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EFFECT OF POTASSIUM APPLICATION ON WHEAT *(Triticum aestivum* L.) IN OLD HIMALAYAN PIEDMONT PLAIN

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Abstract

A field trial was conducted in Rabi season 2001-2002 at the Bangladesh Agricultural Research Institute's Agricultural Research Station (BARI ARS) farm, Thakurgaon to evaluate a higher dose of K (66 kg K/ha) for maximizing yield of wheat and sustain soil native K level for wheat in north-western (NW) region of Bangladesh. To accomplish the objective, three levels of K (T_1= K_0, T_2 = K_{66}, and T_3= K_{38} (Farmers' practice) were tested. T_1= K_0 and T_2 = K_{66} were tested under soil test based (STB) N_{116} P_{15} S_{36} Z_{n1} $B_{1.7}$ fertilization and these two treatments T_1 and T_2 were compared with the farmers' own fertilization practice N_{68} P_{24} K_{38} S_{16} Zn_0B_0 (T_3). Results showed that the treatment (T_2) i. e. K_{66} with STB dose produced the better yield of wheat (var. Protiva). The highest gross return of Tk. 35,610/- and the highest net-return of Tk. 30,479/- was obtained with the treatment T_2 (STB). The dose of 66 kg K/ha for wheat growing in Old Himalayan Piedmont Plain (AEZ-1) was not adequate, and thus needs to be increased to maintain the soil K reserve, since there was an apparent negative balance of K in the soil with sole use of chemical fertilizers. The recommended P dose of 24 kg P/ha in wheat season created a positive balance of P. The STB dose for S and Zn @36 and 1 kg/ha, respectively, in wheat season created a positive balance of S and Zn in soil.

Keywords: Potassium, fertilizer management, wheat and nutrient balance sheet.

Introduction

Wheat is the second cereal crop in Bangladesh and it occupies about 0.80 million ha. It is grown in a vast area of NW part of Bangladesh. Our previous studies showed that most of this area (Takhurgaon, part of Dinajpur and Panchagarh districts) is deficient in potassium. Light textured soils of these areas have low exchangeable K and farmers use low amount of K fertilizer. There are many causes of low K use in farmers' fields, such as the effect of K in vegetative crop growth is not very clear, K fertilizer are more costly than urea, and sometimes it is not available in the local market.

Intensive cropping and use of modem rice varieties for high yield caused heavy depletion of K in soils, particularly in the absence of K application (Tiwari, 1985). Mohanty and Mandal (1989) reported a negative K balance in rice systems at many sites in India. A recent study in BRRI showed that the

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negative K balance was observed even upto 60 kg/ha of the applied K level with diminishing magnitude and suggested that an amount of about 61.34 kg K/ha would be required to sustain soil native K for rice cropping (Ahsan *et al.*, 1997). Nevertheless, there is scanty information for wheat cropping. A study on response of wheat to potassium in NW part of Bangladesh showed that in medium and low K content soils grain yield increased significantly upto 60 kg/ha and 90 kg/ha of the applied K level, respectively (Saha *et al.*, 2001). Considering the above findings, the present study was carried out to evaluate a high dose of K (66 kg K/ha) for maximizing yield of wheat and sustain soil native K level for wheat in NW region of Bangladesh.

Materials and Method

The experiment was conducted in Rabi 2001-2002 at the BARI ARS experimental farm, Thakurgaon (high land (HL); AEZ-1: Old Himalayan Piedmont Plain). At the start of the experiment, composite surface soil samples at a depth of 0-20 cm from 30 spots of the experimental fields were collected. The soil samples were air-dried and ground to pass through a 2-mm sieve for laboratory analysis. The soil samples were analyzed for pH (1:2.5) (Jackson, 1962), total N (Bremner, 1960), texture (Karim *et al.*, 1988), exchangeable K (Page *et al.*, 1982), available P (Bray and Kurtz, 1945), S (Bardsley and Lancaster, 1965) and Zn (Lindsay and Norvell, 1978). The soil of the experimental field is sandy-loam in texture, strongly acidic in nature, severely deficient in sulphur (Table 1). The soil N, K, and Zn content is low (Table l). Wheat variety Protiva was tested.

