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Response of crop residue incorporation on Partial factor productivity, recoveries and efficiencies of applied nutrients under maize-wheat cropping system

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Abstract
An experiment was conducted in farm area of Soil Science and Agricultural Chemistry, Birsa Agricultural University, Ranchi, to study the indigenous nutrient supply from nutrient omission plots with and without incorporation of crop residues and their response on partial factor productivity, recoveries and efficiencies of applied nutrients under maize-wheat cropping system. The experiment comprising five treatments with and without crop residues incorporation, replicated four times in a RBD. The results revealed that Partial Factor Productivity of applied N, P & K under maize – wheat cropping system, for SSNM treatment was 37.88 and 35.19, 78.14 and 72.58 & 78.14 and 72.58 kg grain yield per kg N, P and K applied, which was higher than that of NPK treatment (34.57 and 33.01, 60.11 and 57.40 & 62.85 and 60.01 kg grain yield per kg N, P and K applied) with and without incorporation of crop residues, respectively. The agronomic use efficiency of applied N was higher (25.11 - 25.64 kg increase in grain yield per kg applied N) than applied P (24.69 – 27.43 kg increase in grain yield per kg applied P) and followed by applied K (15.77 – 20.34 kg increase in grain yield per kg applied K) in maize-wheat cropping system with and without incorporation of crop residues. With the incorporation of crop residues the nutrient internal use efficiency increased by 3% in wheat but there was not effect of residue incorporation on N internal use efficiency of maize and maize-wheat cropping system. Apparent recovery efficiency of applied N in maize, wheat and maize-wheat cropping system (61.54 – 62.16, 45.97 – 56.87 and 55.64 – 63.15 kg N taken up per kg N applied) was higher than applied P (9.16 – 12.43, 9.58 – 10.45 and 7.83 – 8.57 kg P taken up per kg P applied) and followed by K (84.24 – 89.79, 56.45 – 67.28 and 38.05 – 49.57 kg K taken up per kg K applied).

Keywords: Agronomic use efficiency, apparent recovery efficiency, n internal use efficiency, partial factor productivity

Introduction

Cereals constitute the staple food in India, and only 61% of the total protein requirement of the Indian population is met through cereals. They use about 63% of the total fertilizer consumed in India, of which rice, wheat and maize use 37, 24, and 2% of the total, respectively (Chanda, 2008) [2]. Cereals are grown under variable conditions (i.e. soil types, cropping systems, agro-ecological regions, etc.). Such variability in land characteristics and growing environments is reflected in the productivity (attainable yield) and subsequently in nutrient requirement by these crops. This necessitates the integration of crop response data with fertilizer decision support for increased productivity, higher economic returns, and better environmental stewardship.

Maize and Wheat two major cereals crops hold prominent position in the Indian agriculture covering 9.38 and 29.65 million hectares area under cultivation with annual production of 28.76 and 98.87 mt, respectively (Economic Survey, 2017-18) [3]. In India the productivity of both maize (30.65 q/ha) and wheat (33.38 q/ha) is substantially lower than countries like China, UK, USA and Australia (Economic Survey, 2017-18) [3]. In N, P and K deficient soils both yield and quality of the crop is poor. The inclusion of these nutrients is essential in the fertilization schedule for higher productivity. Thus, N, P and K have become a key nutrient for light textured soil. Neglecting these nutrients lead to lower yield and inferior crop quality. There are indications of stagnation or even decline in the productivity of this cropping system due to decline in soil organic matter, over mining of nutrient reserve, loss of nutrients and non-availability of cost effective fertilizers. Further, the application of inorganic fertilizers even in balanced form may not sustain soil fertility under continuous cropping.

Fertilizer requirements of cereal crops depend mainly on two things: the initial fertility status of the soil and the targeted yield of the farmer. Soils of low fertility status require more fertilizer as do higher yield targets. At each harvest, nutrients taken up from the soil by the growing crop are exported from the field in the form of grain or stover, further depleting the productive capacity of the soil.

