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Yield trends and changes in physico-chemical properties of soil in maize-wheat cropping system under integrated nutrient management

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Abstract

Aim: Integrated use of organic and inorganic fertilizers has better effects on crop growth and yield components of crop as well as soil health than alone. The main objective of the study was to find out the impact of integrated nutrient management on yield and soil health in maize-wheat cropping system.

Methodology: The maize crop was harvested when cob sheath turned brownish and grains became hard and grains were separated from cobs by hand shelling. When wheat crop matured and dry plants from net plot area were harvested and threshing was done by using wheat thresher and expressed as t ha⁻¹. The soil samples were collected from different plots of the experimental field and were analysed for physical (bulk density, hydraulic conductivity) and chemical (organic carbon, available N, P and K) properties. Infiltration rate was measured at the experimental field with the help of double ring infiltrometer.

Results: Addition of NPK fertilizer along with organic manure and biofertilizers improved yield and increased organic carbon content, available N, P, K and infiltration rate and hydraulic conductivity of the soil while reducing bulk density. Application of 50% recommended dose of fertilizer + 50% recommended dose of nitrogen produced significantly higher maize grain yield and significantly higher wheat grain yields were recorded with the application of 100% recommended dose of fertilizer over control. Lowest bulk density, highest hydraulic conductivity and infiltration rate were recorded with the application of 37.5% recommended dose of fertilizer + 37.5% recommended dose of nitrogen + biofertilizer to wheat. Application of 50% recommended dose of fertilizer + 50% recommended dose of nitrogen to maize and application of 37.5% recommended dose of fertilizer + 37.5% recommended dose of nitrogen + bio fertilizer to wheat resulted in increased available N by 10.2, 19.6% and 15.5, 26.2%, available P by 13.7, 20.4% and 17.1, 33.2%, available K by 5.1, 7.6% and 6.4, 10.7% and organic carbon by 3.1, 7.3% and 4.3, 12.5% over control during 2011 and 2012, respectively.

Interpretation: Grain yield, soil physical and chemical properties was found to be affected by the integrated nutrient management. It can be concluded that integrated use of crop residue mixed farmyard manure and inorganic sources of nutrients along with biofertilizers proved better nutrient management option for higher yield, soil health and net returns from maize-wheat cropping system.

Introduction

Maize (*Zea mays*), is the world's third most important cereal crop after wheat and rice. It is cultivated with different crop sequence under various agro climatic regions of the country. Hence, it is considered as potential driver of crop diversification under different situations (Jat *et al.*, 2011). Wheat is the most important cereal crop of the world. It is the staple food of different countries of the world. With the existing rice-wheat system there is emerging challenges of natural resource-base degradation, declining crop productivity and ecological problems, the maize based cropping systems are emerging as an alternative option for diversification of rice-wheat and rice-rice production systems in south- Asian Indo-Gangetic Plains Region (IGPR). Among different maize-based cropping systems, maize-wheat cropping system ranks first (Jat *et al.*, 2011). Wheat and rice residues are usually burnt on large scale in field to save labour and to enable tillage and seeding machinery to work efficiently in order to sow the next crop without loss of time.

Burning of these residues causes environmental pollution due to emission of toxic and greenhouse gases and lowers the soil biological activity. Under prevailing high temperature due to global warming, direct application of wheat residue in field is not possible. The alternative means to utilize these large quantities of nutrients-rich biomass and to recycle them back to the field is to convert them into a value added product known as compost. Composting is recognized as an economical and suitable option for waste management, as it is easy to undertake and can be conducted at the local site of the produce (Singh and Amberger, 1998).

The application of well decomposed farmyard manure (FYM) to soil has been practiced for many centuries for increasing crop yield, soil organic matter, microbiological activities and improving soil fertility and soil structure for sustainable agriculture for long time (Blair *et al.*, 2005; Kundu *et al.*, 2006). However, proper combination of both organic and inorganic fertilizers have better effects on crop growth and development and yield component of crop than alone (Budaruddin *et al.*, 1999; Hossain *et al.*, 2002; Manna *et al.*, 2005), due to excess and imbalanced use of nutrients and continuous nutrient mining from the soil deteriorated crop productivity and ultimately soil health. Integrated nutrient management system is conceived with least impact on food quality, as well as environment.