Table 1. Physical and chemical properties of the soil at the experimental field, BARI ARS, Thakurgaon farm, 2001-'02.

Soil parameters	Method of determination		SD
Texture	Hydrometer method	Sandy- loam	
pH (1:2.5)		5.34 (Strongly acidic)	0.04
Total N (%)	Micro-Kjeldahl distillation method	0.10 (Low)	0.01
Available P (ppm)	Bray method -1	29.12 (Opt.)	0.51
Exchangeable K(meq/100 g soil)	1 N NH_4OAc method	0.11 (Low)	0.01
Available S (ppm)	0.01M Calcium dihydrogenphosphate extraction	Trace (Very low)	
Available Zn (ppm)	DTPA Extraction	0.88 (Low)	0

The experiment was laid out in a randomized complete block (RCB) design with four replications. To achieve the objectives, three levels of K (T_1= K_0, T_2 = K_{66}, and T_3 = K_{38} (Farmers' practice) were tested. A flat dose of N-P-S-Zn-B was applied @ 116-1.5-36-1-1.7 kg/ha, respectively, for T_1 and T_2 according to the soil test based (STB) for high yield goal (except B). These two treatments T_1 and T_2 were compared with the farmers' own fertilization practice (T_3), in T_3 (Farmers' own fertilization practice) N-P-S was applied @ 68-24-16 kg/ha, respectively. The sources of NPKS and Zn were urea, triple super phosphate, muriate of potash, gypsum and zincsulphate, respectively.

The field was prepared by bullock drawn country plough and ladder. After the preparation, the field was divided into small experimental plots (size: 5 m × 4 m) according to the layout. The full dose of P. K, S, Zn, B and half of N were applied at the time of final land preparation according to the treatments (Table 2). The remaining half of N was applied at 17-21 days after sowing, when the first irrigation was given. The 2nd and 3rd irrigation were given at 55-60 days and 75-80 days after sowing, respectively. Seeds were sown at the rate of 130 kg/ha at the depth of 4-5 cm in a row-to-row distance of 20 cm on 1 December 2001. Appropriate cultural and management practices were followed during the growing season. The crop was harvested from 5 m^2 area for grain yield on 26 March 2002. Straw yield of wheat was harvested from 1 m^2 area. Plant height (cm) was recorded from randomly 10 plants in each treatment. Tiller and spike no./rn^2 was also counted. The grain yield was recorded at 14 % moisture and straw yield at oven dry basis.

A portion of grain and straw samples were collected for chemical analysis. The plant samples were digested with HNO_3 and $HC1O_4$ at the ratio (5:2) and analyzed following the procedure described by Yoshida (1976). The data were statistically analyzed using IRRISTAT version 4.1 (IRRI, 1998). Economic analysis was done using standard procedure.

Results and Discussion

Growth and yield

The application of different nutrient packages positively influenced on the tiller and spike production, grain and straw yield (Table 2). However, it did not influence the plant height and spike length (Table 2). Application of nutrient packages (T_1) and (T_2) significantly increased the number of tiller and spikes/m^2 over the farmers' own fertilizer practice (T_3) and the highest no. of tillers/rn^2 (383) was recorded with the treatment (T_1) followed by (T_2) (374). However, statistically the difference of tiller no. production between (T_1) and (T_2) was identical. The treatment (T_3) (Farmers' own fertilizer practice) produced the lowest no. of tillers/m^2 (276). Similar trend was also found in case of spike

Table 2. Effect of different nutrient packages on the yield components and yield of wheat (Protiva) at BARI, ARS, Thakurgaon farm, 2001-'02.

