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journal or publication title	Journal of Integrated Field Science
volume	4
page range	65-70
year	2007-03
URL	http://hdl.handle.net/10097/40352

Solophos fertilizer improved rice plant growth in aerobic soil

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Keywords: Biomass, Leaf area, Plant height, Soil sickness, Yield decline.

Received 2 January 2007; accepted 9 January 2007

Abstract

Yield decline of continuous monocropping of aerobic rice is the major constraint to the wide adoption of aerobic rice technology. This study was conducted to determine if solophos fertilizer could be used to reverse the yield decline of this cropping system using pot and micro-plot experiments. The soil for the pot experiment was collected from a field where aerobic rice has been grown continuously for 11 seasons at the IRRI farm. Four rates (4, 6, 8, and 10 g pot^{-1}) of solophos application were used in the pot experiment. Micro-plots (1 × 1 m) were installed in the field experiment where the 12th-season aerobic rice was grown. Treatments in the micro-plots were with and without additional solophos application. Solophos rate was 4,407.5 kg ha^{-1} which was equivalent to 10 g solophos pot^{-1} used in the pot experiment. An improved upland variety, Apo, was used for both pot and micro-plot experiments. Application of solophos significantly increased plant height, stem number, leaf area, chlorophyll meter reading, root dry weight, and total biomass in the pot experiment. The growth enhancement by solophos application was also observed in the micro-plot experiment under the field conditions. Photosynthetic rate and spikelet number per m^2 were increased by solophos application in the micro-plot experiment. Although the mechanism of growth promotion by solophos application is not clear, this study suggested that solophos application could be used as one of crop management options that could minimize the yield decline of continuous monocropping of aerobic rice.

Introduction

Aerobic rice is defined as high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is responsive to high inputs, can be rainfed or irrigated, and tolerates (occasional) flooding (Bouman and Tuong 2001). Total water use and water productivity of aerobic rice was 27-51% lower and 32-88% higher than that of flooded rice, respectively (Bouman et al. 2005). Grain yield of 5-6 t ha^{-1} can be achieved in aerobic rice using currently available rice germplasm (George et al. 2002). However, yield decline under continuous monocropping of aerobic rice has been reported in Japan by Nishizawa et al. (1971), in Brazil by Guimaraes and Stone (2000), and in the Philippines by Ventura and Watanabe (1978), George et al. (2002), and Peng et al. (2006). Reduction in growth and yield caused by continuous monocropping of the same land is called soil “sickness”, which may involve the build up of soil-borne pathogens and nematodes, depletion of mineral nutrients, moisture stress and adverse effect on soil structure, and accumulation of toxic substances (Ventura, 1984). The causes of yield decline in the continuous aerobic rice system are still unknown. Understanding the causes of yield decline and developing proper management strategies will be very useful for sustaining the yield stability of aerobic rice under continuous cropping.

Zhou et al. (2002) reported that P fertilizer application increased plant height, tiller number, and root volume of rice grown in aerobic soil. Solophos is a commercial P fertilizer with 18.0% of available P_2O_5, 10.0% of S, and 18.0% of CaO. In this study, a pot experiment was conducted to determine the effect of solophos fertilizer on plant growth of aerobic rice grown under "sick" aerobic soil. The "sick" soil was from K6-7 field at the International Rice Research Institute (IRRI) farm where aerobic rice has been grown continuously for 11 seasons. About 40% yield reduction was reported after aerobic rice has been grown continuously for seven seasons in this field (Peng et al., 2006). The effect of solophos fertilizer was also determined in the K6-7 field using 1 × 1 m micro-plots during the wet season of 2006 when the 12^{th}-season aerobic rice was grown. The objective of this study was to determine if solophos fertilizer could be used to reverse the yield decline of continuous aerobic rice cropping system.

