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Energy scenario, carbon efficiency, nitrogen and phosphorus dynamics of pearlmillet –mustard system under diverse nutrient and tillage management practices

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Under limited moisture conditions integrated nutrient management and conservation agriculture (CA) practices plays a vital role. Information on effect of integrated nutrient management (INM) with CA practices in pearlmillet (*Pennisetum glaucum*) –mustard (*Brassica juncea*) system is lacking. The present experiment was conducted during 2005-06 and 2006-07 in rainy and winter seasons, at IARI, New Delhi, India to investigate the effect of INM and tillage on pearlmillet -mustard system under limited irrigation. Ridge and furrow (RF) sowing produced significantly higher carbon efficiency (CE), energy output, net returns and economic yield (3768 kg ha^{-1}) of pearlmillet-mustard sequence. The application of 30 kg N + 30 kg P_2O_5 + FYM at 6 t/ha to pearlmillet produced significantly higher yield attributes, economic yield (3982 kg ha^{-1}), energy output (194023 MJ ha^{-1}) of the system and CE and net return (189.41 and 315.8 US$ ha^{-1}) of pearlmillet and mustard individually over control, 30 kg N + 20 kg P_2O_5/ha and sole application of FYM at 6 t/ha. Direct application of 60 kg N + 40 kg P_2O_5/ha to mustard produced significantly higher yield attributes, economic yield (3692 kg ha^{-1}), energy output (182097 MJ), net return (296.73 US$ ha^{-1}) and CE (10.80 and 11.51 during both the years), over control and 30 kg N + 20 kg P_2O_5/ha. The application of INM with ridge furrow sowing increased available N and P contents in the soil. Whereas, the consumptive use, moisture use rates and moisture use efficiency were the highest under ridge furrow sowing of pearlmillet-mustard system.

Key words: Carbon efficiency, consumptive use, energy output, pearlmillet-mustard system, N and P balance, soil fertility.

INTRODUCTION

In India, about 28 to 30 Mt of nutrients (N, P, K) are removed from the soil whereas, 18 to 20 Mt are added through all sources, leaving a deficit of about 10 Mt yearly (Singh and Singh, 2003). Therefore, integrated management of organic and mineral fertilizers is, advocated to meet the nutrient needs, improve soil quality, and to obtain

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sustainable and higher yields of pearlmillet–mustard (PM) production system. Pearlmillet (*Pennisetum glaucum*) – mustard (*Brassica juncea*) is most prominent and popular cropping system under limited irrigation conditions in north-western parts of India to meet the national shortfall of food grain and edible oil. The contribution of this cropping system to total food grain and oilseed production is considerably large, being 3.5% of pearlmillet with 7.70 million tonnes of production (Economic Survey, 2006-07).

The PM system is most popular in semi-arid tropics of India, because of its limited water requirement, low requirements of inputs and labour and high profitability compared to other intensive cropping sequences (Satyajeet and Nanwal, 2007).). This system is practiced in about 0.9 million hectares area in India (Yadav et al., 1996). Application of adequate amount and judicious combination of organic and inorganic fertilizers commensurating with the crop needs is considered imperative for realizing sustainable yields of these crops when grown in sequence under limited irrigated (Kaushik and Gautam, 1991; Satyajeet et al., 2007). To optimize the use of organic and mineral sources, information is needed on the rate and pattern of N and P mineralization in the soil from organic source (Hadas and Portnoy, 1994). Application of organic source with wide C/N ratio may increase the immobilization of fertilizer N, thereby influencing crop availability and N losses. On the other hand, combining with fertilizer N lowers the C/N ratio of the organic source, leading to an enhanced N mineralization (Singh et al., 2003).

Judicious and efficient nutrient management in cropping system depends on understanding complex interactions between soil and experimental site properties, crop characteristics, climate, and biological processes influencing nutrient dynamics. Preceding and succeeding crop history and other management practices also affect nutrient management strategies. The complexity of the interacting factors indicates that site specific knowledge may be needed for best nutrient management. The *in situ* soil core technique can be helpful in evaluating management effects on nutrient availability and provide site-specific information needed for improved nutrient management (DiStefano and Gholz, 1986; Raison et al., 1987; Kolberg et al., 1997).Crop establishment is also most important concern in this cropping sequence under limited water condition in such situation conservation agriculture based ridge-furrow method plays a vital role (Jat et al., 2008). Because moisture is the principle growing factor for crop production under rainfed conditions, which needs to be conserved for optimization of nutrient use and maximizing the yield advantages of this cropping system (Jat et al., 2008). Agricultural productivity is closely linked with the carbon and energy efficiency.