The existing nutrient management practices are mainly based on individual crop and in fact there is meager information about maize-wheat cropping system. Information related to yield and soil physical and chemical properties, appropriate integrated nutrient management strategy for maize-wheat cropping system is lacking. Therefore, an attempt was made to examine the impact of integrated nutrient management on the performance of maize-wheat cropping system.

Materials and Methods

The field experiments were conducted during *kharif* and *rabi* 2011-12 and 2012-13 at the Research Farm of Indian Agricultural Research Institute, New Delhi. The soil of the experimental site was sandy clay loam in texture having 61.7% sand, 11.4% silt and 26.9% clay with bulk density of 1.6 g cc^{-1} , field capacity of 17.6 % (w/w) and infiltration rate of 1.3 cm hr^{-1} . The experimental soil was low in organic carbon content (0.39%) and KMnO_4 oxidizable available N (163.1 kg ha^{-1}), medium in phosphorus (0.5 N NaHCO_3 extractable available P 13.4 kg ha^{-1}) and fairly high in ammonium acetate extractable potassium ($1.0 \text{ N NH}_4\text{OAc}$ exchangeable available K 235.1 kg ha^{-1}) slightly alkaline in nature (pH 7.8) with electrical conductivity of 0.42 dS m^{-1} . The meteorological data of experimental period was recorded by meteorological observatory of the Indian Agricultural Research Institute, New Delhi. The climate of experimental site is semi-arid and sub-tropical, characterized by hot dry summer (May-June) and cold winters (Dec-Jan). June is the hottest month of the year with mean maximum temperature of 38.2°C and 42.8°C , while January is the coldest month of the year with mean minimum temperature of 18.5°C and 17.6°C during 2011-12 and 2012-13, respectively. The daily maximum and minimum temperature tend to rise from first fortnight of February and remained same till June. Total annual precipitation was 581.4 mm during 2011-12 and during 2012-13 it was 670.5 mm. Total precipitation was higher in the month of August (224.4 mm and 228.4 mm) during both the years, respectively. The mean relative humidity attained the maximum value (91 % and 92 %) in January during 2011-12 and 2012-13, respectively.

The experiment was laid out in randomised block design (RBD) during first year of maize and in factorial randomised block design (FRBD) in successive crops with three replications, consisting of five different treatments in rainy and winter season, each comprising twenty five treatment combinations. For maize crop five treatments were applied viz. MT_1 - Control (No NPK); MT_2 - 100% RDF; MT_3 - 75% RDF + 25% RDN; MT_4 - 50% RDF + 50% RDN; MT_5 - 50% RDF + 25% RDN + BF and for wheat crop five different treatments were applied viz. WT_1 - Control (No NPK); WT_2 - 100% RDF; WT_3 - 75% RDF; WT_4 - 50% RDF + 25% RDN; WT_5 - 37.5% RDF + 37.5% RDN + BF. The experiments were carried out in two consecutive cropping season to study the direct effect of different treatments on one crop and residual effect on the succeeding crop. Recommended dose of nitrogen were applied through crop residue mixed farm yard manure (CRFYM) and recommended dose of fertilizer (RDF) were applied through chemical fertilizers i.e., urea for N, diammonium phosphate for P and muriate of potash for K. One-third of N for maize, half dose of N for wheat and full dose of P and K through urea, diammonium phosphate and muriate of potash, respectively were applied at the time of sowing and remaining N was applied in two split doses (at knee high and at tasseling stage) in maize and after first irrigation in wheat. Well rotten crop residue mixed farm yard

manure (CRFYM) containing 0.45-0.2-0.45 % N-P-K was applied as per the treatments at the time of sowing. CRFYM was prepared by using 20% fresh cattle dung and urine and 80% crop residues on weight basis with the help of wind-row composting method which involved placing the mixture of raw materials in long narrow piles called wind rows that were agitated regularly. At the time of first turning, the liquid microbial consortium (diluted 1:100 or 1:50 dilution with water) was sprayed on wind-row. The composting took about 60-65 days. The biofertilizers viz. *Azospirillum* for maize and *Azotobacter chroococcum* for wheat and Phosphate solubilizing bacteria i.e., *Pseudomonas striata* for both crops were applied directly to soil in rows during sowing. The maize variety PEHM 2 and wheat variety HD 2967 was sown. The cobs were harvested from the net plot area by plucking manually and grains were separated from cobs by hand shelling. When wheat crop matured, plants from net plot area were harvested separately and produce was left in the field for some days to get dried. Bundle weight was recorded separately for each plot. Threshing was done by using wheat thresher. Dried maize stover from each plot was harvested and weighed. The weight of straw was calculated by subtracting grain weight from bundle weight and was expressed as t ha^{-1} .