Materials and Methods

Pot experiment

A pot experiment was conducted at IRRI using soil collected from the K6-7 field where aerobic rice has been grown continuously for 11 seasons. The soil was Aquandic Epiaquoll with soil chemical and physical properties listed in Table 1. The soil was air-dried, chopped into small pieces, and mixed well for the pot experiment. Four-L porcelain pot filled with 3.0 kg air-dried soil was used in this experiment. Treatments were: four different solophos application rates, oven heating and untreated control. Because biotic and abiotic factors may contribute to "sickness" of aerobic soil under the continuous monocropping of aerobic rice, oven heating of the aerobic soil could alleviate the soil "sickness". Autoclave at 121°C has commonly been used to sterilize soils (Anderson and Magdoff 2005). In this study, pots with aerobic soil were placed inside an oven and treated at 120°C for 12 hours. Solophos rates were: S1 (4.0 g solophos pot^{-1}), S2 (6.0 g solophos pot^{-1}), S3 (8.0 g solophos pot^{-1}), and S4 (10.0 g solophos pot^{-1}). An improved upland variety, Apo, was used because of its good performance under aerobic conditions (George et al. 2002; Lafitte et al. 2002). Pots were placed in a greenhouse using a completely randomized design. Each treatment was replicated six times with six pots.

One day before sowing, different rates of solophos were applied to the pot and then the soil was soaked with tap water and kept saturated for about 1 week to promote good crop establishment after which the pots were kept under aerobic condition. Six pre-germinated seeds were sown in each pot on 5 May 2006 and thinning was done one week after sowing to maintain three uniform seedlings per pot. All pots were watered once every 1-3 days to keep soil moisture near saturation so that aerobic condition was maintained in the pots throughout the experiment. Pesticides were sprayed 3-4 times to control insect damage. Weeds were removed manually.

Plants were sampled on 13 June 2006. Before plant sampling, stem number per pot was counted and plant height from plant base to the tallest tip of leaf in each pot was measured. Three chlorophyll meter (SPAD)

Table 1. Chemical and physical properties of aerobic soil collected from K6-7 field at IRRI farm where aerobic rice has been grown continuously for 11 seasons.

Parameters	Unit	Value	SE
pH	-	7.1	0
Organic C	$g\ kg^{-1}$	16.4	0.03
Total N	$g\ kg^{-1}$	1.74	0.002
Olsen P	$mg\ kg^{-1}$	29.7	0.88
Available K	$mg\ kg^{-1}$	393	1.5
CEC	$cmol_c\ kg^{-1}$	40.5	0.67
Clay	%	58	0.33
Silt	%	33	0.33
Sand	%	9	0

SE represents standard error of mean.

readings were taken on one top-most fully expanded leaf per pot. Plants were separated into leaves, stems including sheath, and roots. Roots were then washed in a sieve with tap water to remove soil particles. Leaf area was measured with a leaf area meter (LI-3000, LI-COR, Lincoln, Nebraska, USA). Dry weights of leaves, stems and roots were determined after oven drying at 70°C to constant weight. Total biomass was the summation of leaf, stem and root dry weights.

Micro-plot experiment

Eight micro-plots of 1 × 1 m were established at 14 days after transplanting (DAT) into the K6-7 field where the 12th-season aerobic rice was grown in the wet season of 2006. In the K6-7 field experiment, twenty-one-day-old seedlings of Apo from wet bed nurseries were transplanted on 28 June 2006 at the rate of 3 seedlings per hill and at a spacing of 25 x 10 cm. Phosphorus (30 kg P ha^{-1} as solophos), potassium (20 kg K ha^{-1} as KCl), and zinc (5 kg Zn ha^{-1} as zinc sulfate heptahydrate) were applied and incorporated in all plots one day before transplanting. Fertilizer N was applied in three splits (20 kg ha^{-1} as basal, 20 kg ha^{-1} at 20 DAT, and 30 kg ha^{-1} at 40 DAT).

Micro-plot treatments were with and without additional solophos application. The treatments were replicated four times. Solophos rate was 4,407.5 kg ha^{-1} which was equivalent to S4 used in the pot experiment. Each micro-plot was surrounded by 30-cm metal plates inserted 15 cm deep in the soil. Plant height, tiller number, chlorophyll meter (SPAD) reading, and photosynthetic rate were recorded on 22 August 2006 at panicle initiation stage. At 14 days after flowering, all plants inside the micro-plot were sampled for growth analysis.

Data were analyzed following analysis of variance (SAS, 1982) and mean comparison between soil treatments was performed based on the Least Significant Difference (LSD) test at the 0.05 probability level for both pot and micro-plot experiments.

