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SHORT COMMUNICATION

Legume residue and N management for improving productivity and N economy and soil fertility in wheat (*Triticum aestivum*)-based cropping systems

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Abstract With the objective of improving productivity, N economy and soil fertility in wheat-based cropping systems, a fixed plot field experiment was conducted during 2009–2011 with two grain legumes, viz. groundnut and soybean for residue management (stover removed and stover incorporated in the succeeding wheat crop) and maize as main plots during rainy season. Wheat was grown in winter season with four levels of *N*, viz. 0, 50, 100 and 150 kg N ha^{-1} as subplots. Grain legumes (groundnut and soybean) as previous crops had a positive effect on growth and yield of succeeding wheat compared to the maize. Wheat grain yield was 4.59–5.02% higher under groundnut and soybean residue incorporation than residue removal. Groundnut and soybean as preceding crops recorded 9.57–10.32% more yields than maize as preceding crop to wheat. Nitrogen economy in wheat through grain legume residue incorporation was 44.5–54 kg N ha^{-1}. Groundnut–wheat cropping system with residue incorporation recorded the highest system productivity (WGEY) (8.84 t ha^{-1}) and net returns (INR 77.5 × 10^3 ha^{-1}) followed by groundnut–wheat with residue removal. Maximum soil organic carbon (0.46%) and soil available N (242 kg ha^{-1}) and *P* (15.73 kg ha^{-1}) were recorded under groundnut–wheat + groundnut residue incorporation, but the highest available *K* (246.3 kg ha^{-1}) was recorded in soybean–wheat + soybean residue incorporation and minimum under maize–wheat. From this study, it is concluded that the inclusion of legumes in wheat-based rotations and their residue incorporation saved the N fertilizer and improved the wheat productivity and soil fertility at the end of 2-year cropping cycle.

Keywords Legume residue · Nitrogen · N economy · Wheat-based cropping system · Soil fertility

Introduction

Wheat-based cropping systems are dominant in north-western parts of the Indian Indo-Gangetic plain region, and rice–wheat system is the major and prime contributor to the central food grain basket. However, the extensive cultivation of this system over the years has caused numerous problems such as mining of soil nutrients and groundwater, formation of hard pan, environmental pollution and appearance of new weed biotypes, insect pests and diseases [1, 2]. In the recent past, there is sizeable increase in the area of maize, soybean and groundnut in India. Area under maize was only 6.6 m ha in 2000–2001 and increased to 7.66 m ha in 2015–2016. The area under soybean was 6.1 m ha during 2000–2001, which was increased to 11.62 m ha in 2015–2016. Apart from rice–wheat systems, maize/soybean–wheat systems are also predominant in India and cultivated area is about 1.83 m ha under maize–wheat and 4.5 m ha under soybean–wheat [3]. In addition to this, groundnut–wheat system also occupies

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considerable area in north-western part of the country. Hence, maize, soybean and groundnut appear to be potential crops for replacing rice during rainy season in the Indo-Gangetic plain region. Diversification of rice–wheat cropping system with grain legumes like soybean and groundnut has been advocated by many researchers to enhance availability of protein, improve soil fertility and overcome the soil and environmental problems causes due to continuous rice–wheat rotations [4]. Grain legumes are an important component of cereal-based crop rotation, and the inclusion of legumes in cropping systems increases soil fertility and consequently the productivity of the succeeding cereals [5]. These grain legumes access atmospheric N_2 through symbiosis with *rhizobium* bacteria and contribute to succeeding non-legume crop after decomposed legume top and root [6].

Although during the last three decades fertilization practices have played a dominant role in the wheat-based cropping systems, crop residues of the previous crop still play an important role in the cycling of nutrients [7]. It is well known that most grain legumes shed their leaves towards maturity and litter together with residues and roots contains varying amounts of biologically fixed atmospheric N_2, which is added to the soil resulting in higher growth and productivity in succeeding wheat crop and improved soil properties at the end of cropping season. However, this may not hold good; even when stover of grain legumes with high N harvest index and modest N_2 fixation is removed from the field, there is often a net removal of N [8]. In India, crop residue application through soil incorporation has beneficial effect to soil health, crop productivity and nutrient use efficiency [9].

The supply of essential plant nutrients in soil is a growth-limiting factor towards production. Among all the nutrients required by a plant, nitrogen (N) is of prime importance that improves growth and yield parameters. During last few years, Indian farmers are facing the challenges of fertilizer crisis with unprecedented hike in prices and their availability at proper time has been a matter of serious concern. As a result, farmers use both the available organic sources and the affordable amount of chemical fertilizers to cut down the high cost of chemical fertilizers for higher crop yields. However, due to energy shortages, increased fertilizer cost, deterioration of soil health and environmental concerns, the use of organic manures has again become important [10]. Therefore, inclusions of grain legumes in cereal-based systems are an important alternative to diversify their farming systems, improve system productivity and soil fertility via symbiotic N_2 fixation and reduce their fertilizer N requirements in succeeding cereal crops. Legumes also represent an important source of protein and supplemental income to the farm family. Generally fertilizer recommendations are made based on the response of individual crops without considering the cropping system as whole, with the result that the recommendations often become less remunerative. However, the response of wheat to N is invariably influenced by the previous legume, fertilizer applied and residue management. Therefore, the present study was conducted to evaluate the effect of legume residue recycling, N fertilization and cropping system effects on productivity, N economy and soil fertility in wheat (*Triticum aestivum*)-based cropping systems.

