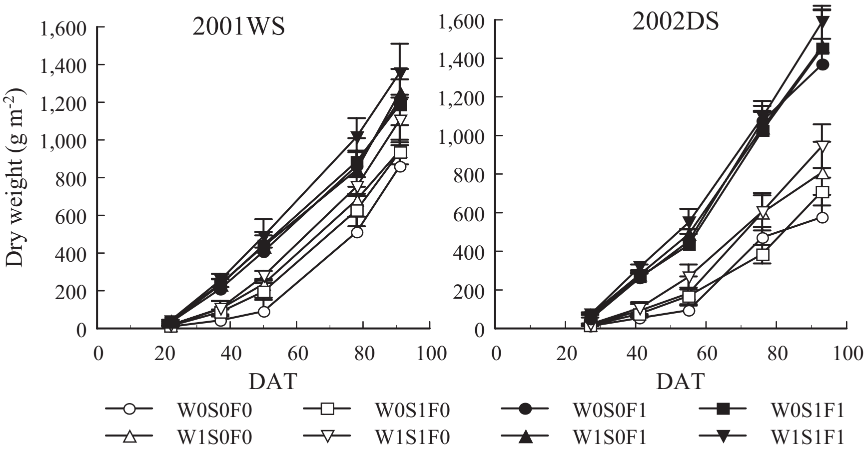

Fig. 2. Changes in dry weight in 2001WS and 2002DS

Vertical bars indicate standard deviation. DAT: Days after transplanting.

W0: Dried fallow, W1: Flooded fallow, S0: No straw, S1: With straw, F0: Low input of N, F1: Full NPK supply.

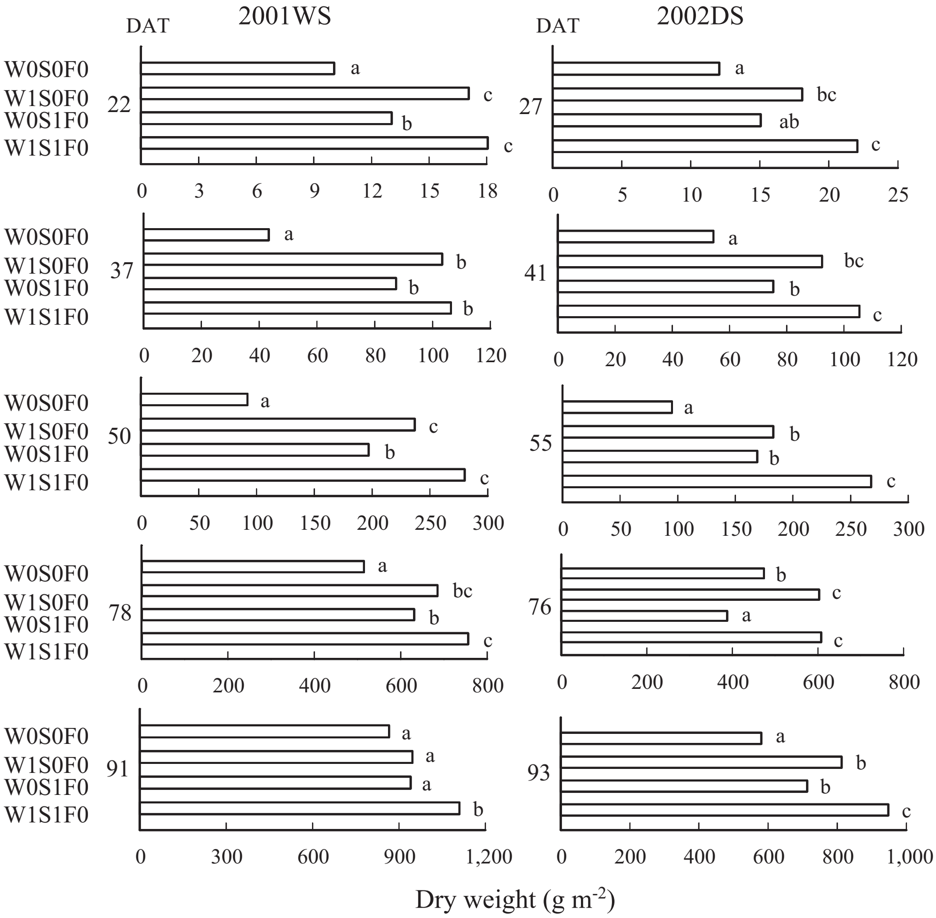

Fig. 3. Changes in dry weight in F0 plots

Symbols with different letters denote a significant difference at the 5% level by Duncan's protected LSD.