Results and discussion

Application of solophos had a significant effect on plant growth and leaf chlorophyll content compared with untreated control in the pot experiment (Figs. 1 and 2). On average, solophos application increased plant height by 46% over the control (Fig. 1a). Solophos input significantly promoted tiller and leaf area production compared with the control (Fig. 1b and

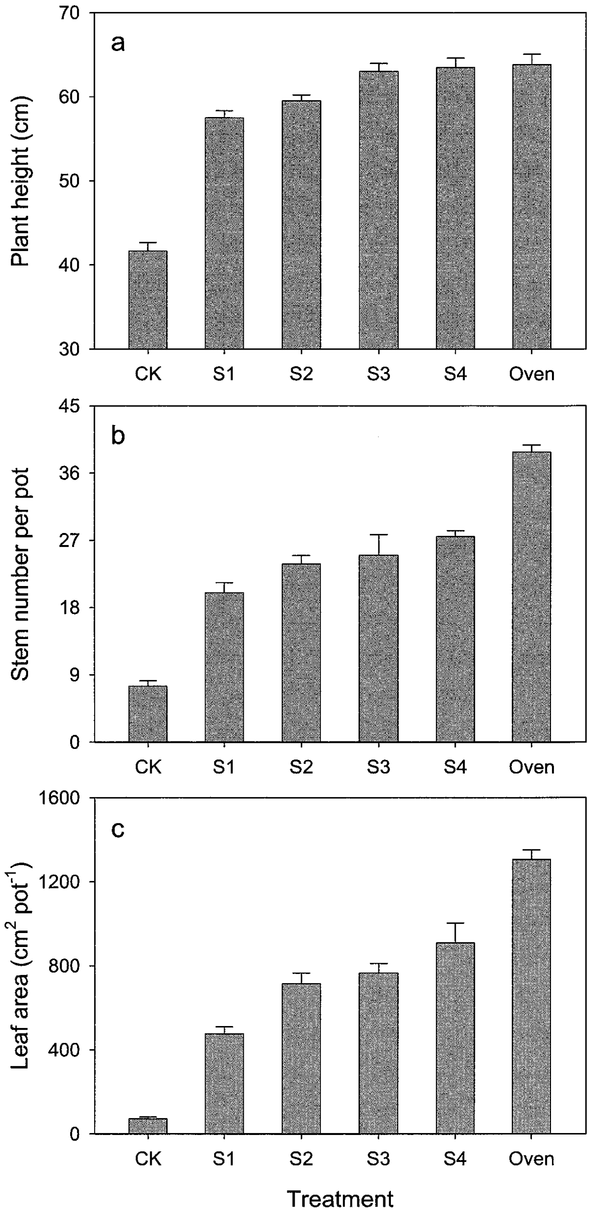

Figure 1. Plant height, stem number per pot, and leaf area per pot of aerobic rice grown under different rates of solophos application (S1 to S4 = 4, 6, 8, 10 g solophos pot^{-1}, respectively), oven-treated, and untreated control in a pot experiment. Soil was from K6-7 field where aerobic rice had been grown continuously for 11 seasons. Soil oven treatment was done at 120°C for 12 hours. Error bars represent standard error of mean (SE).

c). Stem number and leaf area per pot increased with increasing solophos rates. Solophos treated plants also had higher SPAD value, root dry weight, and total biomass than the control (Fig. 2). SPAD value increased as solophos rates increased (Fig. 2a). Plant response in root dry weight and total biomass to solophos application leveled off at 6.0 g solophos pot^{-1} (Fig. 2b and c). Among the plant growth parameters and leaf chlorophyll content, leaf area had the largest response to solophos, followed by total biomass, root dry weight, stem number, plant height, and SPAD value.

Oven heating increased plant growth and leaf chlorophyll content compared with untreated control in the pot experiment (Figs. 1 and 2). Oven heating had larger effects on stem number, leaf area, SPAD value, root dry weight, and total biomass than solophos application. The difference in plant height between solophos and oven treated plants was relatively small (Fig. 1a). The beneficial effect of oven heating of aerobic soil on plant growth suggested that the soil treatment removed some or all factors that had caused soil "sickness". Oven heating might have killed nematodes, fungi, and bacteria in the "sick" aerobic soil. At the same time, heating treatment could facilitate the availability of nutrients due to the changes of soil chemical and physical properties.