Materials and Methods

Experimental Site

A field experiment was conducted during the rainy (June–October) and winter (November–April) seasons of 2009–2010 and 2010–2011 at the research farm of Indian Agricultural Research Institute, New Delhi, in north-western India (28.4°N, 77.1°E; 228 m above sea level) of Indo-Gangetic Plains (IGP). The Indo-Gangetic Plains (IGP) rank as one of the most extensive fluvial plains of the world. The deposit of this tract represents the last chapter of earth's history. It came into existence due to the collision of the Indian and Chinese plates during Middle Miocene. The IGP developed mainly by the alluvium of the Indus, Yamuna, Ganga, Ramganga, Ghaghara, Rapti, Gandak, Bhagirathi, Silai, Damodar, Ajay and Kosi rivers. IGP are drained by rivers of the Indian Craton to the south; the role of cratonic flux (sediments from gneissic and basaltic rocks as source) in genesis of the IGP soils is prominent. During the past five decades, various soil-forming processes such as calcification, leaching, lessivage, salinization and alkalinization, gleization and homogenization have been identified in the IGP. These processes lead to the formation of a variety of soils in the IGP that represent mainly three soil orders—Entisols, Inceptisols and Alfisols. Soils of the IGP across the topographic gradient ($< 0.02\%$) with varying climate from hot arid to per humid belong to Entisols, Inceptisols, Alfisols and Vertisols orders. The soil (0–15 cm depth) at experimental site was sandy loam (Inceptisols—Mahauli series) in texture (sand—65.2%, silt—16.4% and clay—18.4%) with bulk density of 1.55 Mg m^{-3}, field capacity 18.1% (w/w), hydraulic conductivity 11.21 mm h^{-1} and infiltration rate 11.42 mm h^{-1}. It had 0.40% organic carbon, 175 kg $KMnO_4$ oxidizable N ha^{-1}, 12.24 kg 0.5 N $NaHCO_3$ extractable P ha^{-1}, 230 kg 1.0 N NH_4OAc exchangeable K ha^{-1}, 7.6 pH and 0.32 dS m^{-1} EC at the beginning of the experiment. The climate of the region is semi-arid and subtropical. The mean annual rainfall of Delhi is 672 mm of which more than 80% generally occurs during the monsoon season (July–September) with mean annual evaporation of 850 mm. The seasonal weather parameters of cropping season including rainfall, maximum and minimum temperature and evaporation are presented in Fig. 1.

Experimental Design and Treatments

Fixed plot field experiment was established during 2009–2011 with two grain legumes, i.e. groundnut and soybean for residue management (residue incorporated and residue removed) and maize as main plots in rainy season. These main plots of rainy season crops (61.2 m^2) were divided into four subplots (12.6 m^2) for the application of 4 N levels to following wheat in winter season. Cropping system with residue management treatments were, viz. maize–wheat (M-W), groundnut–wheat (G-W), G-W + groundnut residue in wheat, soybean–wheat (S-W), S-W + soybean residue in wheat. Four rates of *N* were 0 (control), 50, 100 and 150 kg N ha^{-1}, and were applied in the subplots. The experimental design was split plot design with three replications throughout. After harvest of grain legumes, stover in residue removal treatment was removed. In residue incorporation treatment, groundnut and soybean stover was chopped into medium-sized pieces and incorporated into top soil of 15 cm by tractor drawn disc harrow about 15–20 days before sowing of wheat.

Crop Management Practices

Management practices of the crops are presented in Table 1. Data on seed yield were recorded from the net plot, whereas yield attributes were recorded from five randomly selected plants at harvest.

Productivity of Wheat-Based Systems

The yield of rainy season crops, viz. maize, groundnut and soybean, was converted into wheat grain equivalent yield (WGEY) based on prevailing average market price of maize grain (INR 9000 t^{-1}), soybean seed (INR 20,000 t^{-1}), wheat grain (INR 12,000 t^{-1}) and groundnut kernel (INR 35,000 t^{-1}) during 2010 and 2011. System productivity was calculated by adding WGEY of component crops of the systems.

N Economy

The saving of N through legumes was worked out based on the relative yields under varying *N* rates and through calculation of maximum yield (Y_{max}) and optimum yield (Y_{opt}) based on N_{max} and N_{opt} derivations from quadratic equations as follows: $N_{max} = -b \div 2c$; $N_{opt} = \{(P_x \div P_y) - b \div 2c\}$ where b and c are the coefficients of the quadratic equations, and P_x and P_y are the cost of N fertilizer (INR 11 kg^{-1}) and price of wheat grain (INR 12,000 t^{-1}), respectively.