Bulk density was determined following the method of Chopra and Kanwar (1991). Infiltration rate was measured with the help of double ring infiltrometer (Bouwer, 1986). Organic carbon content was determined by Walkley and Black method (1934). The available N, P and K was estimated by alkaline potassium permanganate method (Subbiah and Asija, 1959), Olsen's method (Olsen *et al.*, 1954) and neutral ammonium acetate extraction method (Jackson, 1973) respectively, and expressed in kg ha^{-1} . Each sample was analysed in triplicate and the data collected were assessed following standard statistical procedures of Gomez and Gomez (1984) with a probability $P \leq 0.05$ for randomised block design and factorial randomized block design.

Results and Discussion

Growth and development of crop is highly reliant on the weather condition. The quantity and rainfall distribution were highly variable during the crop growing periods, which affected the yield of maize and wheat crop. The suitable time for maize sowing is June for north zone of the country. The heavy rainfall during kharif 2011 started during the second week of June which resulted delay sowing of maize. The maize crop was sown during 3rd week of July resulted in lower plant stand, lower dry matter production and overall productivity of maize during first year. In contrast, during 2012 the timely rains gave chance to sow the crop in time and increased overall growth attributes, yield attributes and yield of maize. Wheat crop received favourable weather conditions which resulted in better performance during both the years. The yield of wheat during 2012-13 was slightly lower than yield obtained during 2011-12. However, the weather

condition was more favourable during first year with respect to rainfall which resulted in comparatively better crop establishment, vegetative growth and high yield. Heavy rainfall (102 mm) during flowering and grain filling period resulted in lodging of plants and lower yield of wheat crop in 2012-13 as compared to 2011-12, which received only 15 mm rainfall during flowering period.

Integrated application of nutrient sources affected grain yield significantly ($F_{P \leq 0.05}$). Significantly higher grain yield of maize (4.24 t ha^{-1} , 5.26 t ha^{-1}) was recorded in 50% RDF + 50% RDN treatment over control during 2011 and 2012, respectively (Table 1 & 4). With the application of 50% RDF + 50% RDN, the grain yield was higher by 0.10, 0.17, 0.27 and 2.23 t ha^{-1} during 2011, while an increment of 0.10, 0.20, 0.43 and 2.19 t ha^{-1} was recorded during 2012 as compared to other treatments. Application of 100% RDF treatment gave statistically similar yield as obtained from different combinations of nutrients and was significantly higher than control. During second year, application of 37.5% RDF + 37.5% RDN + BF treatment to wheat recorded significantly higher maize grain yield (4.88 t ha^{-1}) over control. Interaction effect of treatments applied to maize and previous wheat crop on grain yield of maize were found significant. Direct application of 50% RDF + 50% RDN treatment to maize and application of 37.5% RDF + 37.5% RDN + BF to wheat were found to be the best combination and were recorded significantly highest grain yield (5.30 t ha^{-1}) over other combinations. These results are also in conformity with the findings of Bashir *et al.* (2014), who reported that application of 30 t FYM ha^{-1} had a favorable and significant effect on growth, yield attributes, yield, quality and total N, P and K uptake. Dual inoculation of seed with *Azotobacter* + Phosphorus solubilizing bacteria (PSB) also showed similar results. Higher grain yield with increasing fertility levels may be attributed to the higher synthesis and partitioning of metabolites into economic part. Application of integrated nutrient management as 100% NPK + FYM 10 t ha^{-1} recorded maximum grain yield and its performance was at par with 150% NPK (Yadav *et al.*, 2015).