High level of solophos application in micro-plots increased crop growth significantly in the 12th-season continuous aerobic rice under the field conditions (Table 2). Solophos increased plant height by 60%, stem number by 79%, SPAD value by 45%, and single-leaf photosynthetic rate by 26% at panicle initiation stage compared with the control. There was a strong typhoon on 28 September 2006 and the plants were totally lodged. All lodged plants inside the micro-plots were harvested the next day after the typhoon to determine aboveground total biomass and spikelets m^{-2}. The micro-plots with high level of solophos application had 65% higher aboveground total biomass and 85% more spikelets m^{-2} than the control at 14 days after flowering (Table 3). These data in the micro-plot experiment confirmed the results of the pot experiment. Grain yield and yield components were not available due to the typhoon damage.

Solophos fertilizer was effective in enhancing plant growth of aerobic rice grown in the "sick" soil both in pot and micro-plot experiments. Although solophos is a commercial P fertilizer, we can not conclude

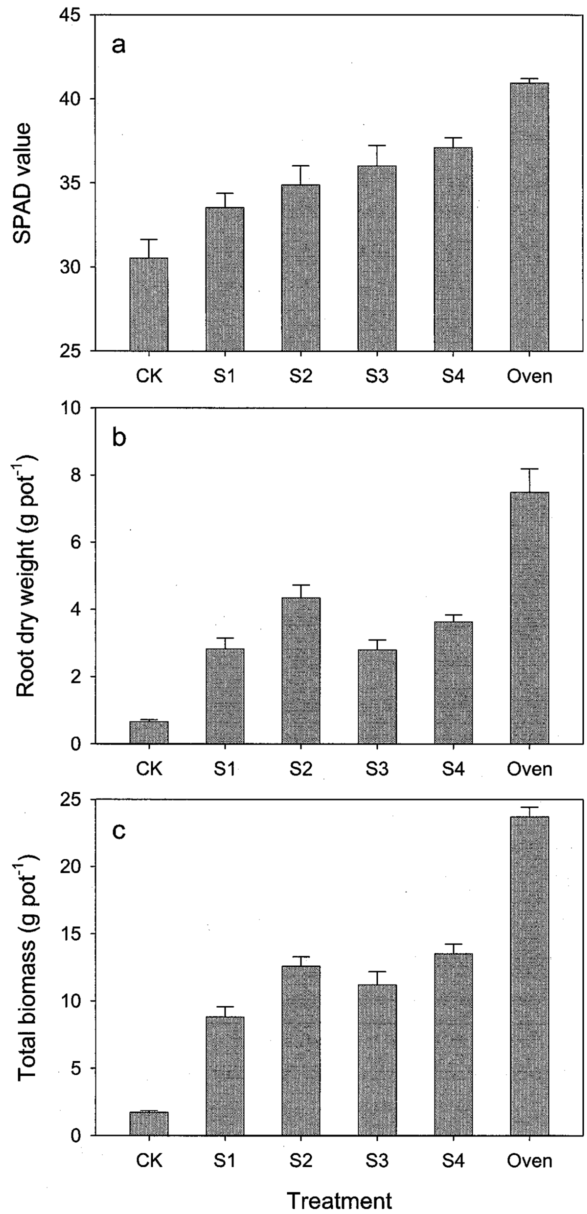

Figure 2. Chlorophyll meter (SPAD) reading, root dry weight per pot, and total biomass per pot of aerobic rice grown under different rates of solophos application (S1 to S4 = 4, 6, 8, 10 g solophos pot^{-1}, respectively), oven-treated, and untreated control in a pot experiment. Soil was from K6-7 field where aerobic rice had been grown continuously for 11 seasons. Soil oven treatment was done at 120°C for 12 hours. Error bars represent standard error of mean (SE).

Table 2. The responses of plant height, stem number, chlorophyll meter (SPAD) reading, and photosynthetic rate to solophos application at panicle initiation stage in the 12th-season aerobic rice grown at IRRI farm in the wet season of 2006.

Parameter	Control	With solophos
Plant height (cm)	62.3 b	99.7 a
Stem number per hill	7.2 b	12.9 a
SPAD value	29.6 b	43.0 a
Photosynthetic rate (μmol m^{-2} s^{-1})	21.6 b	27.3 a

Within a row, mean followed by different letters are significantly different at 0.05 probability level according to Least Significant Difference (LSD) test.