Economic Analysis

The economic analysis in terms of gross and net returns and benefit–cost ratio (returns per rupee invested) was carried out on the basis of existing rate of inputs and output in the local market. Total variable cost included the cost of inputs such as seeds, fertilizers, irrigation, crop residues and the cost for various cultural operations such as ploughing, sowing, weeding, harvesting and threshing. The rental value of land was also considered in the cost of cultivation. Returns were calculated by using the following formula.

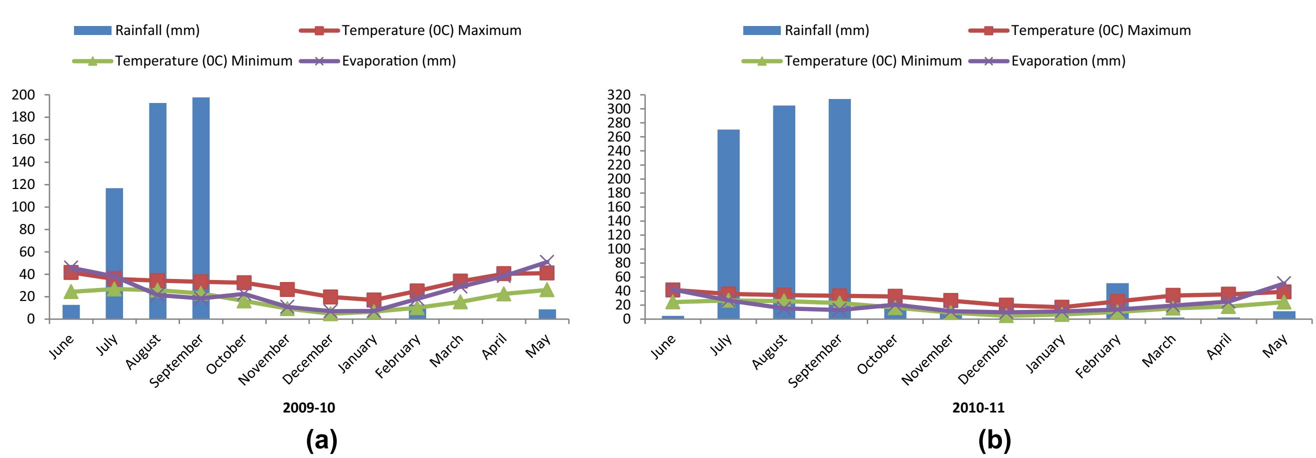

Fig. 1 Weather parameters during cropping period 2009–2010 and 2010–2011

Table 1 Field operations and management of crops during rainy and winter seasons

Activity/operation	Maize	Groundnut	Soybean	Wheat
Cultivar	'BIO-9637'	'GG 20'	'DS-9814'	'HD 2851'
Field preparation	Disc harrow, cultivator followed by wooden planking	Disc harrow, cultivator followed by wooden planking	Disc harrow, cultivator followed by wooden planking	Disc harrow, cultivator followed by wooden planking
Crop establishment and date of sowing	21 July 2009, 6 July 2010	1 July 2009, 6 July 2010	1 July 2009, 6 July 2010	27 November 2009 and 25 November 2010
Seed rate (kg ha^{-1})	25	100	100	100
Sowing method	Sown in line by dibbling two seeds at spacing of 30 cm	Sown in line by dibbling two seeds at spacing of 15 cm	Sown in line by dibbling two seeds at spacing of 10 cm	Tractor drawn seed drill (line sowing)
Row spacing (cm)	60	30	30	22.5
Nutrient management (N, P and K were given through urea, single superphosphate and potassium chloride in all the crops)	120 kg N, 26.2 kg P and 50 kg K ha^{-1}. Half of recommended N and full dose of P and K are applied as basal and remaining half is applied in two equal splits at 30 and 60 days after sowing	25 kg N, 26.2 kg P and 50 kg K ha^{-1} were applied as basal by broadcasting and mixed with soil before sowing	25 kg N, 26.2 kg P and 50 kg K ha^{-1} were applied as basal by broadcasting and mixed with soil before sowing	For wheat four levels of N, control, 50, 100 and 150 kg ha^{-1} were applied as per treatments in two splits: half at sowing and half after second irrigation. Besides N, wheat crop received a recommended dose of 60 kg P_2O_5 and 40 kg K_2O ha^{-1} as basal dose
Weed management	Atrazine applied as pre-emergence herbicide @ 1 kg/ha and two-hand weeding at 20 and 40 DAS	Pendimethalin applied as pre-emergence herbicide @ 1 kg/ha and two-hand weeding at 20 and 40 DAS	Pendimethalin applied as pre-emergence herbicide @ 1 kg/ha and two-hand weeding at 20 and 40 DAS	Tank mix spray of isoproturon and 2,4-D at 30 DAS
Water management	Crop was sown with pre-sowing irrigation, and subsequent irrigation was given based on recommendation of IW/CPE ratio	Crop was sown with pre-sowing irrigation, and subsequent irrigation was given based on recommendation of IW/CPE ratio	Crop was sown with pre-sowing irrigation, and subsequent irrigation was given based on recommendation of IW/CPE ratio	Crop was sown with pre-sowing irrigation, and subsequent irrigation was given based on recommendation of IW/CPE ratio
Harvesting	25 October 2009 and 12 October 2010	2 November 2009, 26 October 2010	2 November 2009, 26 October 2010	10 April 2010 and 4 April 2011

$$\begin{aligned}\text{Gross returns} &= \text{Value of the grain/seed} \\ &\quad + \text{Value of straw/stover} \\ \text{Net returns} &= \text{Gross returns} - \text{Total variable costs} \\ \text{Benefit :Cost ratio} &= \text{Gross returns/Total variable cost}\end{aligned}$$

