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Phosphorus nutrition of rice in relation to flooding and temporary loss of soil-water saturation in a lowland soil of Cambodia

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Abstract

In the rainfed lowlands, temporary loss of soil-water saturation during crop growth is a common factor limiting rice (*Oryza sativa* L.) yield but its effects on phosphorus (P) availability are poorly understood. Rice plants were transplanted into pots containing soils that were either continuously flooded, maintained at field capacity or flooded and then dried to field capacity for 3 weeks during the vegetative stage. A black clay soil (Kandic Plinthaquult) from south-east Cambodia were studied with or without amendment by rice straw and P fertilizer. Under continuously flooded conditions, the growth of rice was vigorous without straw addition and there was a strong response of rice growth to the addition of P fertilizer. The soil underwent reduction, which increased pH from 4.2 to 5.5 in the black clay. By contrast, a loss of soil-water saturation 3 weeks before panicle initiation (PI) markedly impaired the growth of rice. This was not through any effect of water stress, and the growth reductions were not as strong as with continued loss of soil-water saturation from transplanting to PI. Fluctuations in soil pH and Eh corresponded closely to changes in soil-water regimes. Growth reductions were attributed to decreased shoot P levels resulting from the decline in P availability during the loss of soil-water saturation. The addition of rice straw stimulated soil reduction and lessened changes in soil pH and Eh during the loss of soil-water saturation in both soils. Straw addition enhanced P uptake by the rice plants during loss of soil-water saturation, but its beneficial effects could not be attributed to the direct addition of P, N or K to the soils. Thus the application of rice straw may be effective in lessening the effects of temporary loss of soil-water saturation on rice growth in lowland rice soils by minimising the decline in P availability.

Introduction

Globally, rainfed lowlands cover 26% of the total cultivated rice area but they contribute only 17% of total rice production (Crosson 1995). Rainfed lowland rice is grown in levelled and bunded fields with shallow flooding from rainwater. Depending on rainfall, the field may be continuously flooded, or, it may experience periods of loss of soil-water saturation during crop growth. Loss of soil-water saturation affects soil fertility as well as plant water relations. Hence rainfed rice yields are not only low on average but are also relatively variable (Pandey 1997). The levels of available N, P, and K, CEC (cation exchange capacity) and organic carbon contents of the seven main rice soils of Cambodia range from very low to modest (White *et al.* 1997). But the response of rice yields to fertilizer application on these soils has been inconsistent. The sporadic supply of rainwater during the vegetative growth phase of rice may be one of the reasons for the inconsistent response to fertilizer application and low rice yields in Cambodia.

Phosphorus availability for rice in paddy soils varies depending on soil-water regimes (Willett 1991). Changes in pH and Eh caused by wet-dry fluctuations also influence the availability of P because they control the P sorption characteristics of soils (Krairapanond *et al.* 1993). A number of studies on the behaviour and availability of P to upland crops grown following flooded rice crops were conducted in temperate regions (e.g. Willett and Higgins 1978), but little information is available for the rainfed lowlands where temporary loss of soil-water saturation may occur for varying durations during rice growth (Willett 1995).

This study was conducted to compare the growth and P uptake of rice cultivated in continuously flooded soils with that in soils subjected to intermittent or prolonged loss of soil-water saturation during the vegetative growth phase in an acid lowland soil from south-east Cambodia. The effects of rice straw amendments and P fertilizer in moderating the consequences of loss of soil-water saturation were also studied.

Materials and methods

Black clay soil (Kandic Plinthaquult) was collected (0-10 cm) from Toul Koktrap Rice Research Station, about 140 km south-east of Phnom Penh, Cambodia. Selected properties of this soil were as follows: pH (1:5 $CaCl_2$) 4.0; clay 440 g/kg; sand 300 g/kg; Olsen P 1.1 mg/kg; organic C 15 g/kg; total N 1.6 g/kg; exch Al 3.0 cmol/kg; ECEC 3.7 cmol/kg.

Five kg portions of soil (< 2 mm) were placed into 10-litre plastic pots. Each pot received 0 or 10 g of ground air-dry rice straw (<5 cm mesh) and 0 or 10 ml of KH_2PO_4 solution (46 mg P kg^{-1} of soil) making a total of four soil amended treatments each in triplicate: control, +P, +straw, and P+straw. All pots were basally dressed with complete nutrients (Seng *et al.* 1999). From 1 week after transplanting until harvest, 59.8 mg N kg^{-1} of soil as NH_4NO_3 was applied weekly to ensure rice plants would not suffer N deficiency at any stage.

All pots were flooded by the addition of distilled water to a depth of 3–4 cm for 3 weeks before transplanting. After transplanting, one-third of the pots were subjected to continuous flooding (CFd); one-third were maintained under continuous field capacity (FCp) by weighing to gravimetric water contents of 20 %; and the remainder were drained to field capacity for 3 weeks starting 3 weeks after transplanting, and then re-flooded until harvest (IFd). Pots maintained at field capacity were watered daily to weight and a second time each day to prevent signs of water stress in plants.