W0: Dried fallow, W1: Flooded fallow, S0: No straw, S1: With straw, F0: Low input of N, F1: Full NPK supply.

shown in Fig. 2. In the W0 plots, the dry weights were smaller than those in the W1 plots. Especially in the W0S0F0 plots, the dry weights tended to be lower than those in other F0 plots. This inhibition in W0S0F0 plots was prominent during the early stage of growth, and recovered after that. However, the final dry weights in the W0S0F0 plots were lower than those in the W1S1F0 plots. As shown in Fig. 3, the dry weight tended to be in the following order.

W1S1F0 > W1S0F0 > W0S1F0 > W0S0F0

This phenomenon suggests that the growth in the W0S0F0 plots was inhibited, and that the application of straw and/or the introduction of water on fallow improved the situation.

Fig. 4 shows the changes in leaf P contents during the 2001 WS and 2002 DS. The P content in the W0S0F0 plots was lowest in the content of leaf P during the early growth stages. No association of N, K, and Zn with inhibition was found (data not shown). Table 1 shows the available P in the F0 plots. The amount of Olsen P in W0S0F0 was smaller than in other plots.

Analysis of soil pH showed that W0S0F0 plots had the highest pH and that the difference to other plots was most pronounced during early stages of growth (Fig. 5). Those findings suggest that the drainage of water during the fallow season increased the soil pH, while the application of rice straw decreased it. The Fe(II) content in the W0S0F0 plots was lower than in other plots throughout the growth season.

Discussion

1. Growth inhibition of rice

Except for the 2002 WS, grain yields in fertilized plots (F1) were greater than those in F0 plots, suggesting that this difference was caused by the deficiency for one of the elements supplied in NPK fertilizers (Fig. 1). In the 2002 WS, the application of fertilizer in the F1 plots did not affect grain yield. Although this fact was presumably attributed to climatic factors, the mechanism remains to be analyzed.

Rice growth tended to recover during the later stages of cultivation in the W0S0F0 plots (Fig. 3), but the grain yield was lower than in other F0 plots (Fig. 1). This finding suggests that the growth inhibition during the early stage of cultivation reduced the grain yield. Differences in the growth inhibition between the WS and DS were not clear. As mentioned above, flooding soil during fallow (W1), the application of rice straw (S1), and/or application of fertilizer (F1) helped to improve the situation. The presence of the large amount of fertilizer (F1), the presence or absence of water drainage during the fallow season and the application of rice straw hardly affected the rice growth (Fig. 2). As shown in Fig. 3, the dry weight in the F0 plots tended to be W1S1F0 > W1S0F0 > W0S1F0 > W0S0F0. These findings indicate that the effect of the flooded soil in the fallow (W1) to improve the growth was greater than that of the application of rice straw (S1).

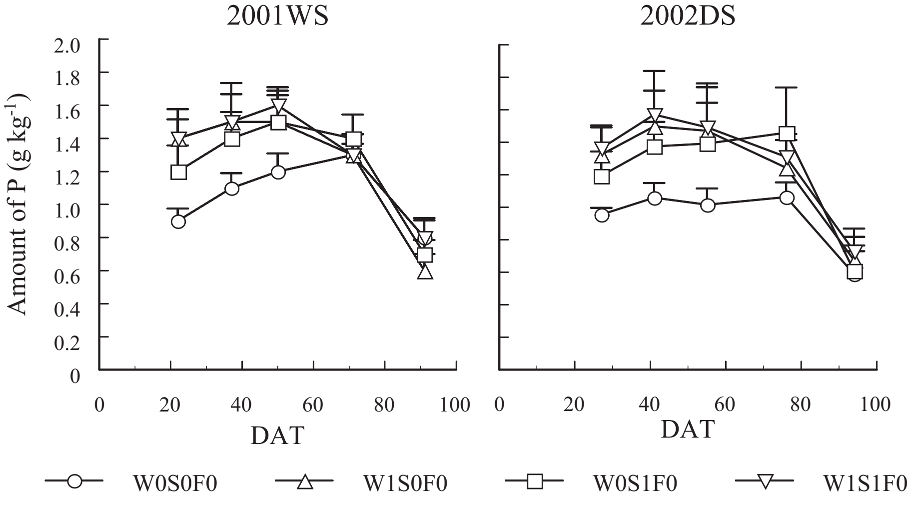

Fig. 4. Changes in P contents in the leaf of F0 plots

Vertical bars indicate standard deviation.
W0: Dried fallow, W1: Flooded fallow, S0: No straw, S1: With straw,
F0: Low input of N, F1: Full NPK supply.