The importance of maize and wheat production is very much relevant for food, fodder and nutritional security in Jharkhand. Crop residues bearing about 25 % of N & P, 50 % of S and 75 % of K uptake by cereal crops are retained in crop residues (Singh *et al.*, 2018; Xu *et al.* 2010) [16, 19]. The incorporation of crop residues has been proven as an effective sources in terms of reducing nutrient inputs (Ma *et al.*, 2003) [7], especially potassic fertilizers. Therefore, residue retention should be strongly recommended in crop production (Wu *et al.*, 2002) [18] and to maintain soil health. The recycling of crop residues has the advantage of converting the surplus farm waste into useful product for meeting nutrient requirement of succeeding crops. This paper summarizes state-of-knowledge on the effects of nutrients and residue management practices on potassium dynamics in maize-wheat based cropping systems in Jharkhand. Maize – wheat is the 3rd most important cropping system in India and 2nd most important in Jharkhand. Soils of Jharkhand (Alfisol) are acidic in reaction, low in availability of nitrogen and phosphorus, medium to high in potassium and poor in water retention capacities, due to sandy loam texture. Alfisols are abundant in Fe, Al and Mn which creates nutrient imbalance in the soil resulting in the deficiency of certain plant nutrients. Both the crops are fertilizer responsive and exhibit their full potential when supplied adequate quantities of nutrients. But poor Economic resource of the Jharkhand Farmers are compel to go for imbalance fertilization that leading to deteriorate soil fertility. Cropping system involving cereal after cereal leads to mining of nutrient from the soil which deteriorates the soil health.

Crop growth is dependent on sufficient supply of each nutrient, and yield is limited by the nutrient in shortest supply. The nutrients most commonly limiting plant growth are N, P, K and S. Hence, improvement of NUE (Nutrient Use efficiency) is an essential pre-requisite for expansion of crop production into marginal lands with low nutrient availability. A review of worldwide data on N use efficiency for cereal crops from researcher-managed experimental plots reported that single-year fertilizer N recovery efficiencies averaged 65% for corn and 57% for wheat (Ladha *et al.*, 2005) [6].

The formulation of fertilizer recommendations tailored to specific crops, climate and soil fertility conditions, as well as farmers' socioeconomic status can increase productivity, and reduce climate-related production risks and undesirable impacts of fertilizer on the environment. The agronomic, recovery and internal efficiencies of N, P and K use: Agronomic efficiency (AE) is calculated in units of yield increase per unit of nutrient applied. It more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return. The calculation of AE requires knowledge of yield without nutrient input, so is only known when research plots with zero nutrient input have been implemented on the farm. It is estimated to know, how many times productivity improvement was gained by use of nutrient input? (Fixen *et al.*, 2014) [4].

The fertilizer N needed by a cereal crop to achieve a profitable target yield is determined from the anticipated yield gain to application of fertilizer N and a targeted efficiency of fertilizer N use to attain the targeted yield. The yield gain is the increase in grain yield due to fertilizer N, which is the difference between the target yield and yield without fertilizer N. Only a fraction of the fertilizer N applied to a cereal is taken up by the crop. Hence, the total amount of fertilizer N required for each tonne of increase in grain yield depends on the efficiency of fertilizer N use by the crop, which is defined as agronomic efficiency of fertilizer N (AEN) — the increase in yield per unit of fertilizer N applied. Partial factor productivity (PFP) is a simple production efficiency expression, calculated in units of crop yield per unit of nutrient applied. It is estimated to know, how much productive is this cropping system in comparison to its nutrient input?. Apparent recovery efficiency (RE) is one of the more complex forms of NUE expressions and is most commonly defined as the difference in nutrient uptake in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied. It is often the preferred NUE expression for studying the nutrient response of the crop. Like AE, it can only be measured when a plot without nutrient has been implemented on the site, but in addition requires measurement of nutrient concentrations in the crop. It is measured to estimate, how much of the nutrient applied did the plant take up? (Fixen *et al.*, 2014) [4].

The main objective of this study was to evaluate soil nutrient constraints for maize-wheat cropping system to use this for the calibration and validation of application of applied nutrients. The study specifically sought to: (i) estimate maize yield response to nutrients supplied from fertilizers and calculates agronomic use efficiencies of N, P and K, (ii) calibrate efficiencies and recoveries of applied nutrients under maize-wheat cropping system.

Materials and Methods

An experiment was conducted in farm area of Soil Science and Agricultural Chemistry, Birsa Agricultural University, Ranchi, during *Kharif* and *Rabi* season of the year 2016-17 and 2017-18 to study the indigenous nutrient supply from nutrient omission plots with and without incorporation of crop residues and their response on partial factor productivity, recoveries and efficiencies of applied nutrients under maize-wheat cropping system.

The experimental area comes under Agro-climatic Zone V, situated at latitude of $23^0 19^{'}$N and longitude $83^0 17^{'}$E with an altitude of 625 metre above MSL and the climate of this region is subtropical with hot and dry summer, comparatively cool in rainy season fallowed by moderate winter. The region receives rainfall from both the streams of monsoon *i.e.* South–West monsoon and North–East monsoon. There was about 1276 mm and 1602 mm rainfall, respectively, during 2016-17 and 2017-18 in 47th weeks.