Field and Laboratory Measurements

Soil physico-chemical and biological parameters were recorded at initial and at end of two cropping cycles. Soil bulk density of surface (0–15 cm) soil was determined by the core sampler method [11] from three randomly chosen areas of each plot. The procedure for determining bulk density was followed as described by Mishra and Ahmad [12]. The soil collected for bulk density in the core sampler was used for determining the hydraulic conductivity using constant head method [12]. Hydraulic conductivity is estimated by using the formula $K = QL/\text{HAT}$ where Q is the quantity of water collected, L is the length of sample (cm), H is the loss in head (cm). Infiltration rate was measured using double-ring infiltrometer by recording the change in the water level in cylinder and it was expressed as mm h^{-1} [13]. Soil samples collected from individual plots were separated for content of organic carbon by wet digestion method [14], available nitrogen by alkaline $KMnO_4$ method [15], available phosphorous by 0.5 M sodium bicarbonate extraction [16] and available potassium by flame photometry [17].

Data Analysis

The data collected from the field and laboratory work were computed and properly tabulated. Then these were subjected to standard analysis using analysis of variance for split plot design as described by Gomez and Gomez [18]. '*F*' test was carried out for significance of comparison and critical difference (CD) at 5% level of probability was worked out wherever *F* values were significant. The CD values were used to draw conclusions from treatment comparison.

Results and Discussion

Yield Attributes and Yield

The effect of different cropping systems, legume residue management and *N* levels on the yield attributes, viz. effective tillers m^{-2}, spike length, grains $spike^{-1}$ and 1000-grain weight of wheat, were significant during both the years (Table 2). Higher values of yield attributes were recorded with groundnut–wheat followed by soybean–wheat cropping system with residue incorporation, and these are significantly superior over no residue treatments. Significantly lower values of yield attributes obtained under maize–wheat cropping system than legume residue management treatments, except 1000 grain weight, in which maize–wheat cropping system was statistically on a par with groundnut–wheat and soybean–wheat without residue incorporation. Incorporation of groundnut and soybean residue and their leaf fall added variable amounts of *N* to the soil, which led to a significant influence on the yield attributes and productivity of the following wheat. Stovers of all legumes are rich in N having narrow C/N ratio which might be resulted in quick mineralization. The beneficial effects of grain legumes after their residue incorporation was significantly more compared to residue removed and maize. Such beneficial effects of legumes have been reported widely [19, 20], attributed to increased nutrient availability to the succeeding crop [21] and better soil physical conditions [22]. These results are in agreement with Kumar and Goh [23] and Surekha et al. [24]. Wheat grain yield recorded the following order: groundnut–wheat + residue = soybean–wheat + residue > groundnut–wheat = soybean–wheat > maize–wheat. On an average over 2 years, incorporation of groundnut and soybean residue resulted in 2.48 and 2.63% increase during both the years compared with their residue removed treatment with respect to straw yield. The rotational effect of legumes on succeeding cereal crops was reported by many workers [25, 26]. The increase in wheat grain and straw yield after incorporation of legume crop residues was reported by Sharma and Behera [27]. Significant increase in wheat gain and straw yield after residue incorporation compared with the residue removed and wheat preceded by mung bean increased the grain and straw yield of wheat than following maize with no fertilization [28]. The positive effect of groundnut stover on subsequent rice [29] and maize [30] had further verification at other places. Similarly, favourable effect of groundnut residue recycling on higher millable cane and sugar yield was recorded compared to soybean and fallow in sandy soil

Table 2 Effect of cropping system, residue management and N levels on yield attributes of wheat

Treatment	Effective tillers/m^2		Spike length (cm)		Grains/spike		1000-grain weight (g)	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
Cropping system								
Maize–wheat (M-W)	310.7	333.3	9.04	9.31	40.8	42.3	40.04	40.08
Groundnut–wheat (G-W)	370.9	424.0	9.11	9.35	43.6	45.1	40.35	41.21
G-W + groundnut residue in wheat[a]	454.6	490.0	9.76	9.85	46.6	48.7	42.00	43.30
Soybean–wheat (S-W)	362.0	412.9	9.06	9.30	43.6	44.2	40.31	41.14
S-W + soybean residue in wheat[a]	428.3	480.8	9.61	9.72	45.8	47.2	41.96	43.03
SEm ±	10.58	12.55	0.12	0.12	0.70	0.57	0.35	0.54
CD (P = 0.05)	34.49	40.95	0.41	0.40	2.30	1.86	1.13	1.75
Nitrogen levels (kg ha^{-1})								
0	297.3	321.5	8.73	8.8	38.0	38.0	39.10	39.80
50	370.2	409.5	9.15	9.45	42.4	44.4	39.56	40.71
100	405.7	459.9	9.54	9.70	46.1	47.7	42.07	42.92
150	468.0	522.0	9.83	10.0	49.7	52.0	42.98	43.38
SEm ±	12.99	13.39	0.08	0.09	1.05	1.10	0.58	0.72
CD	37.52	38.70	0.22	0.25	3.03	3.18	1.68	2.08