The measure of carbon efficiency and energy flow in crop production system provides a good indicator of the technological aspects of crop production system in agriculture (Singh et al., 1997a; Dubey and Lal, 2009; Tandon and Singh, 2009; Parihar et al., 2011). For sustainability in carbon and energy management the efforts have to be double pronged, firstly efficient use of commercial energies, and secondly harnessing renewable energy sources as supplementary and substituting commercial energy sources. Direct-energy inputs to crop production systems are derived from power sources like human, draft animals, engines, tractors, power tillers, and electric motors, etc. required to perform various unit operations as well in direct energy inputs are in the form of seeds, organic manures, fertilizers, pesticides, growth regulators etc. Consumption of energy has been increasing at a steady rate to improve productivity in cropping systems of Indian agriculture. But the energy input-output ratio is declining consistently (Mahendra Pal et al., 1985). Hence, the present investigation was undertaken to find out the best conservation agriculture based crop establishment and efficient nutrient management practices for pearlmillet-mustard cropping system under limited irrigation conditions to achieve sustainable and high productivity, carbon and energy efficiencies and sustainable soil health and quality.

MATERIALS AND METHODS

Experimental site and soil characteristics

The experiment was conducted at the research farm of the Indian Agricultural Research Institute, New Delhi, which is situated at 28°58'N latitude and 77°10'E longitude with an elevation of about 228.6 m above mean sea level and characterized in the long term by a semi-arid and sub-tropical type of climate. The average rainfall is 500.9 mm of which about 85% falls during June to September. The meteorological data of the Indian Agricultural Research Institute's Meteorological Observatory recorded 13.2 and 37.5 mm rainfall, 3.25 and 3.50 mm/day average evaporation, the minimum and maximum temperature ranges from 1.9 to 36°C and 2.2 to 3.5°C and 5.4 and 5.6 h/day average bright sunshine hours during growing seasons in 2005-06 and 2006-07, respectively (Figure 1). The soil of experimental site was sandy loam in texture having 62.4% sand, 18.7% silt and 18.9% clay contents. The experimental soil was having pH 8.0 (1:2.5 soil to water suspension with glass electrode pH meter), organic carbon 0.4%, available N 137.6 kg/ha, available P 13.0 kg/ha and available K 180.1 kg/ha at the beginning of the experiment in 0 to 30 cm soil layer. Chemical analysis of soil nutrients were done by using the Subbiah and Asija (1956) procedure for determination of available N, Olsen's method for available P (Olsen, 1954), 1N ammonium acetate method for available K determination (Hanway and Heidel, 1952), and chromic acid oxidation method for organic carbon (Walkley and Black, 1934). The field capacity and permanent wilting point of the experimental site were 19.12 and 6.52% on weight basis, respectively.

Field experiment

The experiment was conducted at the same site without altering the layout plan and randomization of the treatments and was carried out in randomized block design to pearlmillet and split plot design to