The soil was sandy loam in texture, pH, organic carbon, available N, P and K content of experimental sites were varied from 5.35-5.73, 2.8-4.1 g/kg, 173-238, 13-31 and 118-258 kg/ha, respectively. Each plot was divided into two equal parts before sowing of crops. In one part, straw (maize/wheat) (which was obtained from that plot during last crop) was incorporated along with chemical fertilizer and in another part, only chemical fertilizer was applied as per treatments.

Altogether there were comprising five treatments with and without crop residues incorporation, replicated four times in a Randomized Block Design (Factorial) to give a total of 40 experimental units. The experiment consisted of five treatments including: T1 - ample NPK (250: 120: 120 kg/ha), T2 - omission of N with full P and K (-N = 0: 120: 120 NPK kg/ha), T3 - omission of P with full N and K (-P = 250: 0: 120 NPK kg/ha), T4 - omission of K with full N and P (-K = 250: 120: 0 NPK kg/ha) & T5 - SSNM (200: 90: 100 NPK kg/ha) for maize in kharif season. The corresponding treatments for wheat in rabi season were (T1= NPK) 150: 110: 100 kg/ha, (T2 = -N) 0: 110: 100 NPK kg/ha, (T3 = -P) 150: 0: 100 NPK kg/ha, (T4 = -K) 150: 110: 0 NPK kg/ha and (T5 = SSNM) 120: 70: 60 NPK kg/ha. The recommended fertilizer dose for maize crop was treated as NPK (250:120:120) and SSNM (200:90:100), while wheat was shown in the same plots of Kharif with different dose of NPK (150:110:100) and SSNM (120:70:60). The sources of N, P, and K were urea, single super phosphate and muriate of potash, respectively. The application of nitrogen and potash in maize crop was applied as a base and V_4 stage (consist four leaves) in two splits while in wheat was also completed in two splits (50% basal + 50% Crown root initiation stage) as per the treatments. The maize hybrid used was Pioneer- 3377 with a planting geometry of 70 x 18 cm^2 and the wheat variety was K-307 with a spacing of 30 x 10 cm^2. Soil samples from the plots of each treatments and replication were collected at depth 0-15 cm.

Then nutrient rate in the ample NPK treatment was based on published nutrient uptake values for maize and nutrient use efficiencies in the soil (Setiyono *et al.*, 2010) [12]. All the recommended agronomic practices were followed for raising maize and wheat grown in a system. Grain and straw yields at harvest were recorded and samples were analyzed for total N, P and K to calculate crop uptake of nutrients.

Agronomic efficiency of N by the cropping system was calculated as described by Cassman *et al.* (1998) [1].

Agronomic efficiency (AE) Agronomic Efficiency of applied N, P and K were computed by using the expression:

$$\text{Agronomic Efficiency of applied N (kg/ha)} = \frac{GY_N - GY_0}{FN}$$

(kg grain yield increase per kg N applied)

Where,
GY_N = Grain yield in N applied plot
GY_0 = Grain yield in (-N) plot
FN = Fertilizer N applied in kg/ha.

Similarly, agronomic efficiency of P and K were calculated.

Partial factor productivity (PFP) Partial factor productivity (PFP) of applied N, P and K were computed by using the expression:

$$\text{PFP of applied N} = \frac{GY_N \text{ (grain yield in a treatment with N application)}}{FN \text{ (amount of fertilizer N applied in kg/ha)}}$$

(kg grain yield per kg N applied)

Partial factor productivity of P and K was calculated in the same way.

Apparent recovery efficiency (RE)
Apparent Recovery Efficiency (ARE) of applied N was computed by using the expression:

$$\text{ARE of applied N} = \frac{\text{(Total N uptake by crop with N – Total N uptake by crop without N)}}{\text{Dose of Nitrogen}} \text{ X 100}$$

Physiological Efficiency of applied N

$$\text{Physiological Efficiency of applied N} = \frac{(GY_N - GY_0)}{(UN_N - UN_0)}$$

(kg grain yield increase per kg fertilizer N taken up)
Where,
GY_N = Grain yield in N applied plot
GY_0 = Grain yield in (-N) plot
UN_N = Total plant N accumulations measured in aboveground biomass at physiological maturity (kg/ha) in plots that received N
UN0 = Total N accumulation % in (-N) plot.