[a]Groundnut residue added 4.02 t ha^{-1} during 2009–2010 and 4.25 t ha^{-1} during 2010–2011; soybean residue added 3.92 t ha^{-1} during 2009–2010 and 4.15 t ha^{-1} during 2010–2011

of Thailand [31]. Similarly many studies [32, 33] confirmed that nitrogen contribution is the key factor in the response of cereals following legumes compared with cereals following non-legumes. In cereal–legume rotation, cereals derive both yield and *N* benefits from rotations with grain legume compared with cereal monoculture [34–36].

The yield attributes and yield were significantly increased with increasing *N* rates up to 150 kg ha^{-1} during both the years. Highest values were obtained at 150 kg N ha^{-1}, which was significantly higher than all *N* levels (Table 2). On an average, the application of 150 kg N ha^{-1} compared with no *N* as control increased the grain yield of wheat by 54.76%. Being the cereal, wheat responds well to the higher levels of nutrients. Nitrogen fertilizers help in removal of plant nutrients and water from soil by crop which might have helped in enhancing photosynthesis and translocation of assimilates from sources to sink resulting in higher grain yield [37]. Increasing N fertilizer rate increased the yield attributes which resulted in more grain yield compared with their control [27, 38].

System Productivity

Among the rainy season crops (maize, groundnut and soybean), highest grain (3.54 and 3.86 t ha^{-1}), straw yield (5.76 and 5.58 t ha^{-1}) and harvest index (40.68 and 40.89) were recorded in maize as compared to groundnut and soybean during both years (Table 3). On an average, residue incorporation in the previous wheat enhanced the WGEY of groundnut and soybean during 2010 to the tune of 11.39 and 8.62%, respectively, over their residue removal (Table 4). The system productivity was higher under groundnut–wheat cropping system with residue incorporation (8.84 t ha^{-1}), followed by groundnut–wheat with residue removed (8.28 t ha^{-1}). This attributed to improvement in soil physico-chemical and biological environment in the soil through the addition of nutrients and enhanced microbial resulting in higher levels of crop productivity [39]. Similarly, Ghosh et al. [40] reported that groundnut–groundnut and groundnut–wheat systems were found to be productive and sustainable cropping systems as these had greater total system productivity, sustainable yield index and significant effect on soil organic carbon content. In the present investigation, system productivity increased significantly with each increase in levels of *N* up to 150 kg ha^{-1}, which might be due to increase in grain yield of wheat with N dose. With the application of 150 kg N ha^{-1}, system productivity recorded 2.64, 6.96 and 22.03% increase in WGEY over 100 kg N ha^{-1}, 50 kg N ha^{-1} and control, respectively. Yadav et al. [41] reported that the application of *N* up to 150 kg ha^{-1} significantly increased the grain yield of wheat.

N Economy

There was a differential response of wheat to *N* levels under different cropping systems with legume residue (Table 5). The response of wheat to N levels was quadratic (Fig. 2) indicating the beneficial effect of legumes on N economy especially when the rate of applied N was zero or low and decreased with increasing fertilizer N. The effect of groundnut and soybean was similar when residues were removed and comparatively lower than residue incorporation. The lowest wheat grain yield was achieved in maize–wheat cropping sequence compared to other treatments. Based on the quadratic response functions, the yield maximizing and optimum dose of N was higher than the highest dose of N tested in this study particularly maize–wheat cropping system. This was declined considerably when legumes are included in the system both under residue incorporation and removal. This indicates greater contribution of N from grain legumes through N_2 fixation and its residual effect on succeeding wheat. Optimum N dose was 6–10 kg ha^{-1} lower than maximum dose, but there were no differences between the corresponding yield levels. The inclusion of legumes and residue incorporation did not make much impact on potential yield of wheat compared to maize–wheat. Contribution of nitrogen from

Table 3 Grain, stover yield and harvest index of rainy season crops (maize, groundnut and soybean) during 2009–2010 and 2010–2011 cropping cycle

Treatment	Grain yield (t ha^{-1})		Stover/haulm yield (t ha^{-1})		Harvest index (%)	
	2009	2010	2009	2010	2009	2010
Cropping system						
Maize–wheat (M-W)	3.54	3.86	5.76	5.58	40.68	40.89
Groundnut–wheat (G-W)	2.02	2.04	4.02	3.97	33.89	33.69
G-W + groundnut residue in wheat	2.02	2.25	4.02	4.25	33.89	34.59
Soybean–wheat (S-W)	1.85	1.87	3.92	3.91	32.34	32.09
S-W + soybean residue in wheat	1.85	2.01	3.92	4.15	32.34	32.61

Table 4 Effect of legume residue management, cropping systems and N levels on productivity of wheat-based cropping systems

