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Research Paper

Legume stover and nitrogen management effects on system productivity, energetics and economics of wheat (*Triticum aestivum*)-based cropping systems

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ABSTRACT

A fixed plot field experiment was conducted at New Delhi during the *kharif* and *rabi* season of 2009–10 and 2010–11 to evaluate the effect of cropping systems, legume residue management, and N levels on system productivity, energetic and economics of wheat {*Triticum aestivum*(L.) emend. Fiori & Paol}–based cropping systems. The system productivity was the highest(8.62 t/ha)in groundnut (*Arachis hypogaea* L.)–wheat cropping system with residue incorporation closely followed by without residue incorporation (8.23t/ha). Groundnut–wheat and soybean {*Glycine max* (L.) Merrill}–wheat cropping system with residue incorporation recorded higher mean energy use efficiency (11.84 and 11.80 respectively), while maize (*Zea mays* L.)–wheat produced more gross energy output (268.7 $\times 10^3$ MJ/ha) and net energy (242.55$\times 10^3$ MJ/ha). On an average, groundnut–wheat cropping system with residue incorporation recorded higher net returns (72.01 $\times$ 10^3₹/ha), net returns per rupee invested (1.97) and system productivity (8.62 t/ha). System productivity, gross returns and net returns were the highest with 150 kgN/ha, however application of 150 kg N/ha was statistically similar to 100 kg N/ha with regards to net returns and net returns per rupee invested. There was saving of 50 kg N/ ha in wheat cultivation, when it was grown as succeeding crop after legume.

Key words: Energy, Economics, Nitrogen, System productivity, Wheat-based cropping system

In the past, agricultural growth resulted from application of quality inputs, farm mechanization and other improved agro–techniques including shift to intensive cropping. Injudicious use of agricultural practices in India led to sharp rise in the cost of production and energy use, decline in soil fertility and loss of crop and soil biodiversity. The conservation and management of natural resources and inputs are the key issues for researchers, which need proper consideration. Yield of different crops can be increased up to 30% by using optimal level of energy input (Chaudhary *et al*., 2006). The share of agriculture in national energy consumption has been rising consistently over the last three decades. The net energy and monetary return of a cropping system can be quantified for sound planning of sustainable systems (Chaudhary *et al*., 2006). Energy input–output relationships in cropping systems vary with the crops grown in a sequence, type of soils, nature of tillage operations for seed bed preparation, nature and amount of organic manure and chemical fertilizers, plant protection measures, harvesting and threshing operations, yield levels and biomass production (Singh *et al*., 1997; Mandal *et al*., 2002). Among the field crops, legumes involve much less energy requirement. Crop rotations with legumes are assumed to be energetically favourable to those without legumes due to reduced N fertilizer inputs (Varvel and Wilhelm, 2003). With greater emphasis on agricultural sustainability, legume crop residues are becoming an integral component of many cropping systems. An increase in use of either fertilizers or irrigation water increased the crop yield but reduced the energy–use efficiency. Judicious use of fertilizers and irrigation water reduced the energy cost of irrigation and fertilizers (Aggarwal, 1995). The continual rises in nitrogen fertilizer prices, combined with elevated environmental risk of NO_3^- contamination by leaching and nitrous oxide escape to atmosphere, needs to develop better strategies to improve nitrogen use efficiency. Continuous rice–wheat cropping with indiscriminate use of fertilizers is posing threat to agricultural sustainability and environmental safety. Under, such circumstances crop diversification is the best options, which not only gives more productivity than rice–wheat system, but also ensure the rational use of the resources and resulted in substantial saving of inputs especially water. In addition, diversification will result in much needed increase in productivity of pulses and oil-

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seeds, increase in economic returns of farmers and exploitation of legumes for their atmospheric N_2-fixing capacity and quality residue for recycling so as to improve organic matter in the soil and to reduce fertilizer requirements to achieve more productivity of the system (Gill and Ahlawat, 2006). Wheat-based cropping systems *viz*., maize–wheat, groundnut–wheat and soybean–wheat are commonly followed in north–western India. Thus, the information on energy input–output relationship, economics, system productivity and use efficiencies of N is lacking. The present study was therefore undertaken to assess the effect of legume residue recycling and N fertilization on system productivity, energy and economics of wheat based cropping systems under north-western India.

