Potassium Response in Rice-Maize Systems

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Emerging data from on-farm and on-station experiments in the rice-maize systems in India and Bangladesh have revealed very high system productivity and high responses of maize and rice to applied K. These results suggest that higher K deficits and higher fertiliser K requirement are to be anticipated in the region's R-M systems.

Rice-maize (R-M) systems are vital to meet food requirements and improve food security for a large number of urban and rural poor in South Asia. Rice-maize systems are distributed all over South Asia and currently occupy more than 3 million (M) ha in Asia (Timsina et al., 2010). The spread of the R-M system in South Asia has been driven by the rising demand for maize, especially by the poultry sector, and the tightening of world export-import markets. The more recent development of short-duration rice varieties and maize hybrids with improved drought tolerance is also giving rise to opportunities for the expansion of R-M systems into areas of South Asia with insufficient irrigation or rain for continuous rice cultivation.

The high yielding cultivars and the growing environments of rice (anaerobic) and maize (aerobic) crops have a profound effect, particularly, on K nutrition in R-M systems. Soil solution K is kept at relatively high levels in flooded rice soils. This is because large amounts of soluble Fe^{++}, Mn^{++} and NH_4^+ ions brought into solution displace cations from the clay complex and release exchangeable K into the soil solution. The displacement of K from the exchange complex, however, ceases on the return to aerobic conditions prevalent during maize planting. In fields with adequate drainage, K and other basic cations are lost via leaching. Leaching losses of K can be substantial in highly permeable soils with low cation exchange capacities. Yadvinder-Singh et al. (2005) found that leaching losses of K were 22 and 16% of the applied K in sandy loam and loamy soils, respectively, that were maintained at submerged moisture regimes. For Bangladesh, such losses can be as high as 0.1 to 0.2 kg K/ha/d (Timsina and Connor, 2001). Despite often having a relatively large total K content, the K nutrition of R-M systems grown on the soils of South Asia is not assured, because many heavy textured alluvial floodplain Terai soils of Nepal and northern and eastern India, and soils of Bangladesh contain vermiculite, illite, or other K-fixing minerals (Dobermann et al., 1996, 1998).

Three on-farm experiments in India and Bangladesh and one on-station experiment in India were carried out to elucidate the critical role of K in the sustainability of R-M systems in South Asia.

On-farm Trials at Bhagalpur, Bihar

Twelve on-farm trials were conducted during 2006-07 in Sabour, District Bhagalpur (25°15'N, 87°1'E) of Bihar state. Four treatments were compared: i) farmers' fertiliser practice (FFP), ii) FFP+ 62 kg K/ha (FFP+K_{62}), iii) FFP+K_{62}+40 kg S/ha+5 kg Zn/ha (FFP+K_{62}+S_{40}+Zn_5), and iv) FFP+S_{40}+Zn_5.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Fe = iron; Mn = manganese; Zn = zinc; NH_4^+ = ammonium; K_{ex} = soil exchangeable K; AE_N, AE_P AE_K = Agronomic efficiency of N, P, or K.

Table 1. On-farm productivity of rice, maize and R-M system (t/ha) as influenced by SSNM under R-M system at Sabour, Bhagalpur, Bihar.

Treatment	Rice yield	% Increase over FFP	Maize yield	% Increase over FFP	System-level maize equivalent yield, SMEY
FFP*	5.21	-	6.75	-	12.49
FFP+K_{62}	7.01	35	7.58	12	15.31
FFP+K_{62}+S_{40}+Zn_5	8.23	58	8.06	19	17.13
FFP+S_{40}+Zn_5	6.07	17	7.26	8	13.95
C.D. ($p \le 0.05$)	0.83	-	0.54	-	1.23

*FFP=80 kg N/ha and 23 kg P/ha in rice and 100 kg N/ha and 23 kg P/ha in maize; data are means of 12 farmers fields. Source: AICRP-CS Report (2007-10).

Table 2. Changes in soil K content (mg/kg) due to K application after one R-M cycle at Sabour, Bhagalpur, Bihar.

	FFP*	FFP+K_{62}	FFP+ K_{62}+S_{40}+Zn_5	FFP+ S_{40}+Zn_5
Initial	102.3	102.3	102.3	102.3
After 1 R-M Cycle	97.3	111.2	107.3	96.1
Change over initial	-5.0	8.9	5.0	-6.2

*FFP = farmer fertiliser practice; Source: AICRP-CS Report (2007-10).