Six 20-day-old rice (*Oryza sativa* L.) seedlings, cv. Neang Ourk, were transplanted into each pot and thinned to 4 plants per pot after 5 days. Plants were harvested 8 weeks after transplanting when +P CFd plants were at panicle initiation (PI).

Soil pH and Eh were measured weekly, commencing 3 weeks before transplanting. A portable pH-Eh meter was used with a glass-calomel electrode and a platinum electrode inserted into the soil to 5–10 cm depth.

At harvest, plant shoots were collected from each pot, oven-dried at 70°C for 48 hours. Shoot P contents were determined in concentrated HNO_3 digests (Zarcinas *et al.* 1987) using an Inductively Coupled Plasma Atomic Emission Spectrophotometer.

Results and Discussion

Before flooding, the soil was extremely acidic ($pH \approx 4.2$ in its field moist condition) with low extractable P, organic C, and total N and high Al saturation. pH increased to above 5.5 within 2-3 weeks of flooding (Fig. 1). The addition of rice straw to the soils increased the rates and degree of soil reduction. Similarly, Willett and Intrawech (1988) reported increases in the rate and extent of reduction of poorly buffered, acid, sandy soils when enriched with organic matter.

The growth of rice was more vigorous under continuously flooded conditions than under non-flooded and intermittently flooded conditions. Continuous flooding resulted in higher concentrations of P in the plants (Fig. 2). The relationship between shoot DM and plant P uptake accounted for 98-99 % of the variance in growth in the different water regimes in both soils, suggesting that P was the main factor determining the growth of the rice plants, and this was strongly controlled by soil-water regimes (Fig. 2). An increase in P absorption by the plants is expected from increases in the solubility of native and applied phosphate and increased rates of diffusion of P to absorbing roots in the continuously flooded conditions (Patrick and Reddy 1978).

However, the growth of rice was strongly depressed by a prolonged period of loss of soil-water saturation from transplanting to panicle initiation, even though plants did not suffer any obvious water stress. A substantial decline in shoot P levels with reduction in shoot DM was associated with significant decreases in soil pH and increases in soil Eh, caused by loss of soil-water saturation. Weekly application of N fertilizer into the soils evidently provided adequate N for the plants in the CFd, FCp and IFd treatments, the levels of shoot N being ≥ 30 mg/g which is well above the critical level for rice (Reuter *et al.* 1997).

In most rice soils, the increases in soil pH and decreases in Eh on flooding are associated with the reduction of Fe^{3+} to Fe^{2+} (Ponnamperuma 1978). Concomitantly, the availability of native and added P are increased due to the reductive dissolution of ferric compounds with which P is associated (Willett 1991). But on drying the soil, the P may become immobilized again. Willett and Higgins (1978) reported decreases in P availability and oxalate extractable iron (Fe^{2+}) when previously flooded rice soils were oxidised, though they did not investigate the effects of the decline in P availability on rice growth. The results of this present study indicate substantial depression of P uptake in rice plants in the unsaturated soils and subsequent decreases in shoot DM. Shoot P concentrations in the unsaturated soils were below 13 mg/g, which is considered deficient for rice (Reuter *et al* 1997), but the

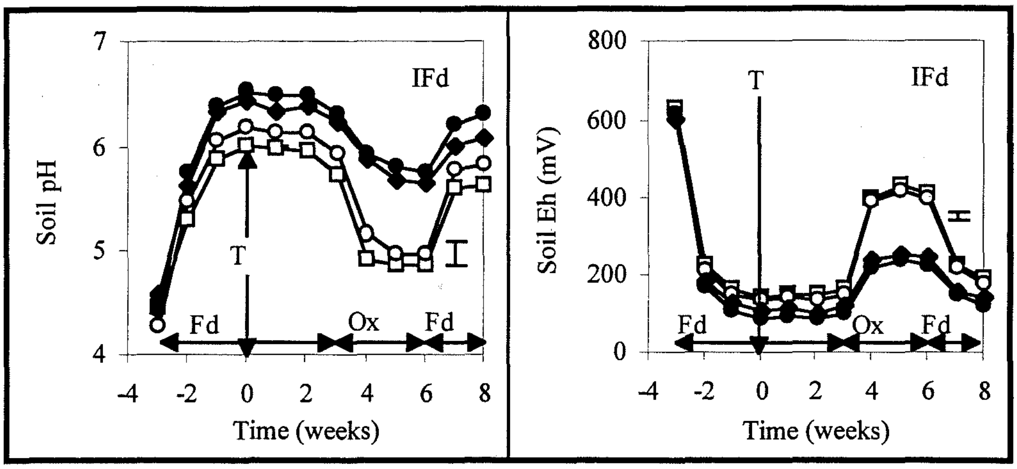

Figure 1. Effect of intermittent flooding (Ifd) on pH and redox potential of black clay soil. Soils were flooded (Fd) for 3 weeks, oxidised (Ox) for 3 weeks by drying to field capacity and re-flooded for 2 weeks.

