



Nutrient management productivity and nutrient-use efficiency in floodplain soils under maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping

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ABSTRACT

An experiment was conducted to evaluate the impacts of inorganic fertilizers applied either alone or conjointly with farmyard manure (FYM) on yield, nitrogen (N), phosphorus (P) and potassium (K)-use efficiency and economics of maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) cropping in floodplain soils. Farmers' field experiments were conducted at three locations with five treatments: absolute control (CK), farmers' practice (FP), recommended NPK (NPK), NPK+FYM and FP+FYM in maize and the same treatments were applied without FYM in wheat. Grain yield and nutrient (N, P and K) uptake increased significantly ($P < 0.05$) with fertilizer application; the highest uptake being in NPK+FYM and the lowest in the CK. Application of NPK+FYM significantly improved agronomic efficiency (AE), physiological efficiency (PE) and recovery efficiency (RE) of N, P and K, over NPK alone. Gross returns above fertilizer cost (GRAFC) increased with NPK+FYM applications, relative to NPK alone. Therefore, NPK+FYM applications could be used to enhance crop productivity and nutrient-use efficiency in these soils.

Key words: Economic efficiency, Gross returns, Nutrient uptake, Production efficiency, Reciprocal internal-use efficiency

Floodplains represent ~10% of the total geographical area of Punjab (NW-India), in which summer maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) are grown sequentially in maize-wheat cropping system. The productivity of maize and wheat in floodplains is relatively low (4.0–4.5 Mg/ha for maize and 3.0–4.0 Mg/ha for wheat) and relies on application of N and P fertilizers (Saini *et al.* 2012), although research has shown depletion of soil K. The harvested crops are removing an extra 9–10 MT of $N+P_2O_5+K_2O$ /yr over their total addition through fertilizers (Tandon 1995). Farmers' apply fertilizers based on their experience (Saini *et al.* 2012). To achieve higher yield, farmers apply higher amounts of N fertilizers in maize and wheat crops (Jia *et al.* 2014), while use of P and K is equally important (Saini *et al.* 2012). Imbalanced application leads to reduced nutrient-use efficiency and grain yield (Tang *et al.* 2008). Nitrogen-use efficiency of maize-wheat system is low (26–31%); a large amount of fertilizer N (₹ 180 kg/ha/yr) is lost to the environment (Miao *et al.* 2011). Continuous maize-wheat cropping without a balanced and efficient use of fertilizers results in yield losses (He *et al.* 2009), which reduces returns (Saini *et al.* 2012). Therefore, wheat-maize

cropping requires a careful management of nutrients for long-term sustainable production (Niu *et al.* 2013). Positive influence of applied organic sources on crop performance has been reported earlier (Singh *et al.* 2010, Saini *et al.* 2012). In most studies, effect of balanced and imbalanced use of fertilizers, applied either alone or together with manure has been investigated relative to the nutrient-use efficiency of a single nutrient (Hui-Min *et al.* 2011) and same on N-, P- and K-use efficiency under maize-wheat cropping has not been extensively investigated. Therefore, experiments at farmers' fields were conducted at three different locations to investigate the effect of inorganic fertilizers, either alone or conjointly with farmyard manure (FYM) on crop grain yield, nutrient-use efficiency and economics of crop production under the maize-wheat cropping system.

MATERIALS AND METHODS

The experiment was conducted at three farmer fields in recent floodplain areas in three villages, viz. Phool, Asalatpur and Rampur Fasse of Rupnagar, during 2011–13. Climate of district was typically sub-tropical, characterized by general dryness (except during the monsoon), a hot summer. Annual rainfall in the district varies from 650–1300 mm. Soil properties of the locations support good crop production.

Cropping sequence and treatments: The treatments include unfertilized control (CK), farmers' practice (FP), NPK, NPK+FYM and FP+FYM in a maize-wheat cropping system replicated thrice on a plot size (12–15 m long ×

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9–12 m wide). The CK plots were 4 m² (2 m × 2 m). The FYM at 15 Mg/ha (fresh weight, moisture=40%) was applied in respective treatments before sowing maize. Maize (var. PMH-1) was sown in rows (60 cm apart) with a plant-to-plant spacing of 20 cm. P and K at 60 kg P₂O₅ and 30 kg K₂O/ha, respectively, were applied at sowing. N was applied at 125 kg N/ha in three equal splits (one-third was applied at sowing, one-third at knee-high stage, and one-third at pre-tesseling stage). For the wheat crop, fertilizer P at 60 kg P₂O₅/ha as DAP + 60 kg N/ha (50% of recommended) + 30 kg K₂O/ha were applied at sowing. Second dose of 60 kg N/ha was applied with first irrigation. Wheat crop (var. DBW-17) was sown in first week of November in rows (22.5 cm apart) with seed-cum-fertilizer drill.