The same rate of K was applied to both crops, while S and Zn were applied to rice only. The average use of fertiliser by farmers of the locality was 80 kg/ha N and 23 kg/ha P in rice and 100 kg/ha N and 23 kg/ha P in maize, while K application was negligible.

Inclusion of K in the FFP significantly ($p \le 0.05$) increased rice yield by 1.8 t/ha and in the FFP+S+Zn treatment by 3.02 t/ha (**Table 1**). Application of 62 kg/ha K increased ($p \le 0.05$) maize yield over FFP by 0.83 t/ha and over FFP+S+Zn by 1.31 t/ha. The productivity of R-M, measured in terms of maize equivalent yield for the system (SMEY), increased significantly with K or with the combined use of K+S+Zn. Use of 62 kg K/ha over FFP produced additional SMEY of 2.82 t/ha ($p \le 0.05$). With K+ S+Zn, on the other hand, the SMEY increased by 4.64 t/ha compared to the applications of individual nutrients.

Soil exchangeable K (K_{ex}) content improved with K fertilisation alone (13.9 mg/kg) or in combination with S and Zn (10 mg/kg), whereas a moderate decline in K_{ex} (1.2 mg/kg) was noticed with S+Zn application over FFP. Application of K or K+S+Zn in R-M enhanced K_{ex} (8.9 mg/kg) as compared to the initial content (5.0 mg/kg) (**Table 2**). On the other hand, omission of K from the fertiliser schedule resulted in a decline of K_{ex} (-5.0 to -6.2 mg/kg). The decline in K content under K omission revealed that higher rates of N (>180 kg/ha) and optimal to sub optimal rates of P (46 to 64 kg P_2O_5) used by farmers encouraged K mining from soil. Thus, adequate K input was essential to prevent or at least mitigate this adverse effect of

Table 3. On-farm yield (t/ha) and agronomic efficiency (kg grain/kg nutrient) with N, P and K applications in rice and maize under R-M system in Bangalore, Karnataka, India.

Treatment	2008-09	2009-10	Treatment	2008-09	2009-10
	- - Rice yield - -			- - Maize yield - -	
Control	2.23	2.50	Control	1.98	2.45
N_{100}	2.94	3.69	N_{150}	2.87	3.49
N_{100} P_{22}*	3.36	5.22	N_{150} P_{33}	4.29	5.27
N_{100} K_{42}*	3.26	4.78	N_{150} K_{33}	3.87	4.67
N_{100} P_{22} K_{42}	4.26	5.80	N_{150} P_{33} K_{33}	6.22	7.09
C.D. ($p \leq 0.05$)	0.22	0.24	C.D. ($p \leq 0.05$)	0.28	0.2
Agronomic efficiency			Agronomic efficiency		
N over control	7.1	11.9	N over control	7.9	6.9
P over N	19.1	69.5	P over N	43.0	53.9
K over N	7.6	26.0	K over N	30.3	35.8
P over NK	45.5	46.4	P over NK	71.2	73.3
K over NP	21.4	13.8	K over NP	58.5	55.2

*Indicated rates of P and K were P_2O_5 (22) and K_2O (42) applied to both crops. Source: AICRP-IFS report (2009-11); data are means of 24 farmers fields in each year.

imbalanced fertiliser use.

On-farm Trials at Bangalore, Karnataka

Twenty-four on-farm trials (each in 2008-09 and 2009-10) were conducted in Bangalore (12°8'N, 77°37'E), Karnataka with five treatments (control; 100 kg/ha N; 100 kg/ha N and 22 kg/ha P_2O_5; 100 kg/ha N and 42 kg/ha K_2O; 100 kg/ha N, 22 kg/ha P_2O_5 and 42 kg/ha K_2O). Results showed that the application of recommended doses of NPK (100, 22, 42 kg N, P_2O_5 and K_2O, respectively) to rice produced grain yields of 4.26 and 5.80 t/ha during 2008-09 and 2009-10, respectively (**Table 3**). Omission of P and K fertilisers caused yield losses of 0.6 to 0.9 t/ha and 1.0 to 1.02 t/ha, respectively. AE_K was between 13.8 to 21.4 kg grain/kg of K. Similar response to K over N alone was 7.6 to 26 kg/kg for K.