Treatments*	Plant height (cm.)	No. of tillers/ m^2	No. of Spikes/ m^2	Spike length (cm.)	Grain (t/ha)	Straw (tlha)
T_1	100.3	383.4	372.1	15.0	3.55	4.67
T_2	99.1	374.0	358.9	14.7	3.87	4.65
T_3	91.5	276.0	255.0	14.0	2.18	2.97
LSD (0.05)	NS	41.0	45.1	NS	0.38	0.74
CV (%)	6.5	6.9	7.9	3.5	6.8	10.5

*T_1= N-P-K-S-Zn-B @ 116-1.5-0-36-1-1.7 kg/ha, respectively;
T_2 =N-P-K-S-Zn-B @ 116-1.5-66-36-1-1.7 kg/ha, respectively;
T_3 (Farmers' dose) N-P-K-S-Zn-B @ 68-24-38-16-0-0 kg/ha, respectively

production (Table 2). However, the highest grain yield (3.87 t/ha) was obtained with the treatment (T_2), which is comparable to the treatment (T_1) (Table 2). Nevertheless, the difference in grain yield between (T_1) and (T_2) was minimum. Similar results were obtained by Anonymous (1), who described that the application of the nutrient package @ $N_{120}P_{35}$ K_{66} S_{20} Zn_5 B_2 produced the average spike no. /m^2 (347) and average wheat grain yield of 3.49 t/ha and by Anonymous (2) using the nutrient package @ $N_{120}P_{60}$ K_{40} S_{20} obtained the average spike no./m^2 (317) and average wheat grain yield of 2.87 t/ha in variety Protiva. Hossain *et al.* (2004) also reported that the nutrient package @ $N_{120}P_{60}$ K_{40} S_{45} produced the spike no./m^2 (305) and wheat grain yield of 3.47 t/ha (var. Protiva). The treatment (T_3) (Farmers' own fertilizer practice) produced the lowest grain yield (2.18 t/ha). No application of Zn and B and application of under-dose of urea and sulphur fertilizer by farmers may be the cause of minimum yield. The obtained results were supported by Halder *et al.* (2007) who described the application of Zn 2 kg/ha and B @ 2 kg/ha increased the wheat grain yield. Similar trend was also found in case of straw yield (Table 2). The highest straw yield (4.67 tlha) was found with the treatment (T_1) followed by that in (T_2) (4.65 t/ha) and (T_3) (2.97 t/ha).

Cost and return

Table 3 shows the economic analysis of different nutrient management packages for wheat (var. Protiva) cropping at BARI, ARS, Thakurgaon (AEZ-1). The highest gross return of Tk. 35,610/- and the highest net-return of Tk. 30,479/- was recorded with the treatment T_2 (STB) compared to the minimum gross return (Tk. 20,410/-) and the net-return (Tk. 16,153/-) with the treatment T_3 (Farmers' practice). Thus, the economic nutrient package for the farmer would be T_2 treatment.

Table 3. Economic analysis of different nutrient management packages for wheat (Protiva) cropping at BARI, ARS, Thakurgaon farm, 2001-'02[a].

Treat-ment	Grain yield (t/ha)	Straw yield (t/ha)	Gross return (Tk./ha)	TVC[b] (Tk./ha)	Net return (Tk./ha)	Pay-back from one Tk. investment
T_1	3.55	4.67	33070	3943	29127	7
T_2	3.87	4.65	35610	5131	30479	6
T_3	2.18	2.97	20410	4257	16153	4

[a]Price (Taka/kg): Urea=6.00, TSP= 14.00, MP= 9.00, Gypsum=5.00, Zinc-sulfate= 25.00 and Borax = 80.00. Price of wheat grain Tk.8000/t; Price of wheat straw = Tk. 1000/t; Four additional man days are required for applying chemical fertilizer per ha. Labour wage/day= Tk.80/-.

[b]*Total variable cost (TVC) incurred in fertilizer purchase and application.