Collection of plant samples and analyses: N concentration in oven dried (50°C) grains and straw samples were determined via Micro-Kjeldahl method. The P concentration was estimated by digesting the samples in di-acid (HNO₃: HClO₄; 4:1) and K concentration via flame photometer.

Calculation of nutrient-use efficiencies: Agronomic efficiency (AE) of applied N, P and K was calculated from ratio of difference in grain yield between fertilizer-treated and control plot to amount of nutrient applied. Physiological efficiency (PE) was calculated from ratio of difference in grain yield between fertilizer treated plot and control plot to that of difference in nutrient uptake by grain+straw obtained from fertilizer-treated plot and CK. Recovery efficiency (RE) of applied nutrient was calculated from ratio of difference in uptake of nutrient by grain+straw from fertilizer-treated plot and CK to that amount of nutrient applied. Reciprocal internal-use efficiency (RIUE) of applied nutrients was calculated as the ratio of uptake of nutrient by grain + straw to the grain yield. Nutrient-use efficiency (NUE) was calculated as ratio of difference in uptake of nutrient by grain + straw from fertilizer-treated plot and CK to that of amount of nutrient applied (Liu *et al.* 2010).

Crop production efficiency and economic analysis: Production efficiency (ProE) was calculated for different fertilizer treatments by dividing the mean crop grain yield by crop duration (102.5, 99.5 and 103.5 days for maize and 147.5, 144 and 145.5 days for wheat at three locations). Economic efficiency (EE) was determined by dividing mean net returns (MNR, US\$/ha) from crop by crop duration. Mean cost of cash inputs (MCCI) was estimated as sum of expenditure incurred for the purchase of cash inputs (US\$/ha). Mean gross returns (MGR) were estimated as a product of grain yield (Mg/ha) and selling price (US\$/Mg) of produce (maize, wheat). Mean gross returns were estimated by using minimum support price (MSP) decided by Government of India for the year. The estimations were based on two-year mean MSP of US\$152.5/Mg of maize and US\$204.6/Mg of wheat. Mean net returns (MNR) were estimated as the difference in MGR and MCCI. Gross returns above the fertilizer cost (GRAFC) for maize (GRAFC_M) and wheat (GRAFC_W) crops were estimated as the difference in product of grain yield (Mg/ha) and price of grains (US\$/

Mg) and amount of N, P, K applied (kg/ha) and price of N, P, K (US\$/kg).

Statistical analysis: Statistical analysis was performed with SPSS for Windows 16.0 (SPSS Inc., Chicago, USA). Data were subjected to one-way analysis of variance (ANOVA) according to randomized complete block design (RBD). Mean separation for different treatments was performed using the Duncan's multiple range test (DMRT). Difference in treatment means at $P < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Crop yield and nutrient uptake: Relative to CK, fertilizer application significantly increased maize and wheat yield (grain and straw) (Table 1). The FP treatment increased maize and wheat yield by 1.63 and 1.18 Mg/ha, respectively, over the CK. The NPK increased grain yield of maize and wheat by 1.77 and 1.36 Mg/ha, respectively, over CK. Conjoint application of NPK+FYM increased the maize and wheat grain yield by ~9 and 6%, respectively, over NPK. Hui-Min *et al.* (2011) also reported that conjoint application of NPK and manure significantly increased grain yield of maize and wheat over NPK. In the present study, NPK+FYM application significantly increased grain yield over FP+FYM, showing that K application was responsible for yield increase. A 10–15% increase in maize grain yield with K over no-K application has been reported (Niu *et al.* 2011). Hui-Min *et al.* (2011) reported that compared with NP, NPK significantly increased wheat grain yield by 21% and maize by 16–72%.

Nutrient uptake in CK was the lowest among treatments (Table 1). Fertilizer application significantly increased nutrient uptake by crops. N, P and K uptake by grain and straw was significantly higher in NPK+FYM, compared with other treatments. In NPK+FYM, an uptake of 134 kg N, 36 kg P and 58 kg K/ha by above-ground maize crop produced a significantly higher grain yield (5.23 Mg/ha) than NPK. Similarly, uptake of 80–159 kg N, 13–28 kg P and 26–52 kg K/ha by wheat biomass is required to attain significantly higher wheat grain yield (4.64 Mg/ha) than NPK alone. Percent increase in N, P and K uptake from 104–113% occurred in maize and from 84–104% in wheat with fertilizer application, over CK (Table 1). Application of 240–275 kg N, 50.2–52.4 kg P and 60 kg K/ha/yr in maize-wheat cropping system could maintain a yield of 4.66–5.23 Mg/ha for maize and 4.19–4.64 Mg/ha for wheat. Zhao *et al.* (2009) reported a yield of 5.3–6.2 Mg/ha of wheat and 4.2–6.0 Mg/ha of maize could be obtained with application of 65.5 kg P/ha/yr. This comparison showed that floodplain soils need more P to achieve higher productivity of maize-wheat system.