MATERIALS AND METHODS

A field experiment was conducted on a fixed site during rainy season (June to October) and winter season (November to April) of 2009–10 and 2010–11 at the research farm of Indian Agricultural Research Institute, New Delhi (28.4° N latitude, 77.1° E longitude and 228.6 m above mean sea level).

The mean annual rainfall of Delhi is 672 mm and more than 80% generally occurs during the monsoon season (July–September) with mean annual evaporation 850 mm.The soil at site was sandy loam (Inceptisol; Mahauli series) with bulk density, field capacity, hydraulic conductivity and infiltration rate of 1.55 Mg/m^3, 18.1 % (w/w),11.21 mm/hr and 11.42 mm/hr, respectively. It had 0.40% organic carbon, 175 kg $KMnO_4$ oxidizable N/ha, 12.24 kg 0.5 N $NaHCO_3$ extractable P/ha, 230 kg 1.0 N NH_4OAc exchangeable K/ ha, 7.6 pH and 0.32 dS/m EC at the start of the experiment. Field experiment was established on July 2009 with two grain legumes, groundnut and soybean for residue management (residue incorporated and residue removed) and maize as main plots in rainy season followed by wheat during winter season 2009–10. The experimental design was randomized block design for first year rainy season crops and split plot design for the following wheat and succeeding rainy season crops with 3 replications throughout. Main plot size was 17m × 3.6m, while sub–plot size was 3.5m × 3.6m. Cropping systems with residue management treatments *viz*, T_1: Maize–wheat (M–W), T_2: Groundnut–wheat (G–W), T_3: G–W+ groundnut residue in wheat @ 5t/ha, T_4: Soybean–wheat (S–W), T_5: S–W+ soybean residue in wheat @ 5t/ha were accommodated in main plots, while four rates of N applied to wheat in sub–plots were: 0 (control), 50, 100, and 150 kg N/ha. Maize 'BIO–9627', Groundnut 'GG–20' and Soybean 'DS–9814', were sown on 22nd July in 2009 and 6th July in 2010. Maize was sown with seed rate of 25 kg/ha in rows spaced at 60 cm and plant to plant 30 cm. Soybean and groundnut was sown with seed rate of 100 kg/ha and 80 kg/ha, spaced at 25–30 cm row to row. For soybean and groundnut a uniform dose of 25 kg N, 60 kg P_2O_5 and 50 kg K_2O/ha was applied as basal by broadcasting, and mixed with soil before sowing. For maize a recommended dose of 120 kg N, 60 kg P_2O_5 40 kg K_2O/ha was applied. Half of nitrogen and full P and Kwere applied as basal dose before sowing and remaining half nitrogen was applied in two equal splits at 30 and 60 DAS. These crops were harvested at different intervals during end of October on their maturity.

After harvest, the residues of grain legumes were used for residue management, i.e. residue incorporated and residue removed in their respective treatments. In residue incorporation treatment, groundnut and soybean stover was chopped into medium size pieces and incorporated @ 5t/ha into top soil of 15 cm by tractor drawn disc harrow about 15–20 days before sowing of wheat. The plots were irrigated prior to cultivation for wheat. The experiment was continued on a fixed site with same treatments until harvest of the wheat 2010–11. Wheat 'HD–2851' was sown in the last week of November and harvested in the middle of April during both the years with a seed rate 100 kg/ha in rows spaced at 22.5 cm. As basal dose 60 kg P_2O_5 and 40 kg K_2O/ha were applied at the time of sowing. The varying rates of N were applied in the sub–plots as per treatments, with 50% at sowing and remaining at 30 DAS and 60 DAS. The yields of rainy season crops *viz.* maize, groundnut and soybean were converted into wheat grain equivalent yield (WGEY) based on prevailing market price. System productivity was worked out by adding wheat grain equivalent yield of *kharif* season crops to wheat grain yield. The energy inputs referred to the both renewable and non–renewable energy. Renewable energy constituted manual, animal/bullock, seed, manure etc., whereas, non–renewable energy encompassed chemical fertilizer (NPK), tractor, diesel, electricity, lubricants, machinery and agro–chemical etc. Total physical, output referred to both grain and by–product yield. The energy output from the economic and by–product yield was also estimated. For estimation of energy inputs and outputs (expressed in MJ/ha) for each items of inputs and agronomic practices equivalents were utilized as suggested by Mittal and Dhawan (1988); Baishaya and Sharma (1990); Panesar and Bhatnagar (1994). Energy–use efficiency was calculated using the formula as suggested by Mittal and Dhawan (1988). The economics of wheat–based cropping systems was worked out on the basis of prevailing market price of different inputs and final produce.