Nutrient uptake by wheat

The effect of different nutrient packages on the nutrient uptake (kg/ha) in grain and straw of wheat (var. Protiva) is presented in Table 4. The grain N uptake by wheat (var. Protiva) under different fertilization varied from 39.4 (T_3) to 86.9 kg/ha (T_2), while straw N uptake varied from 8.0 (T_3) to 23.4 kg/ha (T_1). Grain P uptake varied from 7.8 (T_3) to 13.5 kg/ha (T_2) and straw P uptake varied from 0.8 (T_3) to 2.1 kg/ha (T_1). In wheat straw, P uptake was considerably low. Grain K uptake varied from 8.0 (T_3) to 14.3 kg/ha (T_2) and straw K uptake varied from 41.9 (T_3) to 76.5 kg/ha (T_2). Grain S uptake varied from 2.6 (T_3) to 6.1 kg/ha (T_2) and straw S uptake varied from 2.2 (T_3) to 7.4 kg/ha (T_2). Grain Zn uptake varied from 0.07 (T_3) to 0.18 kg/ha (T_2) and straw Zn uptake varied from 0.05 (T_3) to 0.10 kg/ha (T_1) and (T_2). From Table 4, it was observed that most of the applied N, P, and Zn accumulated in grain of wheat compared to straw and in case of K, it was vice-versa. Most of the applied K accumulated in straw of wheat compared to grain. In case of N, similar results were found by Timsina *et al.* (2006) and Khaleque *et al*. (2008), and in case of P were found by Saleque *et al.* (2006) and Obaid-ur-Rahman *et al*. (2006). The results about K were confirmed by the findings of Panaullah *et al.* (2006). It was observed that 1.0 t wheat straw (as oven dry basis) contained 14-16 kg K and 3-5 kg N (data computed from Table 4). In case of N, similar results were found by Khaleque *et al.* (2008). Wheat straw may be used as a partial source of K and N fertilization. The total amount of N, P, K, S, and Zn uptake by wheat (var. Protiva) is presented in Table 5, which shows that the N uptake varied from 47.4 (T_3) to 108.6 kg/ha (T_2), P uptake varied from 8.6 (T_3) to 15.4 kg/ha (T_2) and K uptake varied from 49.9 (T_3) to 90.8 kg/ha (T_2), S uptake varied from 4.7 (T_3) to 13.5 kg/ha (T_2) and Zn uptake varied from 0.12 (T_3) to 0.28 kg/ha (T_2). The N, P, K, S, and Zn uptake increased with the increase in grain and straw yields. Table 5 shows that the amount of N required to produce 1.0 t of grain of wheat (var. Protiva) under different fertilization varied from 21.7 (T_3) to 28.1 kg (T_2). The amount of P required to produce 1.0 t of grain under different fertilization varied from 3.9 (T_3) to 4.0 kg (T_2) & (T_1). In case of K, it varied from 22.9 (T_3) to 25.0 kg (T_1). S requirement varied from 2.2 (T_3) to 3.5 kg (T_2) and Zn requirement varied from 0.06 (T_3) to 0.07 kg (T_1) and (T_2) to produce 1.0 t grain of wheat (var. Protiva).

Table 4. Effect of different nutrient packages on the nutrient uptake (kg/ha) in grain and straw of wheat (Protiva) at BARI, ARS, Thakurgaon farm, 2001-'02.