Internal Efficiency of N
Internal Efficiency of N was computed by using the expression:

$$\text{Internal Efficiency of N (kg grain yield per kg N taken up)} = \frac{GY_N}{UN_N}$$

Where,
GY_N = Grain yield in N applied plot
UN_N = Total plant N accumulations measured in aboveground biomass at physiological maturity (kg/ha) in plots that received N

Results and Discussion
Partial factor productivity of applied nutrients
Partial Factor Productivity of applied N, P and K under NPK and SSNM treatment in maize-wheat cropping system is presented in Table-1. Partial factor productivity of applied nutrient is kg grain yield per kg N nutrient applied. Partial Factor Productivity of applied N was 30.30 & 29.15, 34.32 & 32.47 and 34.57 & 33.01 kg grain yield per kg N applied in maize, wheat and maize-wheat cropping system with and without incorporation of crop residues, respectively. Partial Factor Productivity of applied P & K was higher in maize (60.73 and 63.13 & 60.73 and 63.13 kg grain yield per kg P & K applied) than that of wheat (46.80 and 44.27 & 51.48 and 48.70 kg grain yield per kg P and K applied). Partial Factor Productivity of applied N, P & K under maize – wheat cropping system, for SSNM treatment was 37.88 and 35.19, 78.14 and 72.58 & 78.14 and 72.58 kg grain yield per kg N, P and K applied, which was higher than that of NPK treatment (34.57 and 33.01, 60.11 and 57.40 & 62.85 and 60.01 kg grain yield per kg N, P and K applied) with and without incorporation of crop residues, respectively. Reduction in partial factor productivity for N has been reported in cereal based system, might be higher investment in N to maintain higher yields. Decline in partial factor productivity for N may be attributed to nutrient imbalance, decline in indigenous soil N supply, subsoil compaction, reduced root volume and increased incidence of pests and diseases (Karim and Ramasamy, 2000) [5].

Table 1: Partial factor productivity of applied N, P, K with NPK and SSNM treatments in Maize-wheat sequence

Parameters	Maize		Wheat		Maize-Wheat Cropping System	
	With CR	Without CR	With CR	Without CR	With CR	Without CR
Partial factor productivity of applied N (NPK)	30.30	29.15	34.32	32.47	34.57	33.01
Partial factor productivity of applied P (NPK)	60.73	63.13	46.80	44.27	60.11	57.40
Partial factor productivity of applied K (NPK)	60.73	63.13	51.48	48.70	62.85	60.01
Partial factor productivity of applied N (SSNM)	30.20	32.68	40.95	38.23	37.88	35.19
Partial factor productivity of applied P (SSNM)	67.11	72.61	70.20	65.54	78.14	72.58
Partial factor productivity of applied K (SSNM)	60.40	65.35	81.90	76.47	78.14	72.58

SSNM = Site Specific Nutrient Management

Efficiencies of applied nutrients

Agronomic efficiency of applied N, P and K, Physiological efficiency of applied N and Internal efficiency of applied N in maize-wheat cropping system is presented in Table-2. The nutrient needed by a cereal crop to achieve a profitable target yield could be determined from the anticipated yield gain to application of nutrient and a targeted efficiency of nutrient use to attain the targeted yield. The yield gain is the increasing grain yield due to nutrient N, P& K which is the difference between the target yield and yield without nutrient N, P & K. Only a fraction of the nutrient applied to a cereal is taken up by the crop. Hence, the total amount of fertilizer N required for each tonne of increase in grain yield depends on the efficiency of nutrient use by the crop, which is defined as agronomic efficiency of nutrient the increase in yield per unit of nutrient applied. The agronomic use efficiency of nutrient N, P and K (AEN, AEP and AEK), is the increase in yield per unit of N, P and K applied, is used as the measure of the efficiency of nutrient N, P and K use. Results showed that agronomic efficiency of applied N was higher (25.11 - 25.64 kg increase in grain yield per kg applied N) than agronomic efficiency of applied P (24.69 – 27.43 kg increase in grain yield per kg applied P) and agronomic efficiency of applied K (15.77 – 20.34 kg increase in grain yield per kg applied K) in maize-wheat cropping system with and without incorporation of crop residues, it seems might be due to organic inputs result in far lower NUEs than does mineral fertilizer, which by its application in two top-dressings aligns better with crop absorption dynamics (Piccoli *et al.*, 2020) [11]. This result is confirmed by Yadvinder-Singh *et al.* (2009) [20] was revealed that lowest agronomic use efficiency of nutrient N, P & K in the straw incorporation treatment. Agronomic efficiency of applied K was higher (24.98 and 27.85 kg increase in grain yield per kg applied K) than agronomic efficiency of applied P and agronomic efficiency of N in with and without crop residue incorporated plot.