Significantly highest grain yield of wheat (5.21 and 4.73 t ha^{-1}) was obtained with the application of 100% RDF over control during both the years (Table 2, 3 & 4). Application of 37.5% RDF + 37.5% RDN + BF to wheat was the second best treatment and produced almost similar yield as obtained with the application of 100% RDF. This treatment was closely followed by 37.5% RDF + 37.5% RDN + BF treatment and recorded significantly higher grain yield (5.11 and 4.58 t ha^{-1}) over control during both the years, respectively. By reducing 25% nutrients through application of 37.5% RDF + 37.5% RDN + BF, the effect on yield is almost negligible as it produced only 2.0 and 3.3 % less grain yield than 100% RDF. Grain yield of wheat was significantly higher with the application of 50% RDF + 50% RDN to maize over control and it was at par with the remaining treatments during 2011-12. Interaction effect of treatments applied to maize and wheat crop on grain yield of wheat were found significant. Application of 50%

Table 1 : Interaction effect of maize and wheat treatments on grain yield (t ha^{-1}) of maize during 2012

Treatment to wheat (Rabi)	Treatment to maize (Kharif)					Mean
	Control	100% RDF	75% RDF + 25% RDN	50% RDF + 50% RDN	50% RDF + 25% RDN + BF	
Control	2.00 ^e	5.00 ^a	5.12 ^a	5.21 ^a	4.43 ^b	4.35
100% RDF	3.17 ^d	5.07 ^a	5.17 ^a	5.27 ^a	4.95 ^a	4.72
75% RDF	3.00 ^d	5.03 ^a	5.13 ^a	5.23 ^a	4.89 ^{ab}	4.66
50% RDF + 25% RDN	3.33 ^d	5.09 ^a	5.17 ^a	5.28 ^a	4.94 ^a	4.76
37.5% RDF + 37.5% RDN + BF	3.83 ^c	5.09 ^a	5.19 ^a	5.30 ^a	4.97 ^a	4.88
Mean	3.07	5.06	5.16	5.26	4.83	

*Superscripted similar letters on the values indicate non-significant differences among the treatments

Table 2 : Interaction effect of Kharif and Rabi treatments on grain yield (t ha^{-1}) of wheat (2011-12)

Treatment to wheat (Rabi)	Treatment to maize (Kharif)					Mean
	Control	100% RDF	75% RDF + 25% RDN	50% RDF + 50% RDN	50% RDF + 25% RDN+BF	
Control	2.70 ^c	4.50 ^b	4.57 ^{ab}	4.65 ^{ab}	4.63 ^{ab}	4.21
100% RDF	5.20 ^a	5.21 ^a	5.21 ^a	5.23 ^a	5.22 ^a	5.21
75% RDF	4.77 ^{ab}	4.89 ^{ab}	4.89 ^{ab}	4.90 ^{ab}	4.89 ^{ab}	4.87
50% RDF + 25% RDN	4.97 ^{ab}	4.98 ^{ab}	4.98 ^{ab}	4.99 ^{ab}	4.98 ^{ab}	4.98
37.5% RDF + 37.5% RDN + BF	5.11 ^{ab}	5.11 ^{ab}	5.11 ^{ab}	5.12 ^{ab}	5.11 ^{ab}	5.11
Mean	4.55	4.94	4.95	4.98	4.97	

*Superscripted similar letters on the values indicate non-significant differences among the treatments

Table 3: Interaction effect of Kharif and Rabi treatments on grain yield (t ha^{-1}) of wheat (2012-13)

Treatment to wheat (Rabi)	Treatment to maize (Kharif)					Mean
	Control	100% RDF	75% RDF + 25% RDN	50% RDF + 50% RDN	50% RDF + 25% RDN+BF	
Control	2.23 ^c	3.90 ^b	3.97 ^b	4.00 ^b	4.00 ^b	3.62
100% RDF	4.70 ^a	4.72 ^a	4.73 ^a	4.77 ^a	4.76 ^a	4.73
75% RDF	4.38 ^{ab}	4.40 ^{ab}	4.40 ^{ab}	4.40 ^{ab}	4.40 ^{ab}	4.40
50% RDF + 25% RDN	4.44 ^{ab}	4.46 ^{ab}	4.46 ^{ab}	4.47 ^{ab}	4.46 ^{ab}	4.46
37.5% RDF + 37.5% RDN + BF	4.57 ^{ab}	4.57 ^{ab}	4.57 ^{ab}	4.62 ^{ab}	4.57 ^{ab}	4.58
Mean	4.06	4.41	4.43	4.45	4.44	

RDF + 50% RDN to maize and application of 100% RDF to wheat was found to be the best combination and was recorded significantly highest grain yield over other combinations.