Treat*	Nutrient uptake (kg/ha) in grain					Nutrient uptake (kg/ha) in straw				
	N	P	K	S	Zn	N	P	K	S	Zn
T_1	75.7	12.0	12.3	4.8	0.16	23.4	2.1	76.3	6.1	0.10
T_2	86.9	13.5	14.3	6.1	0.18	21.7	1.9	76.5	7.4	0.10
T_3	39.4	7.8	8.0	2.6	0.07	8.0	0.8	41.9	2.2	0.05
LSD(o.05)	*5.9*	2.1	2.0	0.6	0.04	3.3	0.6	14.8	*1.5*	0.02
CV (%)	5.1	10.9	10.0	7.8	16.6	10.9	21.6	13.2	16.9	15.9

T_1 =N-P-K-S-Zn-B @ 116-1.5-0-36-1-1.7 kg/ha, respectively;
T_2 =N-P-K-S-Zn-B @ 116-1.5-66-36-1-1.7 kg/ha, respectively;
T_3 (Farmers' dose) =N-P-K-S-Zn-B @68-24-38-16-0-0 kg/ha, respectively

Table 5. Effect of different nutrient packages on the nutrient uptake (kg/ha) by wheat (Protiva) at BARI, ARS, Thakurgaon farm, 2001-'02.

Treat*	Nutrient uptake (kg/ha)					Nutrient required (kg nutrient/t of wheat grain)				
	N	P	K	S	Zn	N	P	K	S	Zn
T_1	99.1	14.1	88.6	10.9	0.26	27.9	4.0	25.0	3.1	0.07
T_2	108.6	15.4	90.8	13.5	0.28	28.1	4.0	23.5	*3.5*	0.07
T_3	47.4	8.6	49.9	4.7	0.12	21.7	3.9	22.9	2.2	0.06
LSD(0.05)	7.8	2.6	14.5	1.8	0.06	-	-	-	-	-
CV (%)	5.3	11.9	11.0	10.6	16.0	-	-	-	-	-

T_1=N-P-K-S-Zn-B @ 116-1.5-0-36-1-1.7 kg/ha, respectively;
T_2 =N-P-K-S-Zn-B @ 116-1.5-66-36-1-1.7 kg/ha, respectively;
T_3(Farmers' dose) =N-P-K-S-Zn-B @ 68-24-38-16-0-0kg/ha, respectively

Apparent nutrient balance

Simplified approach was used for calculating partial net N, P, K, S, and Zn balances based on major inputs: fertilizer, added nutrients through irrigation water, and major outputs (above ground plant uptake). The results of wheat-grown season of the field experiment are presented in Table 6.

Table 6. Effect of different nutrient packages on the soil nutrient apparent balance sheet in wheat (Protiva) cropping at BARI ARS, Thakurgaon farm, 2001-'02.

Treatments	Nutrient elements (kg/ha)														
	N			P			K			S			Zn		
	Added[1]	Uptake	Balance	Added	Uptake	Balance	Added	Uptake	Balance	Added	Uptake	Balance	Added	Uptake	Balance
T_1	48.4	99.1	-50.7	1.6	14.1	-12.5	2.4	88.6	-86.2	36.0	10.9	25.1	1.00	0.26	0.74
T_2	48.4	108.6	-60.2	1.6	15.4	-13.8	68.4	90.8	-22.4	36.0	13.5	22.5	1.00	0.28	0.72
T_3	29.2	47.4	-18.2	24.1	8.6	15.5	40.4	49.9	-9.5	16.0	4.7	11.3	0	0.12	-0.12

[1]40% of applied fertilizer/ manure were considered effective.

Note: Nutrients added (kg/ha/season) through irrigation water are presented below.

Nutrients added (kga/season)	
Nutrients	Through irrigation water*
N	5.0
P	0.1
K	2.4
S	0
Zn	-

* Assumed water requirement in wheat 25 cm.

Nitrogen replenishment through chemical fertilizer was not enough to balance N removal by crop because much of the applied N was lost from soil. The apparent N balance thus was negative: -18.2 (T_3) to -60.2 kg N/ha/season (T_2) (Table 6).