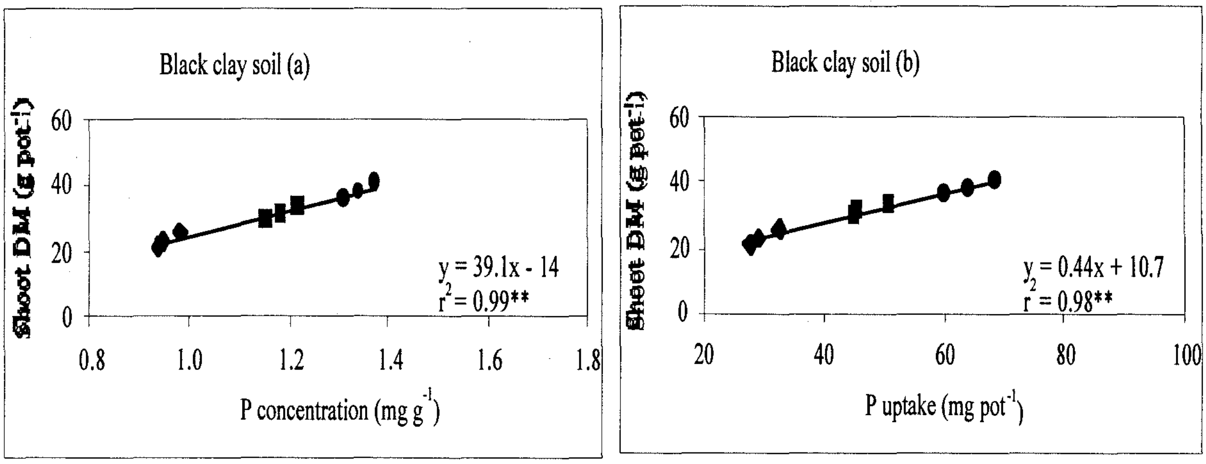

Figure 2. Relationship between shoot dry matter and (a) P concentration in shoots or (b) P content. Field capacity- diamond symbols; Intermittent flooding- squares; Continuous flooding- circles.

concentrations of other nutrients were satisfactory. Therefore, we attribute the reductions in growth of rice under loss of soil-water saturation to decreased plant P absorption. These results indicate that a prolonged period of loss of soil-water saturation, even without causing water stress, can markedly depress the growth of rice.

Leaf K concentrations in the plants, with or without straw addition were well above critical K concentrations (Reuter *et al.* 1997). Hence the increase in K uptake from straw addition does not explain the observed growth increases: P availability was the most limiting factor.

In the IFd treatments, where loss of soil-water saturation was imposed for 3 weeks between transplanting and panicle initiation, re-oxidation of Fe^{2+} would be expected to cause re-immobilisation of P that had been solubilised during reduction (Willett *et al.* 1978). However, re-flooding after the 3-weeks of loss of soil-water saturation would be expected to induce re-mobilisation of P as the soil became reduced again. Accordingly, shoot DM of rice with the intermittent loss of soil-water saturation was higher than continued loss of soil-water saturation, but still lower than continuous flooding. This suggested that intermittent loss of soil-water saturation 3 weeks before panicle initiation also depressed rice growth by depressing P availability.

There was a strong response of rice growth to straw application with corresponding increases in the uptake of N, P and K by the plants. This suggests that straw application enhanced the availability of nutrients to the plants. However, when straw plus P was added, the increase in P uptake (28–57 mg/pot) was much greater than when P alone was added and was greatly in excess of the P supplied by the straw (5 mg P /pot). This suggests that it was the changes in soil redox potential caused by straw addition that increased the availability of P. In the black clay soil straw addition did not greatly increase native P uptake. These results may be explained by suggestions of Willett (1991) who discussed several mechanisms whereby the addition of organic matter to the acid soils may increase the rates and quantity of available P to rice. In addition to the release of P by mineralisation, organic matter may maintain P in the soil solution by complexation with phosphate ions and by sorption competition.

In conclusion, in the black clay soil, the growth of rice was healthy under continuously flooded conditions because the availability of P and other nutrients was satisfactory, and there was no nutrient toxicity evident. Loss of soil-water saturation after transplanting until panicle initiation, whilst not causing water stress, depressed rice growth strongly. The depression of growth in this water regime was related to substantial decreases in P uptake apparently caused by reduced P availability resulting from oxidation of soils with loss of soil-water saturation. The addition of rice straw effectively ameliorated the effects of loss of soil-water saturation on growth reductions of rice by stimulating the rates of soil reduction during the period of loss of soil-water saturation, and increasing the uptake of P by the rice plant.

Rice grown under rainfed conditions frequently experiences periods of loss of soil-water saturation, the time, duration and intensity of which are unpredictable. These common problems occur not only in the rainfed lowlands of Cambodia, but also elsewhere in the world (Fukai *et al.* 1997). The effects of loss of soil-water saturation on growth reduction of rice will apparently be sometimes related to the decreased availability of P and at other times to a direct effect of water stress.

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