Agronomic, physiological and recovery efficiency: AE_N varied between 11.9 and 18.3 kg/kg for maize and between 8.6 and 13.6 kg/kg for wheat (Table 2). The AE_N was the lowest in FP and the highest in NPK+FYM. FYM application significantly increased AE_N applied either alone or together with inorganic fertilizers. AE_P varied between 64.9 and

Table 1 Effect of different treatments on biomass yield, nutrient uptake and percent increase in nutrient uptake by maize and wheat grains grown in a cropping system

Treatment	Biomass yield (Mg/ha)		Nutrient uptake (kg/ha) by grain + straw		
	Grain	Straw	Nitrogen	Phosphorus	Potassium
<i>Maize</i>					
CK	3.03a† (0.03)‡	3.26a (0.04)	61a (1.27)	16a (0.18)	26a (0.31)
FP	4.66b (0.01)	5.28b (0.01)	101b (0.67)	26b (0.10)	45b (0.10)
NPK	4.80c (0.02)	5.53c (0.03)	108c (0.33)	28c (0.13)	48c (0.22)
NPK+FYM	5.23e (0.01)	5.94e (0.01)	134e (0.54)	36e (0.10)	58e (0.10)
FP+FYM	5.14d (0.01)	5.85d (0.01)	130d (0.25)	35d (0.06)	56d (0.10)
<i>Wheat</i>					
CK	3.01a (0.02)	3.18a (0.03)	80a (0.37)	13a (0.10)	26a (0.12)
FP	4.19b (0.02)	4.74b (0.03)	121b (0.70)	20b (0.11)	40b (0.23)
NPK	4.37c (0.01)	4.96c (0.01)	130c (0.25)	22c (0.06)	43c (0.08)
NPK+FYM	4.64e (0.02)	5.28e (0.01)	159e (0.40)	28e (0.10)	52e (0.11)
FP+FYM	4.54d (0.01)	5.19d (0.02)	155d (0.51)	28d (0.10)	50d (0.17)

†Values within a column for a crop, followed by different letters are significant ($P<0.05$) according to Duncan's multiple range test (DMRT). ‡Values in the parentheses indicate standard error from mean.

84.1 kg/kg for maize and between 46.9 and 62.2 kg/kg for wheat. NPK+FYM significantly increased AE_p by 24.2 and 19.8%, respectively, for maize and wheat over NPK alone. PE_N varied between 30.1 and 40.3 kg grains/kg N for maize and between 20.4 and 28.9 kg grains/kg N for wheat, and was in the range of 5.5–87.8 kg grain/kg N for maize and 12.3–95.7 kg grain/kg N for wheat (Liu *et al.* 2010). PE_N for maize and wheat was significantly lower in FP+NPK and NPK+FYM plots, compared with FP and NPK (Table 2). Similar to PE_N , PE_p and PE_K decreased significantly with NPK+FYM, compared with NPK alone. PE_p varying between 111 and 158 kg grains/kg for maize and between

106 and 176 kg grains/kg for wheat was lower than the PE_p of 214 kg grain/kg P for wheat and 240 kg grain/kg P for maize (Tang *et al.* 2008). RE_N varied between 29.1 and 61.0% for maize and 29.7 and 66.3% for wheat (Table 2). NPK+FYM increased RE_N by 55.2 and 59.1%, respectively, in maize and wheat over NPK alone. RE_N was higher by ~22% for NPK+FYM than for FP+FYM. Conversely, imbalanced application of fertilizer nutrients reduced RE_N . Under NPK application, RE_N reached 39–42%, suggesting that balanced fertilization could recover higher amounts of N fertilizers applied to soil, compared with imbalanced application. However, NPK+FYM application significantly

Table 2 Effect of different treatments on agronomic efficiency, physiological efficiency and recovery efficiency of nitrogen, phosphorus and potassium in maize-wheat system