The apparent P balance in the soil resulted from the different fertilizer management practices ranged from -13.8 (T_2) to 15.5 kg P/ha/season (T_3). The treatment T_3 (Farmers' practice) showed a positive P balance. The plots under T_3 received 24 kg P/ha/season from chemical fertilizer and the total P uptake was 8.6 kg /ha/season. It seems that the P input was greater than P uptake under T_1 Moreover, the application of P fertilizer in treatment (T_1) and (T_2) according to the STB (P determined by Bray-method-1) did not show a positive apparent P balance. Under these two treatments, it ranged from -12.5 (T_1) to -13.8 kg P/ha/season (T_2). From this finding, it indicates that the P requirement for acid soils needs further investigation. The apparent balance of K in soil was highly negative. The magnitude of the negative K balance ranged from -86.2 (T_1) to -9.5 kg K/ha/season (T_3). The treatments T_2 and T_3 which received chemical K fertilizer @ 66 kg K/ha and 38 kg K/ha, respectively, showed a less negative balance of K (Table 6).

The apparent S balance in the soil resulted from the different fertilizer management practices ranged from 11.3 (T_3) to 25.1 kg S/ha/season (T_1). T_1 and T_2 where fertilizer was applied according to the STB, yielded a positive balance of S by 25.1 and 22.5 kg S/ha/season, respectively (Table 6).

Like S, the apparent balance of Zn in soil was positive in treatments T_1 and T_2 where Zn fertilizer was applied according to the STB. The magnitude of Zn balance ranged from -0.12 (T_3) to 0.74 kg Zn/ha/season (T_1). The treatment (T_3) showed a negative balance of Zn (-0.12 kg/ha/season), because no additional Zn from chemical fertilizer was added. The application of STB fertilization (T_2) increased apparent Zn balance to 0.72 kg /ha/season (Table 6).

Conclusion

From the above discussion, it was observed that the treatment (T_2) i. e. K_{66} with STB dose produced the better yield of wheat (variety Protiva) in NW region of Bangladesh.

The highest gross return of Tk. 35,610/- and the highest net-return of Tk. 30,479/- was obtained with the treatment T_2 (STB).

It was observed that 1.0 t wheat straw (as oven dry basis) contained 14-16 kg K and 3-5 kg N and to produce 1.0 t grain of wheat (var. Protiva) needs 25 kg N, 4 kg P, 24 kg K, 3 kg S, and 0.07 kg Zn. Potassium application @ 66 kg K/ha was not enough for cultivating wheat in Old Himalayan Piedmont Plain (AEZ-1), and thus needs to be increased to maintain the soil K reserve, since there was an apparent negative balance of K in the soil with sole use of chemical fertilizers. The recommended P dose of 24 kg P/ha in wheat season created a positive balance of P. The STB dose for S and Zn @ 36 and 1 kg/ha, respectively in wheat season created a positive balance of S and Zn in soil.

References

Ahsan, K., M. A. Saleque, M.J.Abedin and N.J. Bhuiyan, 1997. Multiple year-response of wetland rice to potassium fertilizer and apparent potassium balance in soil. *Thai J. Agric. Sci.* **30:** 501-509.

Anonymous (1). Proj. 2. Crop and soil management http://www.Cimmyt.org/ Bangladesh/ publications/

Anonymous (2). Nitrogen use efficiency and management in different wheat genotypes under surface seeded condition in rice-wheat cropping system www.cimmyt.cgiar.org./Bangladesh/publications/NRS%20publications/smersol/ Atau rI.pdf.

Bardsley, C. E. and J. D. Lancaster. 1965. Sulphur. In: C. A. Black *et al.* (ed.) Methods of Soil Analysis. Agronomy 9, Part 2. American Society of Agronomy. Madison, Wisconsin, USA. 1102-1116.

Bray, R. H. and L. T. Kurtz. 1945. Determination of Total, Organic and Available Forms of Phosphorus in Soils. *Soil Sci.* **59:** 39-45.

Bremmer, J. M. 1960. Determination of nitrogen in soil by the Kjeldahl method. *J. Agric. Sci.* **55:** 11-33.