	WGEY of rainy season crops (t ha^{-1})		Wheat grain yield (t ha^{-1})		System productivity (t ha^{-1}) based on WGEY		Wheat Straw yield (t ha^{-1})	
	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011	2009–2010	2010–2011
Cropping system								
Maize–wheat (M-W)	2.70	2.95	3.96	3.97	6.67	6.91	6.68	6.95
Groundnut–wheat (G-W)	3.85	3.86	4.33	4.42	8.18	8.28	7.09	7.38
G-W + groundnut residue in wheat[a]	3.85	4.30	4.56	4.64	8.40	8.84	7.27	7.57
Soybean–wheat (S-W)	2.34	2.32	4.30	4.40	6.64	6.72	7.06	7.35
S-W + soybean residue in wheat[a]	2.34	2.52	4.51	4.58	6.85	7.10	7.24	7.55
SEm ±	–	0.090	0.050	0.046	0.081	0.054	0.038	0.042
CD (P = 0.05)	–	0.296	0.162	0.151	0.264	0.176	0.124	0.137
Nitrogen levels (kg ha^{-1})								
0	–	3.15	3.47	3.52	–	6.67	5.95	6.37
50	–	3.18	4.37	4.44	–	7.61	7.02	7.35
100	–	3.21	4.65	4.72	–	7.93	7.48	7.75
150	–	3.22	4.85	4.92	–	8.14	7.83	7.97
SEm ±	–	0.024	0.030	0.031	–	0.035	0.045	0.039
CD (P = 0.05)	–	NS	0.087	0.091	–	0.101	0.130	0.111

[a]Groundnut residue added 4.02 t ha^{-1} during 2009–2010 and 4.25 t ha^{-1} during 2010–2011; soybean residue added 3.92 t ha^{-1} during 2009–2010 and 4.15 t ha^{-1} during 2010–2011

Table 5 Yield maximizing (N_{max}) and optimizing rates of N (N_{opt}), and corresponding wheat yields in cropping season (mean of 2009–2010 and 2010–2011)

Treatment	N rate (kg ha^{-1})		Wheat yield (t ha^{-1}) at			N rate required to obtain Y_0 (kg ha^{-1})
	N_{opt}	N_{max}	N_0 N (Y_0)	N_{opt} (Y_{opt})	N_{max} (Y_{max})	
Cropping system						
Maize–wheat (M-W)	177	187	2.95	4.69	4.70	0.0
Groundnut–wheat (G-W)	125	133	3.61	4.82	4.83	39.5
G-W + groundnut residue in wheat[a]	121	128	3.81	5.05	5.05	54.0
Soybean–wheat (S-W)	126	133	3.50	4.90	4.91	32.0
S-W + soybean residue in[a] wheat	121	127	3.68	4.97	4.97	44.5

[a]Groundnut residue added 4.02 t ha^{-1} during 2009–2010 and 4.25 t ha^{-1} during 2010–2011; soybean residue added 3.92 t ha^{-1} during 2009–2010 and 4.15 t ha^{-1} during 2010–2011

legume crops and their residue was maximum under control, and the dose of N required to obtain wheat yield equal to that without N (Y_0) indicated saving of N fertilizer in wheat under grain legume–wheat. The saving was 44.5–54 kg N ha^{-1} due to incorporation of groundnut and soybean residue, while in case of residue removed, it was 32–39.5 kg N ha^{-1}. The saving in N due to legume attributed to biological N fixation by legumes and their beneficial effect on rhizosphere [21]. Variation in N saving between the legumes and stover management practices attributed to variable N contribution of legume due to N fixation and residue incorporation. Sharma and Behera [27] reported a saving of 49–56 kg N ha^{-1} with groundnut and green gram, and 31–37 kg N ha^{-1} with cowpea and soybean residue incorporation. 25 kg ha^{-1} N saving was reported when wheat was grown after grain legumes [42].

Economic Analysis

Maximum cost of cultivation was recorded under groundnut–wheat cropping system with residue incorporation (INR 36.66 × 10^3 ha^{-1}), while minimum under soybean–wheat cropping system with residue removed (Table 6).

Fig. 2 Response of wheat to different N levels grown after preceding rainy season crops during 2009–2010 and 2010–2011