Treatment	Agronomic efficiency (AE, kg/kg)			Physiological efficiency (PE, kg/kg)			Recovery efficiency (RE, %)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
<i>Maize</i>									
FP	11.9a† (0.24)	64.9a (1.33) ‡		40.3c (0.42)	158c (1.01)	87.8c (0.56)	29.1a (0.32)	40.6a (0.37)	
NPK	14.8b (0.43)	67.6a (1.99)	71.1a (2.09)	37.6b (0.18)	145b (0.78)	82.3b (0.44)	39.3b (0.29)	46.6b (0.38)	86.3a (0.48)
NPK+FYM	18.3d (0.35)	84.0b (1.60)	84.7b (1.57)	30.1a (0.26)	111a (0.83)	70.5a (0.39)	61.0d (0.36)	76.0c (0.42)	125.3b (1.22)
FP+FYM	15.3c (0.28)	84.1b (1.56)		30.7a (0.18)	112a (0.86)	72.3a (0.40)	50.2c (0.34)	75.3c (0.38)	
<i>Wheat</i>									
FP	8.6a (0.13)	46.9a (0.71)		28.9c (0.44)	176c (1.88)	83.1c (0.43)	29.7a (0.28)	26.7a (0.21)	
NPK	11.3b (0.17)	51.9a (0.76)	54.6a (0.80)	27.2b (0.36)	160b (1.79)	78.2b (0.40)	41.7b (0.34)	34.4b (0.26)	69.9a (0.51)
NPK+FYM	13.6d (0.17)	62.2b (0.79)	65.5b (1.36)	20.5a (0.27)	107a (1.33)	63.7a (0.32)	66.3d (0.42)	58.0c (0.38)	102.8b (1.89)
FP+FYM	11.1c (0.25)	60.2b (1.01)		20.4a (0.29)	106a (1.11)	64.8a (0.34)	54.5c (0.36)	57.4c (0.31)	

†Values within a column for a crop, followed by different letters are significant ($P<0.05$) according to Duncan's multiple range test (DMRT). ‡Values in the parentheses indicate standard error from mean.

increased RE_N by >20% over NPK alone (Table 2). RE_P varied between 40.6 and 76.0% in maize and 26.7 and 58.0% in wheat. RE_K varied between 86.3 and 125.3% in maize and 69.9 and 102.8% in wheat. RE_K for maize and wheat was significantly higher by 45.2 and 47.1%, respectively, with the application of NPK+FYM, compared with NPK alone. RE_K observed in the present study was much higher than that reported (39–40%) in China (Tan *et al.* 2012).

Reciprocal internal-use efficiency: $RIUE_N$ for maize varied between 19.8 and 25.8 kg/Mg grain yield, and 26.4 and 34.4 kg/Mg grain yield for wheat (Fig 1). $RIUE_P$ varied from 5.2–6.8 kg/Mg grain yield for maize, and from 4.3–6.1 kg/Mg grain yield for wheat. However, $RIUE_K$ varied between 8.7 and 11.0 kg/Mg grain yield for maize and 8.6 and 11.2 kg/Mg grain yield for wheat. For maize, the $RIUE_N$ was ~3.8-times higher than $RIUE_P$ and 2.3-times higher than $RIUE_K$. However, for wheat $RIUE_N$ was 5.9 and 2.3-times higher than $RIUE_P$ and $RIUE_K$. Amount of N and P required to produce 1 Mg of crop grain was lowest with NPK+FYM application, and highest in FP. The FP+FYM and NPK+FYM treatments decreased the amount of nutrients required to produce 1 Mg grains, compared with inorganic fertilizer applied plots. $RIUE$ increased with increase in grain yield, indicates that amount of nutrient uptake increased

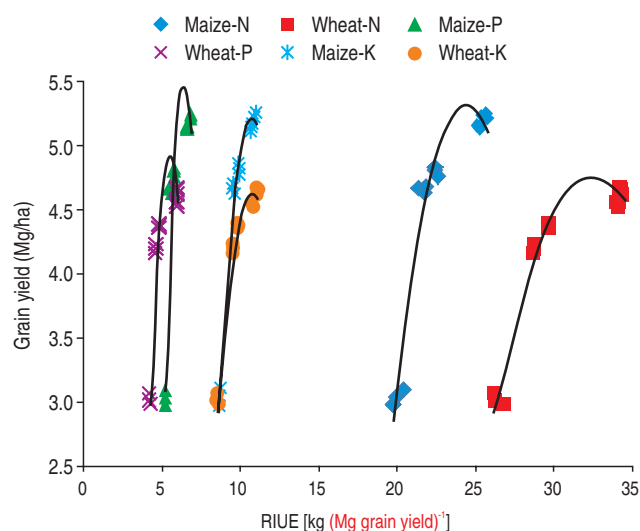


Fig 1 Relationship between reciprocal internal use efficiency ($RIUE$) of nitrogen, phosphorus and potassium and grain yield of maize and wheat (Data pooled for two years).

with grain yield. In the present study an estimated average $RIUE_N$, $RIUE_P$ and $RIUE_K$ of 23.0, 6.0 and 10.1 kg/Mg grain yield for maize was within the range reported for south-east Asia and Nebraska (Setiyono *et al.* 2010).