The data collected from the field and laboratory work were subjected to statistical analysis using analysis of variance technique for split plot design. '*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. Economic analysis was done based on prevailing market prices in respective years.

RESULTS AND DISCUSSION

Productivity

Among the rainy season crops, wheat grain equivalent yield (WGEY) was recorded maximum in groundnut and minimum in soybean during both the years (Table 1). 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. Residual effect of N given to wheat was not recorded on *kharif* season crops during 2010. Significant effect of preceding legume and its residue incorporation was recorded on wheat yield as compared to maize. Incorporation of groundnut and soybean residue in wheat crop improved system productivity by 4.73 % and 4.49 % in groundnut–wheat and soybean–wheat over no residue incorporation in respective system (Table 1). The system productivity was the highest under groundnut–wheat cropping system with residue incorporation (8.84 t/ha), which was followed by groundnut–wheat with residue removed (8.28 t/ha). On an average groundnut–wheat+groundnut residue incorporation recorded 44.16 % increase in WGEY over maize–wheat system (Table 1). Soybean–wheat cropping system with residue removed recorded the lowest system productivity (6.72 t/ha). This attributed to improvement in soil physico-chemical and biological properties due to residue incorporation resulting in higher levels of crop productivity. Singh *et al*. (2009) also recorded higher system productivity due to residue application, which improved the soil physico–chemical and biological environment in the soil through addition of nutrients and enhanced microbial activity. Similarly, Ghosh *et al*. (2003) 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, which might be due to increase in grain yield of wheat with N dose. With application of 150 kg N/ha, system productivity recorded 2.64, 6.96, and 22.03 % increase in WGEY over 100 kg N/ha, 50 kg N/ha and control respectively. Yadav *et al.* (2005) reported that application of N up to 150 kg/ha significantly increased the grain yield of wheat. They reported that increase in grain yield was 12.3 and 17.3 % higher with 150 and 180 kg/ha, respectively, over 120 kg N/ha.

Economics

Rainy season crops

The cost of cultivation of rainy season crops was recorded minimum with soybean (14.23 ×10^3₹/ha and 14.11 ×10^3 ₹/ha) and maximum under maize (16.92 ×10^3₹ /ha and 16.80 ×10^3 ₹/ha) in 2009 and 2010 respectively.

Table 1. Effect of cropping system, residue management and N levels on wheat grain equivalent yield and system productivity (t/ha) in wheat-based cropping system

Treatment	Yield of rainy season crops (t/ha)		WGEY of rainy season crops(t/ha)		Wheat yield (t/ha)		System productivity (WGEY) (t/ha)	
	2009–10	2010–11	2009–10	2010–11	2009–10	2010–11	2009–10	2010–11
Cropping system								
Maize–wheat (M–W)	3.54	3.86	2.70	2.95	3.97	3.96	6.67	6.91
Groundnut–wheat (G–W)	2.02	2.02	3.85	3.86	4.33	4.42	8.18	8.28
G–W+ groundnut residue in wheat @5 t/ha	2.02	2.25	3.85	4.30	4.56	4.64	8.40	8.84
Soybean–wheat (S–W)	1.85	1.85	2.34	2.32	4.30	4.40	6.64	6.72
S–W+ soybean residue in wheat @5 t/ha	1.85	2.01	2.34	2.52	4.51	4.58	6.85	7.10
SEm±	–	–	0.090	0.030	0.050	0.046	0.081	0.054
CD (P=0.05)	–	–	0.296	0.098	0.162	0.151	0.264	0.176
Nitrogen levels (kg/ha)								
0	–	2.36	–	3.15	3.47	3.52	–	6.67
50	–	2.38	–	3.18	4.37	4.44	–	7.61
100	–	2.41	–	3.21	4.65	4.72	–	7.93
150	–	2.43	–	3.22	4.85	4.92	–	8.14
SEm±	–	–	–	0.024	0.030	0.031	–	0.035
CD (P=0.05)	–	–	–	NS	0.087	0.091	–	0.101