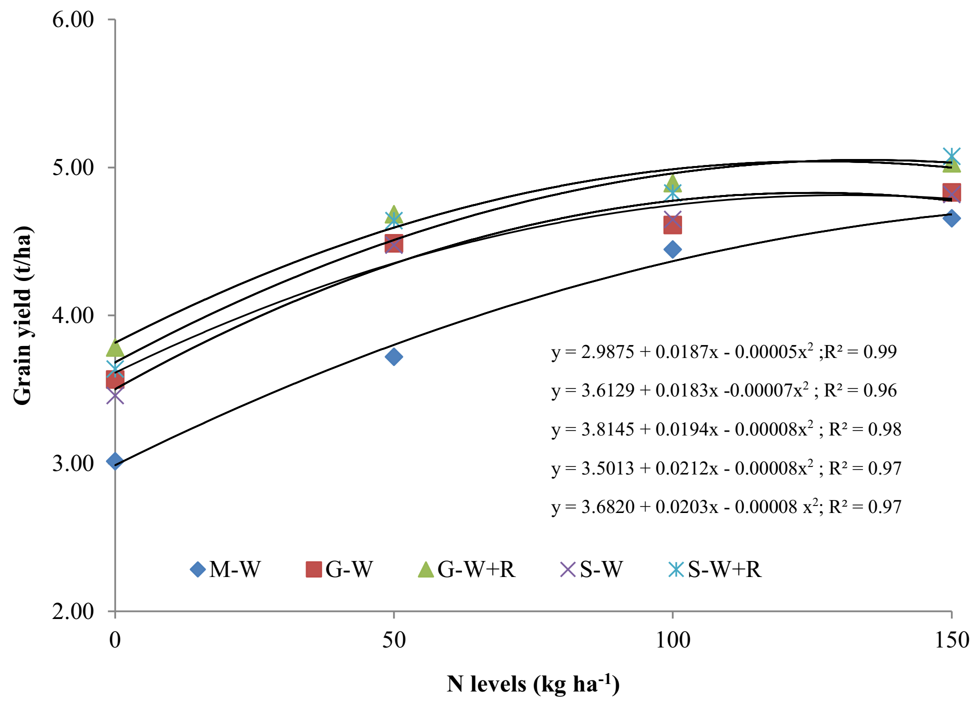

Table 6 Effect of cropping systems, legume residue management and N levels on economic analysis of wheat-based cropping systems (mean of 2009–2010 and 2010–2011)

Treatment	Cost of cultivation[b] ($\times 10^3$ INR ha^{-1})	Gross returns ($\times 10^3$ INR ha^{-1})	Net returns ($\times 10^3$ INR ha^{-1})	B–C ratio
Cropping system				
Maize–wheat (M-W)	34.69	93.36	58.80	1.70
Groundnut–wheat (G-W)	34.16	106.09	72.06	2.12
G-W + groundnut residue in wheat[a]	36.66	114.02	77.48	2.12
Soybean–wheat (S-W)	32	88.02	56.14	1.76
S-W + soybean residue in wheat[a]	34.5	92.76	58.39	1.70
SEm±	–	0.618	0.618	0.018
CD (P = 0.05)	–	2.014	2.014	0.058
Nitrogen levels (kg ha^{-1})				
0	33.45	87.08	53.63	1.60
50	34	99.12	65.12	1.91
100	34.55	103.24	68.70	1.98
150	35.1	105.95	70.85	2.01
SEm ±	–	0.413	0.413	0.012
CD	–	1.192	1.192	0.035

[a]Groundnut residue added 4.02 t ha^{-1} during 2009–2010 and 4.25 t ha^{-1} during 2010–2011; soybean residue added 3.92 t ha^{-1} during 2009–2010 and 4.15 t ha^{-1} during 2010–2011

[b]Price of product: Maize grain (₹ 9000 t^{-1}), maize stover (₹ 1000 t^{-1}), soybean seed (₹ 20,000 t^{-1}), soybean stover (₹ 500 t^{-1}) wheat grain (₹ 12,000 t^{-1}), wheat stover (₹ 2,000 t^{-1}) and groundnut kernel (₹ 35,000 t^{-1}), groundnut stover (₹ 500 t^{-1}) and 50 = ~ US $1 during the period of investigation

The maximum gross (INR 114.02 $\times 10^3$ ha^{-1}) and net returns (INR 77.48 $\times 10^3$ ha^{-1}) and benefit–cost ratio (2.12) were recorded under groundnut–wheat cropping system with residue incorporation closely followed by groundnut–wheat with residue removed, which may be ascribed to direct and cumulative effect of residue incorporation on wheat and groundnut and high yield of groundnut and remunerative prices for groundnut as compared to soybean. Sharma and Behera [27] also reported similar results. The gross returns and net returns were computed maximum at 150 kg N ha^{-1}, which were significantly higher than all N levels. Net returns per rupee invested were also recorded maximum with 150 kg N ha^{-1}, which was significantly higher than other levels except 100 kg N ha^{-1}. The increase in N application increased the wheat yield, which resulted in more gross and net returns at high level of N. However, the application of 150 kg N ha^{-1} was statistically similar to 100 kg N ha^{-1} with regard to benefit–cost ratio. It indicated that saving of 50 kg N ha^{-1} in wheat cultivation is possible, if wheat grown as succeeding crop to legume.

Soil Fertility

Soil Organic Carbon

Legume residue incorporation significantly increased the SOC under groundnut–wheat and soybean–wheat by 5.99 and 4.65% over without residue incorporation, respectively (Table 7). This may be due to the application of crop residues in these residue incorporation treatments which added the organic matter to the soil. The results corroborate with the many reports that highlight the relevance of N inputs and residue retention to the build-up of soil organic matter. Total organic carbon increased with the addition of crop residues in no tillage relative to conventional tillage with no residue [43]. Soil organic C was 1.04 times greater in the residue retained than in the residue removed treatment [28]. Further, the organic C content was consistently greater for treatment following wheat after mung bean than treatment following wheat–maize under 0-N. Similar results were reported by Surekha et al. [24] and Shafi et al. [44]. The application of 50, 100 and 150 kg N ha^{-1} significantly increased the SOC by 5.51, 7.43 and 8.63% over control, respectively. N fertilization helps in easy decomposition of residues of soybean and groundnut crops that would results in add organic matter in the soil. This may also be attributed due to the sufficiency of nutrients provided by inorganic fertilizers, thereby increasing the aboveground and root biomass and hence organic matter [45]. Soil organic C increased up to 35% in the N fertilized, residue retained sorghum–wheat plots compared to initial status of barely maintained 0-N sorghum–wheat plots [46]. Slight improvement in organic C was observed particularly when legume residues were incorporated over initial values [27].

