Optimal Phosphorus Management in Rice-Wheat Systems

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The annual rice-wheat system brings together conflicting and complementary practices as repeated transitions from aerobic to anaerobic to aerobic soil conditions result in unique changes in the physical, chemical, biological, and nutritive properties of soil. The rice-wheat rotation is one of the world's largest agricultural production systems, and occupies about 14 million hectares (M ha) of cultivated land in the Indo-Gangetic Plains in India, Pakistan, Bangladesh, and Nepal. Its production provides staple grains for more than one billion people, or about 20 percent of the world's population.

Both rice and wheat are exhaustive feeders, and a rice-wheat double-cropping system can quickly deplete soil of its nutrient content. A rice-wheat sequence that yields 7 t/ha of rice and 4 t/ha of wheat takes up more than 300 kg nitrogen (N), 30 kg phosphorus (P), and 300 kg potassium (K) per hectare from the soil. Even with the current recommended rate of fertilization for this system, a negative balance of the primary nutrients exists. The system commonly shows signs of fatigue and is no longer exhibiting increased production with higher input use.

This article addresses how farmers can manage P in their rice–wheat rotations in order to maintain yields, while sustaining – or improving – soil P status. Key questions addressed are: 1) How much P fertilizer should be applied in one rotation cycle? and 2) How much P should be applied to the wheat and rice phases of this rotation?

The amount of P to apply on wheat and rice depends on crop P demand, potentially available soil P resources, and the chemical processes that cause fluctuations in soil P supply under aerobic and anaerobic conditions. On a Typic Ustochrept (10 kg Olsen P/ha) at Ludhiana, India, seven P fertilizer treatments applied to rice and wheat (**Table 1**) were compared from 1990 to 1999.

Phosphorus accumulation and wheat yield in rice-wheat P treatments receiving 60 or 90 kg P_2O_5/ha to wheat (i.e., [1] $P_{0\text{-}60}$, $P_{0\text{-}90}$, $P_{30\text{-}60}$, and $P_{60\text{-}60}$) were significantly greater than in those receiving less than 60 kg P_2O_5/ha, or rice-applied P treatments (i.e., $P_{0\text{-}0}$, $P_{60\text{-}0}$, and $P_{30\text{-}30}$). Phosphorus application to rice increased P accumulation by rice, but did not consistently increase rice yields because flooding can decrease soil P sorption and increase P diffusion, resulting in higher P supply to rice. Applying only 60 kg P_2O_5/ha to wheat and no P to rice led to a

[1]Treatment abbreviations denote P_2O_5 rate applied to wheat followed by P_2O_5 rate applied to rice.

Table 1. Grain yields of rice and wheat (nine-year average) and total P input-output balance for different P management strategies in the field experiment at Ludhiana, India

P applied, kg P_2O_5/ha		Grain yield, t/ha		P accumulation, kg/ha		Total P input-output balance, kg/ha
Rice	Wheat	Rice	Wheat	Rice	Wheat	
0	0	5.03	2.41	16.6	7.5	-271.2
0	60	5.13	4.69	17.1	14.8	-51.2
0	90	5.08	4.82	17.8	15.4	54.8
30	30	5.27	4.21	19.0	12.5	-48.0
30	60	5.15	4.72	18.6	15.4	47.9
60	0	5.38	3.36	20.1	10.5	-39.6
60	60	5.30	4.94	20.0	15.9	148.7

negative P balance and a decline in soil P (**Table 1**). The P balance was positive in treatments in which more than 90 kg P_2O_5/ha/year was applied.

A sustainable P management strategy must ensure high and stable overall food production, high annual profit, and sufficient P supply to achieve potential yield increases. Major agronomic considerations derived from our experiment are described below.

A rice-wheat system with a total P input less than 60 kg P_2O_5/ha/year was inferior with regard to yield, P uptake, overall profit, P input–output balance, and maintenance or improvement of soil fertility. Only treatments with a total P input of 90 to 120 kg P_2O_5/ha/year had a positive P balance and led to maintenance or an increase in soil P levels.

Sustainable management should aim at increasing Olsen P to a level between 12.5 to 25 kg P/ha on soils of the Indo-Gangetic Plains. Discounting the inferior P_{60-0} treatment (low wheat yield), this range of available P was only achieved with the P_{30-60} and P_{60-60} treatments.

Total P input should be close to the amounts removed (output) by high yields occasionally achieved to ensure sufficient supply in favorable years and after other constraints to growth are removed. Attainable yields of 6 t/ha wheat and 7 t/ha rice require a total P supply of about 42 kg P/ha/year (17 kg P/ha for wheat and 25 kg P/ha for rice).

Soil P supply should be emphasized in wheat instead of rice. Any increase in the solution P concentration through P fertilizer application will have greater benefits in wheat. On soils testing 11 kg Olsen P/ha, a significant wheat yield response up to 90 kg P_2O_5/ha has been observed at several locations in northwest India. Band application of P below the seed and use of sufficient irrigation should be standard practice to increase soil P supply to wheat.

Management strategies with no P applied to rice were less sustainable in agronomic terms, even though the yield response to in-crop application was inconsistent due to factors other than P deficiency. Raising rice yields beyond the present level of 5.5 t/ha will require in-crop P application.

Summarizing, the agronomic indicators in our experiment suggest that: 1) the total P input should be in the range of 90 to 120 kg P_2O_5/ha/year, 2) at least 60 kg P_2O_5/ha must be applied to wheat to achieve yields greater than 5 t/ha, and 3) not more than 35 to 55 kg P_2O_5/ha should be applied to rice. **BCI**

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