Grain yield is the manifestation of yield attributing characters. With the application of nutrients through various combinations of CRFYM and fertilizer there was improvement in yield. These nutrients are crucial for many plant metabolic processes viz. photosynthesis, protein synthesis, translocation of photosynthates, activation of plant enzymes *etc.* The combined effect of fertilizers and beneficial impact of CRFYM help in increasing the availability of various macro and micro nutrients in soil. CRFYM supplies nitrogen, phosphorus and potassium in available forms to the plants in right proportion and uniformly for longer period through biological decomposition along with

micronutrients which resulted into higher yields (Sharma and Subehia, 2003; Prasad *et al.*, 2010; Yadav *et al.*, 2014).

Bulk density and hydraulic conductivity at two soil depths (0-15 and 15-30 cm) and infiltration rate were measured at termination of study i.e. after the harvest of last wheat crop (Table 4). In general, the effect of integrated application of CRFYM and inorganic fertilizers on bulk density was more pronounced than the sole application of NPK fertilizer. Results revealed that the bulk density at 0-15 cm depth varied from 1.50-1.60 g cc^{-1} and at 15-30 cm depth from 1.60-1.65 g cc^{-1} . Application of 37.5% RDF + 37.5% RDN + BF to wheat recorded lowest bulk density (1.50 and 1.60 g cc^{-1}) at 0-15 cm and 15-30 cm soil depth, respectively. However, the highest bulk density (1.60 and 1.65 g cc^{-1}) was recorded under control plots. While, lowest bulk density (1.56 and

Table 4: Effect of CRFYM and fertilizer combinations on yield performance of maize and wheat crop and soil physical properties after two years of study

Treatment	Grain yield of maize (t ha ⁻¹)		Grain yield of wheat (t ha ⁻¹)		Bulk density (g cc ⁻¹)		Hydraulic conductivity (cm hr ⁻¹)		Infiltration rate (mm hr ⁻¹)
	2011	2012	2011-12	2012-13	0-15 cm	15-30 cm	0-15 c m	15-30 cm	
Treatment to maize									
Control	2.23 ^b	3.07 ^c	4.55 ^b	4.06 ^a	1.57 ^a	1.63 ^a	1.18 ^a	1.05 ^a	12.5 ^a
100% RDF	4.07 ^a	5.06 ^a	4.94 ^a	4.41 ^a	1.57 ^a	1.63 ^a	1.18 ^a	1.05 ^a	12.5 ^a
75% RDF + 25% RDN	4.14 ^a	5.16 ^a	4.95 ^a	4.43 ^a	1.57 ^a	1.63 ^a	1.18 ^a	1.05 ^a	12.6 ^a
50% RDF + 50% RDN	4.24 ^a	5.26 ^a	4.98 ^a	4.45 ^a	1.56 ^a	1.63 ^a	1.18 ^a	1.05 ^a	12.6 ^a
50% RDF + 25% RDN + BF	3.97 ^a	4.83 ^b	4.97 ^a	4.44 ^a	1.57 ^a	1.62 ^a	1.18 ^a	1.05 ^a	12.6 ^a
Treatment to wheat									
Control		4.35 ^c	4.21 ^c	3.62 ^c	1.60 ^a	1.65 ^a	1.17 ^a	1.03 ^d	12.2 ^c
100% RDF		4.72 ^{ab}	5.21 ^a	4.73 ^a	1.58 ^a	1.63 ^a	1.17 ^a	1.05 ^{bc}	12.5 ^b
75% RDF		4.66 ^b	4.87 ^b	4.40 ^b	1.60 ^a	1.64 ^a	1.17 ^a	1.04 ^{cd}	12.3 ^c
50% RDF + 25% RDN		4.76 ^{ab}	4.98 ^{ab}	4.46 ^{ab}	1.57 ^a	1.61 ^a	1.18 ^a	1.06 ^b	12.8 ^a
37.5% RDF + 37.5% RDN + BF		4.88 ^a	5.11 ^{ab}	4.58 ^{ab}	1.50 ^b	1.60 ^a	1.20 ^a	1.08 ^a	12.9 ^a