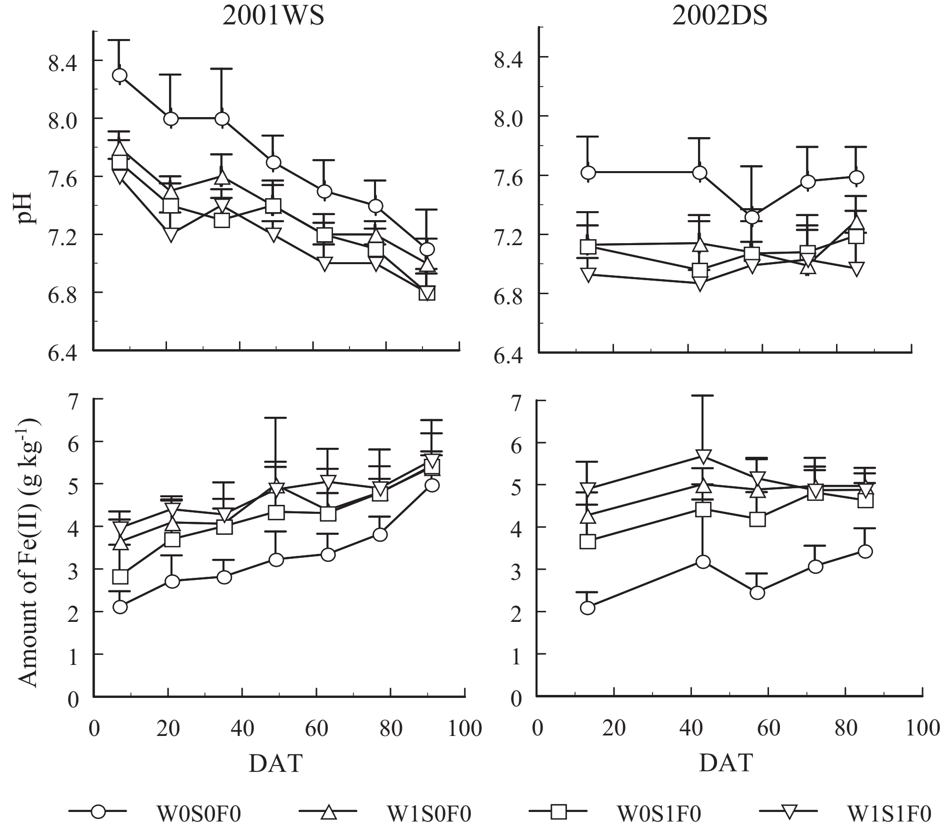

Fig. 5. Changes in the amounts of soil Fe(II) and pH values in the F0 plots
Vertical bars indicate standard deviation.

Table 1. Amount of available P in soil (F0 plot)

Plot	Olsen P (mg kg^{-1})
W0S0F0	1.4
W1S0F0	2.3
W0S1F0	1.9
W1S1F0	2.5

2. The relationship between P uptake and growth inhibition

Rice growth was not inhibited in the F1 plots (Fig. 2), indicating that N, P, and/or K was associated with the inhibition. Under the current condition, however, the deficiencies of N and K were not confirmed by the analysis of these elements in leaf (data not shown). Phosphorus deficiency occurs in acidic or alkaline soil such as acidic latosol soil, acid sulfate-rich soil, and calcareous soil[20]. Sasaki and Hirata[17] reported that rice plants require P uptake, especially in the early stage of growth. When the amount of P in the plant is not sufficient, the plant moves P from old to new tissue. This means that the P deficiency barely occurs during the late stage of growth if P uptake during early growth is sufficient. Dobermann and Fairhurst[2] show the critical level of deficiency using the concentration of nutrient in the leaf. According to the report, the optimal level of leaf P concentration from mid-tillering to panicle initiation (PI) is 2–4 g kg^{-1}, and the critical level during this period for P deficiency is 1 g kg^{-1}. In the current study, the leaf P content of W0S0F0 plots was below 1 g kg^{-1} at mid-tillering which suggests that the growth inhibition in W0S0F0 plots was caused by P deficiency (Fig. 4). The presence of P deficiency[3] was supported by the findings in the changes of dry weight (Fig. 3) and in the amount of available P in soil (Table 1).