WGEY: Wheat grain equivalent yield

Maize registered high cost of cultivation during both the years mainly due to application of 120 kg N/ha, which was 5 times higher than legume crops. Gross returns (44.43 $\times 10^3$ ₹/ha, 51.54 $\times 10^3$ ₹ /ha in respective season), net returns (28.04 $\times 10^3$ ₹/ha, 35.40$\times 10^3$ ₹/ha in respective season) and net returns per rupee invested (1.71, 2.19 in respective season) were observed highest in groundnut (residue incorporated and removed) and minimum in soybean grown for residue incorporation and residue removed (Table 2). This might be due to the high minimum support price (MSP) for groundnut (₹ 21000/ t and ₹ 22000/t as compared to soybean (₹13900/t and ₹ 14400/t during 2009–10 and 2010–11) respectively. Moreover, groundnut produced more pod yield than soybean during both the years. Economics did not reveal significant variation due to residual effect of different levels of N to wheat on rainy season crops during 2010.

Succeeding wheat

Wheat after maize and legumes with residue removed recorded statistically similar cost of cultivation (17.74 $\times 10^3$ ₹/ha and 17.89 $\times 10^3$ ₹/ha during 2009–10 and 2010–11 respectively), which was considerably lower than wheat with legumes (groundnut and soybean) residue incorporation (20.24 $\times 10^3$ ₹/ha and 20.39 $\times 10^3$ ₹/ha during 2009–10 and 2010–11 respectively). Significantly, the highest gross returns (58.83 x10^3₹ /ha and 62.48 $\times 10^3$ ₹/ha) and net returns (38.59 $\times 10^3$ ₹/ha and 42.08 $\times 10^3$ ₹/ha) were recorded when wheat was grown after groundnut with residue incorporation during 2009–10 and 2010–11 respectively (Table 2). Significantly the lowest gross returns (51.63 $\times 10^3$ ₹/ha and 53.83 $\times 10^3$ ₹/ha) and net returns (33.89 $\times 10^3$ ₹/ha and 35.93 $\times 10^3$ ₹/ha) were recorded in wheat after maize. The highest net returns per rupee invested was recorded under groundnut–wheat with residue removed (2.16 and 2.33 in respective season) closely followed by soybean–wheat with residue removed (2.14 and 2.31). Maximum values of gross returns, net returns and net returns per rupee invested were recorded at 150 kg N/ha during both the seasons (Table 2). In the sequence, wheat was also more remunerative crop because of good yields and remunerative prices. In wheat, maximum cost of cultivation was recorded under groundnut–wheat and soybean–wheat with residue incorporation than residue removed and maize–wheat treatment. This was attributed to the additional expenditure of ₹ 2500/ha incurred on residue @ 5 t/ ha in wheat. The highest gross returns, net returns were recorded when wheat was grown after groundnut + residue incorporation which ascribed to high wheat yield due to improvement in soil parameters with residue incorporation. Net returns per rupee invested were high in groundnut–wheat followed by soybean–wheat with residue removed than their residue incorporation, which was due to more expenditure incurred in residue incorporation plots. Wheat responded significantly upto to 150 kg N/ha, as the soil was low in available N, variety grown was high yielding and crop received irrigation as and when required. Similar effects of preceding crops on wheat and N response were also reported by Sharma and Behera (2009).

Cropping systems

Maximum cost of cultivation was recorded under groundnut–wheat cropping system with residue incorporation (36.63 $\times 10^3$ ₹/ha and 36.53 $\times 10^3$ ₹/ha), while minimum under soybean–wheat cropping system with residue removed. During both the years, groundnut–wheat cropping system with residue incorporation recorded maximum gross returns (103.26 $\times 10^3$ and 114.02 $\times 10^3$₹/ha), and net returns (66.63 x 10^3 and 77.48 $\times 10^3$₹/ha) during 2009–10 and 2010–11, respectively (Table 2) followed by groundnut–wheat cropping system with residue removed. Net returns per rupee invested was the highest and similar with groundnut–wheat cropping system with and without residue incorporation (2.12 and 2.12) during 2010–11, while in 2009–10 it was slightly high in groundnut–wheat with residue removed (1.94) than with residue incorporation (1.81). The gross returns and net returns were computed maximum at 150 kg N/ha, which were significantly higher than all N levels. Net returns per rupee invested was also recorded maximum with 150 kg N/ ha, which was significantly higher than other levels except 100 kg N /ha during both the seasons. Economics parameters of cropping system followed trend similar to wheat. The maximum gross and net returns 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 (2009) also reported similar results. The increase in N application increased the wheat yield, which resulted in more gross and net returns at high level of N. However, application of 150 kg N/ha was statistically similar to 100 kg N/ha with regards to net returns per rupee invested. It indicated that saving of 50 kg N/ha in wheat cultivation can be possible, if it is grown as succeeding crop to legume. Kumar and Prasad (1999) also reported the saving of N when wheat grown after legumes.