*Superscripted similar letters on the values indicate non-significant differences among the treatments

Table 5 : Effect of CRFYM and fertilizer combinations on soil chemical properties after harvest of maize crop

Treatment	Available N (kg ha ⁻¹)		Available P (kg ha ⁻¹)		Available K (kg ha ⁻¹)		Organic carbon (g kg ⁻¹)	
	2011	2012	2011	2012	2011	2012	2011	2012
Treatment to maize								
Control	143.67 ^b	141.24 ^a	11.67 ^c	11.45 ^e	259.46 ^a	257.31 ^c	4.43 ^a	4.33 ^d
100% RDF	147.67 ^b	158.09 ^d	11.93 ^{bc}	12.07 ^d	261.19 ^a	267.03 ^b	4.43 ^a	4.45 ^c
75% RDF + 25% RDN	157.17 ^a	165.00 ^c	12.30 ^{bc}	12.54 ^c	265.17 ^a	272.00 ^{ab}	4.47 ^a	4.51 ^{bc}
50% RDF + 50% RDN	159.83 ^a	175.70 ^a	13.53 ^a	14.39 ^a	273.33 ^a	278.41 ^a	4.57 ^a	4.67 ^a
50% RDF + 25% RDN + BF	159.03 ^a	169.49 ^b	12.67 ^b	13.34 ^b	269.10 ^a	274.92 ^a	4.47 ^a	4.55 ^b
Treatment to wheat								
Control		160.43 ^a		12.62 ^a		268.20 ^a		4.47 ^a
100% RDF		161.64 ^a		12.77 ^a		269.93 ^a		4.51 ^a
75% RDF		161.22 ^a		12.75 ^a		268.93 ^a		4.50 ^a
50% RDF + 25% RDN		162.66 ^a		12.79 ^a		271.11 ^a		4.51 ^a
37.5% RDF + 37.5% RDN + BF		163.57 ^a		12.87 ^a		271.51 ^a		4.52 ^a

*Superscripted similar letters on the values indicate non-significant differences among the treatments

1.63 g cc⁻¹) were recorded with the application of 50% RDF + 50% RDN to maize at 0-15 and 15-30 cm soil depth, respectively but difference was not significant. This could be ascribed to the greater level of organic carbon content maintained as a result of integrated nutrient application. However, there was marginal reduction in bulk density under sole NPK treatments than control, probably due to increased biomass production with consequent increase in organic-matter content of the soil by application of graded doses of chemical fertilizers (Bharadwaj and Omanwar, 1992). The bulk density was increased with increase in soil depth; moreover bulk density was recorded higher at the lower layers of soil profile than upper layers under all the treatments. This might be due to higher organic matter concentration at the top layer and higher compaction in the sub-surface layer due to cultivation and mass of the soil above (Ghuman and Sur, 2001). Increase in bulk density has been attributed to deterioration of the structure with fertilizers when applied alone. A decrease in bulk density of soil

due to application of CRFYM may be ascribed to the addition of organic matter and more favorable effect on soil aggregation and improvement in structural status of soil (More, 1994; Bellakki and Badanur, 1997; Babhulkar *et al.*, 2000; Sudha *et al.*, 2014). Parthasarathi (2010) also attributed the improvement in bulk density of soil treated with organic manures, mainly due to enhanced microbial population and activity that resulted in the formation of aggregates and increased porosity.