3. The relationship between soil pH and growth inhibition

It was reported that rice has a comparatively high tolerance of high pH[6], namely, a high soil pH barely inhibits rice growth directly. In the current study, however, the high values of soil pH in the W0S0F0 plots were related to growth inhibition. The changes in the values of pH seem to be synchronized with those in Fe(II) contents (Fig. 5). To analyze the relationship between Fe(II) content and pH values, the data shown in Fig. 5 were re-plot-

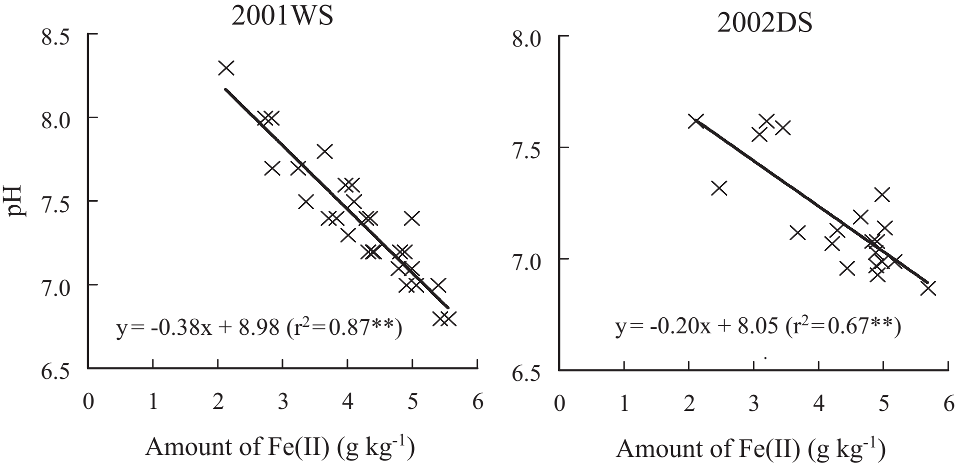

Fig. 6. Relationship between pH and Fe(II) in soil
**: Significant at 1% level.

ted in another figure (Fig. 6). On the basis of this analysis, there was a significant negative correlation between the values of pH and the Fe(II) content. In a previous study in relation to single, double, and triple rice cropping in the tropics, Nozoe et al.[12] reported that the pH of those soils decreased with the increase in the annual number of croppings. This indicates that the pH value tended to be high with the increase in the periods of fallow, and with the increase in the intensity of drying. The results obtained in the current study support those results. Ponnamperuma et al.[15] reported a negative correlation between the partial pressure of soil carbon dioxide (CO_2) and the pH value when the soil pH was high. Carbon dioxide is generated as a terminal product of the decomposition of organic materials and the soil organic materials serve as an electron donor for the soil reduction. As the soil reduction proceeds, the soil pH decreases because the partial pressure of CO_2 increases. In the current study, the pH in the W0S0F0 plots was higher than those in other plots (Fig. 5). During the experiment since 1972, it can be estimated that the amounts of biomass in soil of W0S0F0 plots had become smaller than those of other plots because the growth in W0S0F0 plots had been inhibited. High pH in W0S0F0 plots was presumably caused by the low pressure of CO_2 from the small amount of biomass in the soil.

In relation to the mechanism of the suppression of P uptake under high pH conditions, the high concentration of calcium (Ca) in the soil decreases the amount of available P[2]. Phosphate is adsorbed to Fe(III) oxides and the Fe(II) is oxidized to Fe(III) during the fallow season[8]. During the following cropping season, the phosphate becomes available with the reduction of Fe(III) oxides to Fe(II). In the current study, however, the mechanism of the P deficiency is not clear. The application of rice straw might increase the amount of P in rice from the rice straw, which subsequently improves the suppression of P uptake by decreasing soil pH.

Cassman et al.[1] reported that rice yields declined during 20 or more years under intensively submerged conditions in other long-term experiments at IRRI. This yield decline was associated with the decrease in N-supplying capacity of soil[13]. The values of soil pH of double- and triple-crop rice were 6.5 and 6.2, respectively. The mechanism of growth inhibition in the current study was different from that of the yield decline because the soil pH of the current experiment was higher (Fig. 5) and the growth inhibition of the current study was attributed to the P deficiency.

In the current study, soil drying in the fallow inhibited the following rice growth. It is necessary to take into account that this inhibition was observed under the special conditions such as low available P content in soil and high soil pH. Therefore, rice growth would not be inhibited when the amount of fertilizers was sufficient, and under conditions of low soil pH, which is the more common situation in the tropics. After the rice cultivation, however, the land tends to be left without any management in the tropics, and the soil is dry especially in fallow of DS. Therefore, it can be estimated that the soil drying in fallow inhibited rice growth in a certain part of lands with high soil pH. Although the application of P improves the situation, the amount of P that is applied in the tropics is small[5,11] because N application is more efficient in increasing yield than P application. The application of rice straw also improves the situation. However, much rice straw is removed or burned[4]. Even under normal conditions in the tropics, applications of P as well as rice straw are recommended to increase yield. Based on the current results observed in this study, these management options also help to reduce the inhibition. Currently, the growth inhibition by soil drying in fallow season was confirmed only on the IRRI farm. Therefore, it is necessary to study whether rice growth is inhibited outside of IRRI as well, and if necessary, to issue recommendations to farmers to overcome that inhibition.

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