Available N

Maximum available N was recorded under groundnut–wheat with residue incorporation (242.0 kg ha^{-1}), while it was minimum under maize–wheat (176 kg ha^{-1}). Moreover, residue application under groundnut and soybean resulted higher available N than residue removed by 30.10 and 25.64%, respectively (Table 7). Higher available N under groundnut and soybean residue incorporation suggests that legumes obtain much of their own nitrogen

Table 7 Effect of cropping system, legume residue management and *N* levels on soil chemical parameters after 2 years at wheat harvest

Treatment	Organic carbon (%)	Available *N* (kg ha^{-1})	Available *P* (kg ha^{-1})	Available *K* (kg ha^{-1})
Cropping system				
Maize–wheat (M-W)	0.424	177.0	13.04	223.8
Groundnut–wheat (G-W)	0.434	186.0	14.21	235.7
G-W + groundnut residue in wheat[a]	0.460	242.0	15.73	243.7
Soybean–wheat (S-W)	0.430	183.0	13.93	237.3
S-W + soybean residue in wheat[a]	0.450	230.7	15.62	246.3
SEm ±	0.005	1.877	0.169	1.700
CD (*P* = 0.05)	0.016	6.123	0.553	5.545
Nitrogen levels (kg ha^{-1})				
0	0.417	195.2	14.46	234.5
50	0.440	201.2	14.44	236.6
100	0.448	206.7	14.49	238.6
150	0.453	211.9	14.63	239.7
SEm ±	0.006	1.223	0.174	1.558
CD	0.018	3.531	NS	NS

[a]Groundnut residue added 4.02 t ha^{-1} during 2009–2010 and 4.25 t ha^{-1} during 2010–2011; soybean residue added 3.92 t ha^{-1} during 2009–2010 and 4.15 t ha^{-1} during 2010–2011

through N_2 fixation [47] and the grain legumes release N through the root, nodule or fallen leaf turnover during the growth period which added variable quantities of N, P and K to the soil. Roldan et al. [43] reported that total organic N was greater with residue additions of $\geq 66\%$ than without residues. Bakht et al. [28] and Shafi et al. [44] also reported significant increase in N content of soil due to crop residue incorporation. Available N status in soil increased significantly with each increased level of N up to 150 kg N ha^{-1}. This is attributed to more uptake of N from the control plots, while at 150 kg N ha^{-1} crops have not utilized the applied N more efficiently, resulting in lower and higher available N in soil, respectively. Moreover, legume residue incorporation along with higher dose of N might have accelerated the mineralization process and contributed to the higher N in soil.

Available P

The maximum soil available P was recorded in groundnut–wheat with residue incorporation (15.73 kg ha^{-1}), followed by soybean–wheat with residue incorporation (15.62 kg P ha^{-1}), which were significantly higher than groundnut–wheat (14.21 kg ha^{-1}) and soybean–wheat (13.93 kg ha^{-1}) with residue removed (Table 7). Maize–wheat had significantly lowest amount of available P in soil than all treatments (13.04 kg ha^{-1}). The richness in combined application of uniform recommended dose and residue incorporation satisfied the requirement of the crop in terms of uptake and resulted in higher available P content. Legumes help in solubilizing the insoluble P in soil through humic substance excreted by roots, increasing soil microbial activity and improving the soil physical environment [48, 49].

Available K

The maximum available K was obtained with soybean–wheat with residue incorporation (246.3 kg K ha^{-1}), followed by groundnut–wheat with residue incorporation (243.7 kg K ha^{-1}), which was 3.79 and 3.39% higher than residue removed (Table 7). Greater addition of K through legume residue and recommended dose of fertilizer might have enhanced the available K content in the residue incorporation treatments. This is in agreement with results of Verhulst et al. [50], which indicated the soil was rich in those nutrients where adequate amounts of fertilizers have been applied. Both available P and K in soil were not influenced to different levels of N; however, both were increased slightly with each increased levels of N from 0 to 150 kg N ha^{-1} and these nutrients may get replenished from the fixed reserve of fixed sources [51].

Conclusion

We conclude that wheat grown after groundnut with residue incorporation recorded the highest system productivity and resource use efficiency. Nitrogen economy in wheat was 44.5–54 kg N ha^{-1} through legume residue incorporation and 39.5–44.5 kg N ha^{-1} without residue. This study shows that sustainability of wheat-based cropping systems can be attained by the inclusion of grain legumes (with residue recycling) in rotation with cereals as against the existing exhaustive cereal–cereal systems like maize–wheat in north-western part of India.

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