Similarly, hydraulic conductivity varied from 1.17-1.20 at 0-15 cm depth and from 1.03-1.08 at 15-30 cm depth with the application of different treatments to wheat. Application of 37.5% RDF + 37.5% RDN+BF to wheat recorded higher value of infiltration rate (12.9 mm hr⁻¹) and hydraulic conductivity (1.20 and 1.08 cm hr⁻¹) at 0-15 cm and 15-30 cm soil depth, respectively. However, the higher value of hydraulic conductivity (1.18 and 1.05 cm hr⁻¹) at 0-15 and 15-30 cm soil depth, and infiltration rate

Table 6: Effect of CRFYM and fertilizer combinations on soil chemical properties after harvest of wheat crop

Treatment	Available N (kg ha ⁻¹)		Available P (kg ha ⁻¹)		Available K (kg ha ⁻¹)		Organic carbon (g kg ⁻¹)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Treatment to maize								
Control	156.28 ^a	161.41 ^a	12.60 ^a	14.14 ^a	267.96 ^a	271.73 ^a	4.44 ^a	4.43 ^b
100% RDF	157.15 ^a	164.35 ^a	12.61 ^a	14.19 ^a	268.20 ^a	272.79 ^a	4.50 ^a	4.45 ^a
75% RDF + 25% RDN	157.77 ^a	164.74 ^a	12.68 ^a	14.24 ^a	268.47 ^a	273.66 ^a	4.48 ^a	4.51 ^a
50% RDF + 50% RDN	158.80 ^a	166.60 ^a	12.69 ^a	14.61 ^a	269.04 ^a	275.67 ^a	4.50 ^a	4.52 ^a
50% RDF + 25% RDN + BF	158.20 ^a	165.60 ^a	12.69 ^a	14.40 ^a	268.73 ^a	274.43 ^a	4.49 ^a	4.52 ^a
Treatment to wheat								
Control	141.00 ^d	134.97 ^e	11.61 ^d	11.04 ^d	258.93 ^c	254.33 ^c	4.37 ^c	4.18 ^d
100% RDF	160.77 ^b	169.04 ^c	12.41 ^c	14.63 ^c	269.80 ^b	278.13 ^{ab}	4.47 ^b	4.40 ^c
75% RDF	155.47 ^c	160.27 ^d	12.06 ^{cd}	14.12 ^c	265.47 ^b	271.13 ^b	4.45 ^c	4.42 ^c
50% RDF + 25% RDN	164.20 ^{ab}	175.53 ^b	13.19 ^b	15.27 ^b	271.60 ^a	279.92 ^a	4.52 ^b	4.64 ^b
37.5% RDF + 37.5% RDN + BF	166.77 ^a	182.90 ^a	14.00 ^a	16.53 ^a	276.60 ^a	284.77 ^a	4.61 ^a	4.78 ^a

*Superscripted similar letters on the values indicate non-significant differences among the treatments

(12.6 mm hr⁻¹) was measured in 50% RDF + 50% RDN treated plot of maize crop. Interaction effects of treatments applied to maize and wheat crop on bulk density was insignificant. The improvement in infiltration rate and hydraulic conductivity in CRFYM treated plots might be attributed to increased organic matter of soil resulting in improved soil structure and aeration. The trend of variation in bulk density was opposite, i.e., relatively lower bulk density in the 0-15 cm soil depth was associated with high hydraulic conductivity and vice-versa at 15-30 cm soil depth. These results are in conformity with the findings of Saha *et al.* (2010) and Gudadhe *et al.* (2015) who reported improved soil physical properties due to incorporation of organic manure in soil.

The availability of NPK and organic carbon in soil was influenced significantly due to application of different treatments except available K and OC during 2011, after harvest of maize (Table 5). The higher values of available N (159.8 and 175.7 kg ha⁻¹), P (13.5 and 14.4 kg ha⁻¹), K (273.3 and 278.4 kg ha⁻¹) and organic carbon (4.57 and 4.67 g kg⁻¹) were recorded with the application of 50% RDF + 50% RDN followed by 50% RDF + 25% RDN + BF during 2011 and 2012, respectively. Application of 50% RDF + 50% RDN to maize resulted in increased available N by 10.2 and 19.6%, available P by 13.7 and 20.4%, available K by 5.1 and 7.6%, and OC by 3.1 and 7.3% over control during 2011 and 2012, respectively. Residual effect of wheat treatments on nutrient status of soil after harvest of maize crop was insignificant during 2012.