Energetics

Rainy season crops

The input energy requirement in maize was higher than

Table 2. Effect of cropping system, residue management and N levels on economics of wheat based cropping systems.

Treatment	2009–10									2010–11								
	Gross returns (× 10^3 ₹/ha)			Net returns (× 10^3 ₹/ha)			Net returns per rupee invested			Gross returns (× 10^3 ₹/ha)			Net returns (× 10^3 ₹/ha)			Net returns per rupee invested		
	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total
Cropping system																		
Maize–wheat (M–W)	35.5	51.6	87.1	18.6	33.9	52.5	1.1	1.9	1.5	39.5	53.8	93.4	22.9	35.9	58.8	1.4	2.0	1.7
Groundnut–wheat (G–W)	44.4	56.1	100.6	28.0	38.4	66.4	1.7	2.1	1.9	46.4	59.7	106.1	30.3	41.8	72.1	1.9	2.3	2.1
G–W+ groundnut residue in wheat @5 t/ha	44.4	58.8	103.3	28.0	38.6	66.6	1.7	1.9	1.8	51.5	62.5	114.0	35.4	42.1	77.5	2.2	2.1	2.1
Soybean–wheat (S–W)	27.7	55.8	83.5	13.5	38.0	51.5	0.9	2.1	1.5	28.6	59.4	88.0	14.6	41.5	56.1	1.0	2.3	1.8
S–W+ soybean residue in wheat @5 t/ha	27.7	58.3	86.0	13.5	38.1	51.5	0.9	1.9	1.4	31.0	61.7	92.8	17.0	414	58.4	1.2	2.0	1.7
SEm±		0.58			0.58			0.03		0.36	0.52	0.62	0.36	0.52	0.62	0.02	0.03	0.02
CD (P=0.05)		1.89			1.89			0.10		1.16	1.69	2.01	1.16	1.69	2.01	0.07	0.09	0.06
Nitrogen levels (kg/ha)																		
0	–	45.3			27.4			1.5		39.0	48.1	87.1	23.6	30.1	53.6	1.5	1.7	1.6
50	–	56.6			38.0			2.1		39.2	59.9	99.1	23.9	41.3	65.1	1.5	2.2	1.9
100	–	60.1			41.1			2.2		39.6	63.6	103.2	24.2	44.5	68.70	1.6	2.3	2.0
150	–	62.7			43.1			2.2		39.8	66.1	106.0	24.4	46.4	70.9	1.6	2.4	2.0
SEm±		0.37			0.37			0.02		0.28	0.39	0.41	0.28	0.39	0.41	0.02	0.02	0.01
CD (P=0.05)		1.06			1.06			0.06		NS	1.11	1.19	NS	1.11	1.19	NS	0.06	0.04

Price of produce/t (2009–10), Maize grain ₹ 8,400, Maize stover ₹ 1,000, Groundnut grain ₹ 21,000, Groundnut stover ₹ 500, Soybean grain ₹ 13,900, Soybean stover ₹ 500, Wheat grain ₹ 11,000, Wheat stover ₹ 1,200.