Halder N. K., M. A. Hossain, M. A. Siddiky, N. Nasreen and M. H. Ullah. 2007. Response of wheat varieties to Boron application in Calcareous Brown Floodplain Soil at Southern Region of Bangladesh. *J. Agron.* **6** (1): 21-24.

Hossain M. Ilias, C. Meisner, J. M. Duxbury, J. G. Lauren, M. M. Rahman, M. M. Meer and M. H. Rashid. 2004. Use of raised beds for increasing wheat production in rice-wheat cropping systems. http://www.cropscience.org.au/icsc2004/poster/1 /2/968hossaina.htm

IRRI. 1998. International Rice Research Institute Irristat for windows, Version 4.1, Biometrics unit, International Rice Res. Inst. Philippines.

Jackson, M. L. 1962. *Soil Chemical Analysis.* Prentice Hall, Inc., Englewood Cliffs, N. Jersey. USA.

Karim Z., S. M. Rahman, M. Idris and A. J. M. S. Karim.1988. A Manual for the Determination of Soil Physical Parameters. Bangladesh Agricultural Research Council. Farmgate, NewAirport Road, Dhaka- 1215. Publication No.31 pp 3-6.

Khaleque, M. A., N. K. Paul and C. A. Meisner. 2008. Yield and N use efficiency of wheat as influenced by bed planting and N application. *Bangladesh J. Agril. Res.* **33**(3): 439- 448.

Lindsay, W. L. and W. A. Norvell. 1978. Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Sci. Soc. Am.* **42:** 42 1-428.

Mohanty, S.K. and L. N. Mandal. 1989. Transformation and budgeting of N, P, and K in soils for rice cultivation. *Oryza.* **26:** 213-231.

Obaid-ur-Rahman, M. A. Zaka, H. U. Rafa and N. M. Hassan. 2006. Effect of balanced fertilization on yield and phosphorus uptake in wheat-rice rotation. *J. Agric. Res.* **44** (2): 105-114.

Page, A. L., R. H. Miller and D. R. Keeney. 1982. Methods of Soil Analysis Part 2. 2nd Ed. Am. Soc. Agron. Madison, Wisconsin, USA.

Panaullah G. M., J. Timsina, M. A Saleque, M. Ishaque, A. B. M. B. U. Pathan, D. J. Connor, P. K. Saha, M. A. Quayyum, E. Humphreys and C. A. Meisner. 2006. Nutrient uptake and apparent balances for rice-wheat sequences. III. *Potassium. J. Plant Nutrition* **29:** 173-187.

Saha, P. K., M. A. Saleque, G. M. Panaullah and N. I. Bhuiyan, 2001. Response of wheat to potassium in deep tube well project areas of north-western Bangladesh. *Bangladesh J. Agril. Res.* **26** (4): 613-617.

Saleque M. A, J. Timsina, G. M. Panaullah, M. Ishaque, A. B. M. B. U. Pathan, D. J. Connor, P. K. Saha, M. A. Quayyum, E. Humphreys and C. A. Meisner. 2006. Nutrient uptake and apparent balances for rice-wheat sequences. II. *Phosphorus. J. Plant Nutrition* **28:** 157-172.

Timsina, J., G. M. Panaullah, M. A. Saleque, M. Ishaque, A. B. M. B. U. Pathan, M. A. Quayyum, D. J. Connor, P. K. Saha, E. Humphreys and C. A. Meisner. 2006. Nutrient uptake and apparent balances for rice-wheat sequences. I. Nitrogen. *J. Plant Nutrition* **29:** 137-155.

Tiwari, K. N. 1985. Changes in potassium status of alluvial soils under intensive cropping. *Fertilizer News.* **30**(9): 17-24.

Yoshida, S., A. F. Douglas, J. H. Cock, K. A. Gomez. 1976. Laboratory Manual for Physiological Studies of Rice. IRRI, Los Banos, Laguna, Philippines, 14-18 and 27-34.