Higher agronomic efficiency of potassium due to the continuous addition of crop residue (since crop residue contain nearly to 75% to 80% potassium) (Singh *et. al.*, 2018). Improved crop residue and organic waste management aids in avoiding K depletion (Singh *et. al.*, 2004; Oborn *et al.*, 2005) [13, 10]. Furthermore, crop K requirements could be improved by retention of crop residue (Singh *et. al.*, 2010; Singh *et. al.*, 2018) [15, 16] further improving K use efficiency (KUE).

Crop physiological N requirements are controlled by the efficiency with which N in the plant is converted to biomass and grain yield. Because cereal crops are harvested for grain, the most relevant measure of physiological N efficiency (PEN) is the change in grain yield per unit change in N accumulation in aboveground biomass.

Physiological efficiency of applied N of wheat (41.69 – 50.34 kg grain yield increase per kg fertilizer N taken up) was higher than that of maize (36.89 – 37.93 kg grain yield increase per kg fertilizer N taken up) with and without incorporation of crop residues. The relationship between grain yield and the N contained in aboveground biomass at physiological maturity provides a measure of PEN across a wide range of production environments. Similar results have been reported by Meena *et al.* (2018) [8].

The nutrient internal use efficiency is defined as amount of grain yield produced per unit of nutrient taken up by the plant (Yang *et. al.* 2003, Naklang *et. al.* 2006) [21, 9]. The nutrient internal efficiency is closely related to nutrient utilization and incorporation efficiency in the plant and depends on both the potential of plant productivity and all the factors related to plant nutrition processes (absorption, transport, metabolism, distribution) on plant growth (Wilson *et al.* 2004) [17]. The N internal use efficiency of maize, wheat and maize-wheat cropping system was (39.14 & 40.54), (46.59 & 50.73) and (87.93 & 95.84) with & without incorporation of crop residues. Similar findings of the internal use efficiency of N, P, and K were observed by Zhao *et al.* 2015 [22]. With the incorporation of crop residues the nutrient internal use efficiency increased by 3% in wheat but there was not effect of residue incorporation on N internal use efficiency of maize and maize-wheat cropping system.

Table 2: Efficiency of Nutrient use (%) as affected by residue incorporation and Nutrient use in Maize- Wheat sequence

Parameters	Maize		Wheat		Maize-Wheat Cropping System	
	With CR	Without CR	With CR	Without CR	With CR	Without CR
Agronomic Efficiency of Applied N	22.93	23.34	14.91	23.09	25.64	25.11
Agronomic Efficiency of Applied P	24.25	21.36	25.45	23.32	27.43	24.69
Agronomic Efficiency of Applied K	24.98	27.85	9.33	3.89	15.77	20.34
Physiological Efficiency of Applied N	36.89	37.93	41.69	50.34	81.21	90.26
Internal Efficiency of N (kg/kg)	39.14	40.54	46.59	50.73	87.93	95.84

Recoveries of applied nutrients

Apparent Recovery Efficiency of applied N, P and K is presented in Table-3. Recovery efficiency is the proportion of applied N fertilizer that is taken up by the crop and is determined by the difference in the total amount of N measured in aboveground biomass at maturity in replicated plots that receive N fertilizer and a control plot without applied N. Apparent recovery efficiency of applied N in maize, wheat and maize-wheat cropping system (61.54 – 62.16, 45.97 – 56.87 and 55.64 – 63.15 kg N taken up per kg N applied) was higher than Apparent recovery efficiency of applied P (9.16 – 12.43, 9.58 – 10.45 and 7.83 – 8.57 kg P taken up per kg P applied) and K (84.24 – 89.79, 56.45 – 67.28 and 38.05 – 49.57 kg K taken up per kg K applied).

Table 3: Recovery of nutrients under maize-wheat sequence

Parameters	Maize		Wheat		Maize-Wheat Cropping System	
	With CR	Without CR	With CR	Without CR	With CR	Without CR
Apparent Recovery of Applied N	62.16	61.54	56.87	45.97	63.15	55.64
Apparent Recovery of Applied P	9.16	12.43	9.58	10.45	7.83	8.57
Apparent Recovery of Applied K	84.24	89.79	67.28	56.45	49.57	38.05

Conclusion

The findings revealed that the Partial Factor Productivity of applied N, P and K under maize – wheat cropping system, for SSNM treatment was higher than that of NPK treatment kg grain yield per kg N, P and K applied with and without incorporation of crop residues, respectively. Agronomic efficiency of applied N was higher than applied P and followed by applied K in maize-wheat cropping system with and without incorporation of crop residues. With the incorporation of crop residues the nutrient internal use efficiency increased by 3% in wheat but there was not effect of residue incorporation on N internal use efficiency of maize and maize-wheat cropping system.

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