Price of produce/t (2010–11), Maize grain ₹ 8,800, Maize stover ₹ 1,000, Groundnut grain ₹ 22,000, Groundnut stover ₹ 500, Soybean grain ₹ 14,400, Soybean stover ₹ 500, Wheat grain ₹ 11,500, Wheat stover ₹ 1,200.

groundnut and soybean, which may be attributed to its higher N requirement and other field operations. The highest gross energy output (124.08×10^3 MJ/ha and 126.42×10^3 MJ/ha) and net energy output (110.29×10^3 MJ/ha and 113.39×10^3 MJ/ha), was recorded by maize, due to production of more economic yield and biomass. Maize, a C_4 crop with negligible photo–respiration, has ability to utilize the solar energy more efficiently, which reflected in grain and total biomass production compared with C_3 crops. Groundnut ranked second in energy output and net energy, because energy density within a unit mass of its kernel is much higher than in cereals and pulses. Gross and net output energy was more in year 2010 than year 2009; which was resulted due to higher biomass yields of rainy season crops in 2010. Energy use efficiency of rainy season crops was more in 2010 than 2009. Maximum energy efficiency was recorded in groundnut, closely followed by soybean. In 2010 energy use efficiency was slightly high in groundnut and soybean grown after residue incorporated wheat than no residue incorporated wheat. The lowest energy use efficiency was recorded in maize (9.07 and 9.62) during 2009 and 2010 (Table 3). This variation in energy use efficiency among the rainy season crops ascribed to variation in energy output and input. Energetic of rainy season crops in 2010 were not influenced due to residual effect of N levels given to wheat. These findings are in agreement with that of Singh *et al*. (1997).

Succeeding wheat crop

Input energy of wheat after *kharif* crops was almost similar, except residue incorporation of groundnut and soybean, where it was slightly more. Input energy consumption in wheat increased with increase in level of N from control to 150 kg N/ha (8.18×10^3 MJ/ ha to 17.27×10^3 MJ/ ha). The highest gross energy output (157.86×10^3 MJ/ha and 162.92×10^3 MJ/ha in respective seasons) and net energy output (139.58×10^3 MJ/ ha and 144.50×10^3 MJ/ha in respective seasons) was produced under groundnut–wheat with residue incorporation followed by soybean–wheat with residue incorporation (Table 3). Gross and net energy output with residue incorporation was significantly higher than respective residue removal treatments. The lowest gross and net energy output was recorded in wheat after maize during both the years. The energy use efficiency was also recorded significantly highest under groundnut–wheat (13.0 and 13.5) and soybean wheat (12.9 and 13.4) with residue incorporation than their respective residue removed treatments and maize–wheat during 2009–10 and 2010–11. Gross and net energy output increased with each increase in N levels, while reverse trend was observed in energy use efficiency. The highest gross and net energy output was observed at 150 kg N/ha, which was significantly higher than all N levels, while the maximum energy efficiency was observed at 0–N, which was significantly higher than other levels of N in both the years. Wheat produced significantly high gross output, net energy and energy use efficiency when it was grown after groundnut and soybean with their residue incorporation, while lowest energy values were recorded in wheat grown after maize. Residue incorporation along with different N levels resulted in more grain and straw yield consequently produced maximum gross output energy, net energy and energy use efficiency. This may be attributed to favorable residual fertility of preceding legumes on the succeeding wheat crop (Singh *et al*., 1997). Increase in N levels increased the energy input and gross and net energy output, while the reverse was true in energy use efficiency. However, increase in gross and net energy output with increase in N levels was proportionately less as compared to increase in energy input, which further resulted in decrease in energy use efficiency with increasing N levels. This behavior of wheat energy parameters in response to N ascribed to very low N use efficiency in general and further decline in N use efficiency with increasing N levels. Similar results of increased energy with increase in N were also reported by Kumar and Prasad (1999).

Cropping systems

Maximum input energy requirement of 26.40×10^3 MJ/ha and 25.86×10^3 MJ/ha during 2009–10 and 2010–11, respectively was recorded in maize–wheat and the minimum was under groundnut–wheat and soybean–wheat cropping system with residue removal. Input energy of cropping systems was increased with each increase in levels of N up to 150 kg N/ha. The highest gross energy output was produced under maize–wheat cropping system (265.91×10^3 MJ/ha and 271.46×10^3 MJ/ ha in respective season) and the lowest was recorded under soybean–wheat with residue removal. Gross energy output was more in 2010–11 than 2009–10 (Table 3). Net energy output followed trend across the treatment similar to gross energy output during both the years. The highest energy use efficiency was recorded under groundnut–wheat (11.31 and 12.37 in respective season) closely followed by soybean–wheat (11.29 and 12.31 in respective season) with residue incorporation, while the lowest with maize–wheat (10.07 and 10.58) during both the years. The highest gross and net energy output was observed at 150 kg N/ha, which was significantly higher than all N levels. In contrast to gross and net energy output, the maximum energy use efficiency was observed at 0–N, which was significantly higher than other levels of N in both the

Table 3. Effect of cropping system, residue management and N levels on energetics of wheat-based cropping systems.