Table 3. The responses of aboveground total biomass and spikelet number per m^2 to solophos application at 14 days after flowering in the 12th-season aerobic rice grown at IRRI farm in the wet season of 2006.

Parameter	Control	With solophos
Biomass (g m^{-2})	842.6 b	1391.3 a
Spikelets m^{-2} (x1000)	25.9 b	48.1 a

Within a row, mean followed by different letters are significantly different at 0.05 probability level according to Least Significant Difference (LSD) test.

that the enhancement in plant growth was due to the improvement of P nutrition. First of all, 60 kg P ha^{-1} and 30 kg P ha^{-1} as solophos were applied in the dry and wet seasons respectively, every year since 2001 in the K6-7 field. Secondly, the "sick" soil contained 29.7 mg Olsen-P kg^{-1}, which was higher than the critical level for normal plant growth. We observed that Olsen-P content of the continuous aerobic rice soil has increased as the season progressed (data not shown). Thirdly, oven heating treatment on the "sick" soil did not alter Olsen-P or Bray-P contents. Therefore, it is unlikely that P deficiency is the cause of the soil "sickness" that was responsible for the yield decline of continuous monocropping of aerobic rice. In the subsequent experiments, the effects of solophos application and oven heating on soil physical and chemical properties, soil pathogens, and nematodes will be studied. Although the mechanism of growth promotion by solophos application is not clear, this study suggested that solophos application could be used as one of crop management options that could minimize the yield decline of continuous monocropping of aerobic rice.

Acknowledgement

This project was partially supported by CGIAR Challenge Program on Water and Food (Project No. 16) and the National Natural Science Foundation of China (Project No. 30471027).

References

Anderson, B. H. and F. R. Magdoff (2005) Autoclaving soil samples affects algal-available phosphorus. J. Environ. Qual., 34: 1958-1963.

Bouman, B. A. M. and T. P. Tuong (2001) Field water management to save water and increase its productivity in irrigated rice. Agric. Water Management 49: 11-30.

Bouman, B. A. M., S. Peng, A. R. Castañeda and R. M. Visperas (2005) Yield and water use of irrigated tropical aerobic rice systems. Agric. Water Management 74: 87-105.

George, T., R. Magbanua, D. P. Garrity, B. S. Tubaña and J. Quiton (2002) Rapid yield loss of rice cropped successively in aerobic soil. Agron. J., 94: 981-989.

Guimaraes, E. P. and L. F. Stone (2000) Current status of high-yielding aerobic rice in Brazil. Paper presented at the Aerobic Rice Workshop, 7-8 September 2000, International Rice Research Institute, Los Baños, Philippines.

Lafitte, R. H., B. Courtois and M. Arraudeau (2002) Genetic improvement of rice in aerobic systems: pregress from yield to genes. Field Crops Res. 75: 171-190.

Nishizawa, T., Y. Ohshima and H. Kurihara (1971) Survey of the nematode population in the experimental fields of successive or rotative plantation. Proc Kanto-Tosan Plant Protection Society 18: 121-122.

Peng, S., B. Bouman, R. M. Visperas, A. Castañeda, L. Nie and H. K. Park (2006) Comparison between aerobic and flooded rice in the tropics: agronomic performance in an eight-season experiment. Field Crops Res. 96: 252-259.

SAS Institute, (1982) SAS user's guide: Statistics. 4th ed. SAS Inst., Cary, NC.

Ventura, W. and I. Watanabe (1978) Growth inhibition due to continuous cropping of dryland rice and other crops. Soil Sci. Plant Nutr., 24: 375-389.

Ventura, W. (1984) Soil sickness caused by continuous cropping of upland rice, mungbean, and other crops. IRRI Res. Pap. Ser. 99, pp. 13.

Zhou, C. L., J. L. Yi, Q. R. Shen, L. Z. Hong, K. Wang, J. H. Ding and M. W. Wang. 2002. Comparing investigation on biomass, grain output and P uptake of paddy rice cultivated in aerobic and inundation. Jiangsu Agric. Sci. (in Chinese) 5: 1-3.