Like rice, the maize grain productivity was maximum in plots treated with the recommended doses of NPK (6.22 to 7.09 t/ha). Omission of K resulted in significant ($p \leq 0.05$) yield losses of 1.82 to 1.93 t/ha over the two years (**Table 3**). At these response levels, AE_K was 55.2 to 58.5 kg/kg, respectively. These results agreed closely with another on-farm study by Majumdar et al. (2012) in which yield losses due to the omission of K application to rice and maize were 90 to 1,806 kg/ha (mean = 622 kg/ha) and 140 to 1,320 kg/ha (mean = 700 kg/ha), respectively. Considerable increases in AE_N and AE_P due to K application were observed in this experiment. Synergistic effects of balanced fertilization were earlier reported by Tiwari (2002), which revealed that efficiency of applied N and P increased with increasing initial available K status of soils. Thus, to obtain full benefit from P fertilisation and to maintain high soil K status, adequate K supply should be ensured.

On-station Experiment at Bhagalpur, Bihar

Nutrient management in the R-M system was investigated under on-station situation at Sabour, Bhagalpur (25°15'N, 87°1'E), Bihar from 2006-07 to 2008-09. Eight treatments were compared: 3 levels of P_2O_5 (0, 30 and 60 kg/ha) and 3 levels of K_2O (0, 50 and 100 kg/ha) to both crops; 4 levels of S (0, 20, 40 and 60 kg/ha) to rice only; and 150 kg N/ha to both crops. The results revealed that the application of 150 kg N, 30 or 60 kg P_2O_5, and 100 K_2O to each crop along with 40 kg/ha S application in rice gave highest productivity of the individual crops and of the system. Gradient rates of K application brought significant yield gains over K omission in both crops as well as for the total system (**Table 4**). Total N, P and K uptake increased with increasing K application rate in rice crop, maize crop, and in the R-M system in this experiment (Timsina et al., 2013). Application of 50 kg K_2O/ha led to a significant ($p \leq 0.05$) increase in total uptake of N and K over K omission. The magnitude of these increases were 15.1, 21.6 and 18.6% for N and 31.2, 20.1, and 25.2% for K in rice, maize, and the R-M system, respectively (Timsina et al., 2013). On the other hand, increase in total P uptake was significant ($p \leq 0.05$) only at 100 kg/ha K_2O application compared with K omission. Thus, balanced fertilization with K not only increased rice and maize productivities, but also helped to mitigate N and P stresses by increasing uptake of these nutrients.

Table 4. Productivity of rice, maize and R-M system (t/ha) as influenced by different site-specific nutrient management (SSNM) options at Sabour, Bhagalpur, Bihar (mean of 3 years).

Nutrient rates, kg/ha	Rice	Maize	System-level maize equivalent yield (SMEY)
N_{150} P_{30} K_{100} S_{40}	7.42	7.99	16.16
N_{150} P_{60} K_{100} S_{40}	7.78	8.55	17.13
N_{150} P_{0} K_{100} S_{40}	6.38	6.91	13.94
N_{150} P_{30} K_{50} S_{40}	7.19	7.72	15.65
N_{150} P_{30} K_{0} S_{40}	6.16	6.71	13.49
N_{150} P_{30} K_{100} S_{60}	7.46	8.18	16.39
N_{150} P_{30} K_{100} S_{20}	6.96	7.65	15.33
N_{150} P_{30} K_{100} S_{0}	6.66	7.49	14.83
SR*	6.32	7.40	14.37
FFP**	5.03	6.55	12.10
C.D. ($p \leq 0.05$)	0.61	0.67	1.54

*SR=state-recommend rates of nutrient application; **FFP = farmer fertiliser practice; Indicated rates of P and K were as P_2O_5 and K_2O and S was applied to rice crop only. SR = 100 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha in rice and 120 kg N, 75 kg ha P_2O_5 and 50 kg K_2O/ha in maize; FFP = 70 kg N, 35 kg P_2O_5 and 10 kg K_2O/ha in rice and 100 kg N, 30 kg P_2O_5 and 20 kg K_2O/ha in maize. Source: AICRP-CS Report (2007-10).