Treatment	2009–10									2010–11								
	Gross output energy ($\times 10^3$ MJ/ha)			Net energy ($\times 10^3$ MJ/ha)			Energy use efficiency (output/ input ratio)			Gross output energy ($\times 10^3$ MJ/ha)			Net energy ($\times 10^3$ MJ/ha)			Energy use efficiency (output/ input ratio)		
	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total	Rainy season crops	wheat	Total
Cropping system																		
Maize–wheat (M–W)	124.1	141.9	265.9	110.4	129.1	239.5	9.1	11.6	10.1	126.4	145.0	271.5	113.3	132.3	246.0	9.6	11.9	10.6
Groundnut–wheat (G–W)	87.0	152.3	239.2	78.0	139.6	217.6	9.8	12.5	11.1	86.2	157.2	243.5	77.9	144.5	222.4	10.3	13.0	11.8
G–W+ groundnut residue in wheat @5 t/ha	87.0	157.9	244.8	78.0	145.1	223.1	9.8	13.0	11.3	93.8	162.9	256.8	85.5	150.2	235.6	11.2	13.5	12.4
Soybean–wheat (S–W)	82.6	151.5	234.0	74.1	138.7	212.8	9.8	12.5	11.1	82.5	156.6	239.0	74.5	143.9	218.4	10.4	12.9	11.8
S–W+ soybean residue in wheat @5 t/ha	82.6	156.8	239.3	74.1	144.0	218.1	9.8	12.9	11.3	88.3	161.7	250.0	80.4	149.0	229.4	11.2	13.4	12.3
SEm±	–	1.14	–	–	1.14	–	–	0.11	–	0.66	0.71	0.98	0.65	0.71	0.98	0.08	0.08	0.05
CD (P=0.05)	–	3.71	–	–	3.71	–	–	0.35	–	2.13	2.31	3.20	2.13	2.31	3.20	0.24	0.27	0.17
Nitrogen levels (kg/ha)																		
0		125.3			117.1			15.3		94.7	131.4	226.1	85.6	123.2	208.8	10.5	16.0	13.2
50		152.0			140.7			13.6		95.0	157.1	252.1	85.9	146.0	231.8	10.5	14.0	12.5
100		161.8			147.6			11.4		95.9	166.4	262.2	86.7	152.1	238.8	10.6	11.7	11.3
150		169.1			151.8			9.8		96.2	172.0	268.1	87.1	154.7	241.7	10.6	10.0	10.2
SEm±		0.91			0.91			0.09		0.46	0.81	0.75	0.46	0.81	0.75	0.05	0.08	0.04
CD (P=0.05)		2.63			2.63			0.25		NS	2.33	2.17	NS	2.33	2.17	NS	0.23	0.12

years. Singh *et al*. (1997) also observed beneficial residual effect of legumes on the succeeding cereal crop. In spite of less wheat output energy, maize–wheat cropping system recorded highest gross and net energy output was mainly due to higher maize grain and total biomass energy than groundnut and soybean. Based on 2 year average, groundnut–wheat and soybean–wheat cropping system with residue incorporation recorded higher EUE than maize–wheat cropping system, mainly because of 22.25 % and 24.88 % lower energy requirement. Similarly Baishya and Sharma (1990) and Mandal *et al*. (2002) reported that legumes require much less energy expenditure than other crops. N levels applied to wheat in wheat based cropping system resulted in same trend in system energy parameters as in case of wheat.

It can be concluded that maximum system productivity, energy use efficiency, net returns, net returns per rupee invested, were significantly higher in groundnut–wheat followed by soybean–wheat with residue incorporation compared to residue removal and maize–wheat system. Increase in N levels resulted in higher values of economics, energy but EUE decreased with increase in N, while net returns per rupee invested increased significantly only up to 100 kg N/ha. Among the systems, groundnut–wheat system with groundnut residue incorporation is more productive and economical with less requirement for N as compared to maize–wheat system.

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