After harvest of wheat crops, significantly higher values of available N (166.77 and 182.9 kg ha⁻¹), P (14.0 and 16.53 kg ha⁻¹), K (276.6 and 284.77 kg ha⁻¹) and organic carbon (0.46 and 0.48%) were recorded with the application of 37.5% RDF + 37.5% RDN + BF treatment to wheat, during 2011-12 and 2012-13, respectively (Table 6). Application of 37.5% RDF + 37.5% RDN + BF to wheat increased the available N by 15.5 and 26.2%, available P by 17.1 and 33.2%, available K by 6.4 and 10.7%, and organic carbon by 4.3

and 12.5% as compared to control during 2011 and 2012, respectively. Effect of different nutrient treatments applied to maize crop on soil chemical properties after harvest of wheat crop was insignificant. The data revealed that the highest available nitrogen, phosphorus and potassium after harvest of each crop was observed with the treatment, which received the nutrients from CRFYM and fertilizer combination. Increase availability of nutrient in treatment applied with CRFYM might be due to the fact that CRFYM provides a slow-release supply of organically bound nutrients such as nitrogen, phosphorus and other nutrients. It enhances chelation and thus, bioavailability of nutrient elements to plants. CRFYM accelerates mineral weathering and aids in solubilization of plant nutrients from insoluble minerals. FYM also provides slowly available carbon and energy source to support a large diverse, metabolically active microbial community which helps in solubilization and availability of nutrients to crop plants (Wolf and Wagner, 2005). Bhattacharya *et al.* (2004) reported that soil organic carbon contents of soil were higher in FYM treated plots. Similar findings were also observed by Sarwar *et al.* (2012) who reported nitrogen application irrespective of the source did not significantly enhance the SOM contents as compared to control. Treatments containing 50% N substituted with FYM showed the highest increase (15%) in SOM. Rasool *et al.* (2007) also reported that addition of FYM and inorganic N fertilizer enhanced the soil organic carbon content by 44% and 37%, respectively.

The economics of maize and wheat was significantly influenced due to different CRFYM and fertilizer combinations (Fig. 1 a-d). The cost differential in different treatments arose mainly due to differences in the dose and costs of CRFYM and chemical fertilizers. Higher cost of cultivation was observed with the treatment which received maximum amount of recommended dose of nitrogen through CRFYM. The quantity of organic manure

Fig. 1 : Economics of maize and wheat as influenced by crop residue mix FYM and fertilizer combinations (a) maize, 2011, (b) maize, 2012 (c) wheat, 2011-12 and (d) wheat, 2012-13

required to replace inorganic fertilizer is high and hence, the cost of cultivation is higher compared to chemical fertilizers. But owing to the beneficial effect of organic manure the farmers need to apply organic manures. Application of 100% RDF to maize recorded minimum cost of cultivation (26.57×10^3 and 34.31×10^3 ₹ ha⁻¹) and maximum net profit (28.22×10^3 and 42.74×10^3 ₹ ha⁻¹) followed by 75% RDF + 25% RDN during 2011 and 2012, respectively. Minimum cost of cultivation of wheat crop was recorded with 75% RDF (25.55×10^3 and 28.53×10^3 ₹ ha⁻¹) during 2011-12 and 2012-13, respectively. Higher net returns (72.06×10^3 and 61.85×10^3 ₹ ha⁻¹) were recorded in the treatment which received 100% RDF followed by 75% RDF during 2011-12 and 2012-13, respectively. The gross and net returns of maize were higher during 2012 as compared to 2011, and gross and net returns of wheat were higher during 2011-12 as compared to 2012-13. It might be due to more crop growth, yield and minimum support price. This confirms the findings of Kumar *et al.* (2007), Yadav *et al.* (2015) and Joshi *et al.* (2013) who reported application of organic manures recorded maximum cost of cultivation and gross returns which are attributed

to high cost of vermicompost/FYM and high gross returns may be due to higher grain and stover yield.

The findings of the present study underline the importance of integrated nutrient management for maximizing the crop yield and maintaining the soil fertility. Based on two years study it can be concluded that as compared to 100% RDF, combined use of crop residue mixed farmyard manure and inorganic sources of nutrients along with biofertilizers proved better nutrient management option for obtaining higher yield, maintaining soil health and net returns from maize-wheat cropping system.

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