Agronomic and recovery efficiencies of P were greater when 100 kg K_2O was applied along with N, P and S. This indicates that balancing K supply in the fertilisation schedule improves the efficiency of other nutrients (Timsina et al., 2013). These results are consistent with the findings of other workers (Dwivedi et al., 2011; Tiwari et al., 2006). Application of gradient rates of K improved the exchangeable K content in the soil after three cycles of rice-maize cropping, with more than 12% increase in exchangeable K content at 100 kg K_2O per ha application rate (data not shown). However, the highest contents of available N,

Table 5. Grain yield (t/ha) of winter maize grown after rice in omission plot trials, ACIAR R-M and IPNI project sites, Bangladesh.*

Treatment	------ 2009-10 ------			------ 2010-11 ------		
	Comilla (n=18)	Rajshahi (n=9)	Rangpur (n=5)	Comilla (n=17)	Rajshahi (n=17)	Rangpur (n=8)
-K	5.3	7.8	7.5	3.4	6.7	6.0
NPK	8.3	9.3	8.3	9.0	8.8	8.1
NK Low P	8.0	8.2	7.7	8.7	8.0	6.0
NP Low K	7.9	8.5	7.3	9.0	7.7	5.8
N Low PK	7.9	8.8	6.8	8.8	7.7	5.7
C.D. ($p \leq 0.05$)	0.8	0.6	1.2	0.7	0.5	0.9

*N, P_2O_5, and K_2O rates for the full NPK treatment were 240, 170 and 240 kg/ha, respectively. Low P and low K rates were 100 and 170 kg/ha P_2O_5 and K_2O, respectively.

Olsen-P and extractable S were recorded in the no-K treatment, where the K_{ex} content was lowest. Greater mining of soil N, P and S due to increased biomass production and higher uptake of N, P and S content with +K compared with no-K could be the reason for the decline in soil N, P and S contents.

On-farm Trials in Bangladesh

Site-specific nutrient management (SSNM) studies in R-M systems were conducted from 2008 to 2011 in several farmers' fields in three districts of Bangladesh, viz., Comilla, Rajshahi and Rangpur. At all these sites, winter maize was planted after monsoon rice. Exchangeable K contents in soils at Comilla and Rajshahi were 0.15 and 0.19 cmol/kg (more than the critical level of 0.1 cmol/kg for lowland rice and less than 0.2 cmol/kg for upland crops), while soils at Rangpur contained a very high level of K (0.32 cmol/kg).

On-farm omission plot trials with winter maize after rice showed that omission of K decreased maize yields significantly at all sites in both years, with the highest reduction observed at Comilla (**Table 5**). The yields were maintained or just slightly reduced with the application of a low level of K (~70% of the full rate). Interestingly, for both years of the experiment, the soil test available K poorly explained the yield of maize in –K treatments (Timsina, unpublished data).

The response of maize to applied N, P and K varied for both years, and was variable among farmers' fields within a district in each year. In 2009-10, there was more than 3 t/ha response to K in more than 60% of the farms at Comilla, while, in the other two districts, a similar response was only observed in about 20% of the farms. In 2010-11, all fields at Comilla and 50 to 60% fields in the other two districts showed >3 t/ha response (data not shown). Comilla had the lowest level of soil K_{ex}, and therefore, the response to K application was highest. In both years, the AE_K varied widely across districts as well as across farmers' fields within a district. In individual fields, AE_K ranged from 0.2 to 29.4 kg grain/kg K applied in the first year of the experiment and from 0 to 38.3 kg grain/kg K applied in the second year. The mean AE_K in the three districts ranged from 4.1 (Rangpur) to 15.4 kg grain/kg K applied (Comilla) in the first year and from 10.1 (Rangpur) to 28.2 kg grain/kg K applied (Comilla) in the second year (data not shown). These results demonstrate high variability in grain yield of winter maize grown after rice across farmers' fields in Bangladesh and also remarkably high yield response to K in all districts, especially in Comilla. Comilla is also the district with the lowest level of soil exchangeable K and the highest AE_K. Under these conditions, if K fertiliser is not applied to winter maize as per crop demand, a tremendous yield loss accompanied by a decline in soil K supplying capacity will occur causing loss of sustainability of R-M systems.

Summary

The emerging R-M system in South Asia offers a major challenge to maintaining K balance in the soil for two main reasons: a) the ecosystems in which the R-M systems thrive (eastern and southern India, Bangladesh, Nepal, and parts of Pakistan) do not have high K content in irrigation water and b) the retention of residues of rice and maize in the field is not a common practice. Additionally, the dry matter yield of the R-M system is usually much higher than that of Rice-Rice and Rice-Wheat that leads to higher extraction of nutrients from the soil. In the absence of residue retention practices, large amounts of K are exported out of the field with harvested product and the residues. This suggests that higher K deficits and fertiliser K requirement are to be anticipated in the R-M system, and that field-specific application of K and retaining some amount of crop residues will be required to maintain and improve crop yield and soil K fertility. BC-SA

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