Table 3 Effect of fertilizer application on production efficiency, economic efficiency, mean cost of cash inputs, gross returns, net returns, benefit:cost ratio and gross returns (in US\$/ha) above the fertilizer cost for maize-wheat system (data pooled for two years)

Treatment	Production efficiency (kg/ha/d)	Economic efficiency (US\$ ha/d)	Mean cost of cash inputs (MCCI) †	Mean gross returns (MGR) ‡	Mean net returns (MNR)§	Benefit-cost ratio (B/C)
<i>Maize</i>						
CK	29.8a*	20.7a	182.4	462.1	279.9	1.53
FP	45.7b	29.3b	227.5	695.4	467.9	2.05
NPK	47.1c	29.4b	230.2	732.0	501.8	2.18
NPK+FYM	51.3d	31.6c	250.2	797.6	547.4	2.19
FP+FYM	50.0d	31.4c	247.5	783.9	536.4	2.17
<i>Wheat</i>						
CK	2.87a	2.95a	186.4	617.8	431.4	2.31
FP	4.80b	4.34b	231.5	857.2	625.7	2.75
NPK	4.95b	4.52b	234.2	894.0	659.8	2.82
NPK+FYM	5.46c	4.91c	234.2	947.2	713.0	3.04
FP+FYM	5.40c	4.83c	231.5	928.8	697.3	3.01
	GRAFCM♦	GRAFCW♥	GRAFCCSΔ			
FP	689	828	1518			
NPK	701	851	1552			
NPK+FYM	785	894	1679			
FP+FYM	786	882	1668			

†, ‡, § MCCI, MGR and MNR were computed by converting Indian Rupee (INR₹) to United States Dollar (US\$), considering 1US\$=60 INR ₹*Values within a column for a crop, followed by different letters are significant ($P < 0.05$) according to Duncan's multiple range test (DMRT). ♦GRAFCM=Gross returns (US\$/ha) above the fertilizer cost for maize crop, ♥GRAFCW=Gross returns (US\$/ha) above the fertilizer cost for wheat crop, ΔGRAFCCS=Gross returns (US\$/ha) above the fertilizer cost for maize-wheat cropping system as a whole.

Production efficiency and economic evaluation of different treatments: ProDE varied between 29.8 and 51.3 kg/ha/d for maize and 20.7 and 31.6 kg/ha/d for wheat (Table 3). Application of NPK+FYM to maize significantly increased the ProDE by 4.2 kg maize grain/ha/d (~9%) over NPK alone. MCCI for maize varied between US\$182.4 and US\$ 250.2/ha and produced MGR of US\$ 462.1 and US\$ 797.6/ha (Table 3). In wheat, MCCI varied between US\$ 186.4/ha and US\$ 234.2/ha, producing MGR of US\$ 617.8/ha and US\$ 947.2/ha. MNR from maize and wheat crops were highest in NPK+FYM. B:C ratio was also higher in NPK+FYM compared with other treatments. In maize, application of NPK+FYM and FP+FYM resulted in ~12–14% higher GRAFC_M than FP and NPK alone (Table 3). An increase of ~5% in GRAFC_W for wheat was observed in NPK+FYM, compared with NPK alone. For the cropping system, GRAFC_{M+W} were higher by ~8–10% with conjoint application of inorganic fertilizers and FYM, compared with inorganic fertilizers alone. The EE for maize and wheat production was significantly higher for NPK+FYM and FP+FYM plots, compared with FP and NPK (Table 3).

Because of higher grain yield from applied fertilizers either alone or conjointly with FYM in maize than wheat, maize could be given priority over wheat while determining nutrient management strategies. Application of 240–275 kg N, 50.2–52.4 kg P and 60 kg K/ha/yr in a maize-wheat cropping system maintained 4.66–5.23 Mg maize grain yield/ha and 4.19–4.64 Mg wheat grain yield/ha. Estimates revealed that 23 kg N, 6 kg P and 10 kg K for maize and 30.6 kg N, 5.2 kg P and 10 kg K for wheat would be required per Mg of grain yield.

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