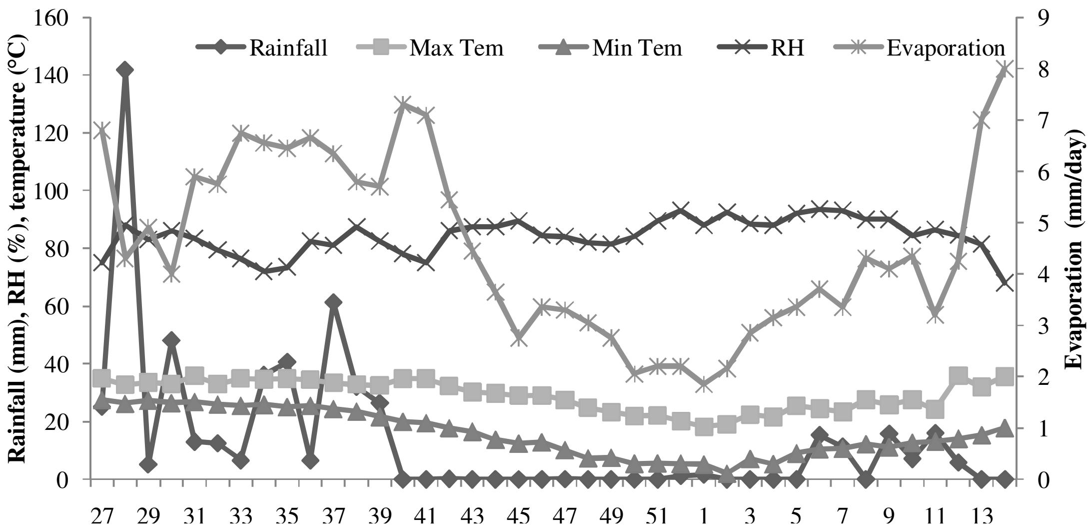

Figure 1. Weather parameters during cropping period (mean of two years).

Table 1. Treatments used on pearlmillet–mustard cropping system in the field experiment at the Indian Agricultural Research Institute, Delhi, India (2005–2007).

Treatment code	Treatment detail
Main plot treatment to pearlmillet	
Tillage practices	
L_1	Flat sowing
L_2	Ridge and furrow sowing
Nutrient management	
F_0	Control
F_1	30 kg N + 20 kg P_2O_5 ha^{-1}
F_2	60 kg N + 40 kg P_2O_5 ha^{-1}
F_3	30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}
F_4	FYM at 6 t ha^{-1}
Sub plot treatment to mustard	
M_0	Control
M_1	30 kg N + 20 kg P_2O_5 ha^{-1}
M_2	60 kg N + 40 kg P_2O_5 ha^{-1}

mustard with three replications. The treatments consisted of ten combinations (Table 1) to pearlmillet of two crop establishment practices: Flat sowing, ridge and furrow sowing and five nutrient management – control, 30 kg N + 40 kg P_2O_5/ha, 60 kg N + 40 kg P_2O_5/ha, 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha and FYM at 6 t/ha alone, for mustard all preceding treatments were splitted into three direct applied nutrients levels to mustard were – control, 30 kg N + 20 kg P_2O_5/ha and 60 kg N + 40 kg P_2O_5/ha were assigned in sub-plots. The well decomposed farm yard manure with composition (C 10.4%, N 0.53%, C:N ratio 19.6:1, P 0.22% and K 0.59%) was applied two weeks before sowing and incorporated in soil (Table 3). Nitrogen and phosphorus were applied as per treatments through urea and phosphorus through single super phosphate. The fertilization rates of nitrogen and phosphorus are applied based on the recommended doses of these nutrients in the zones or location of respective soil and agro-climatic conditions.

'Pusa compositae-383' of pearlmillet and 'Pusa Agrini' of mustard varieties was sowed at 50 and 45 cm apart in rows. Pearlmillet during rainy season was sowed on 19 July 2005 and 15 July 2006, while mustard during winter season was sowed on 25 October 2005-06 and 21 October 2006-07, using 5 and 4 kg seed per hectare, respectively. Other management practices were adopted as per recommendations of the individual crops (pearlmillet and mustard) under limited water supply. The sowing of pearlmillet as well as mustard were carried out uniformly with flat sowing and ridge and furrow sowing methods. Farm yard manure at 6 t/ha was incorporated two weeks prior to sowing as per the treatments to the crops. The application of fertilizers as per the treatments viz., no nutrient, 30 kg N + 20 kg P_2O_5/ha, 60 kg N + 40 kg P_2O_5/ha, 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha and sole application of FYM at 6 t/ha to preceding pearlmillet crop and no nutrient (control), 30 kg N + 20 kg P_2O_5/ha and 60 kg N + 40 kg P_2O_5/ha to succeeding mustard was done before sowing the seed. Chemical fertilizers (urea and single super phosphate) were applied at plough sole depth (below the soil surface) two days before sowing. The only one experiment was conducted for two years with two crops, that is, pearlmillet during kharif and mustard during rabi season) the treatment of succeeding mustard crop were super imposed on the respective main plot treatments of the preceding pearlmillet.

Plant sampling and biometric observations

The biometric observations pertaining to plant height, dry matter accumulation and yield attributes were recorded from five representative plants of pearlmillet and mustard, which were selected randomly from each treatment at 30 DAS and at harvest in pearlmillet and 40 DAS and at harvest in mustard, respectively during the growing seasons. Crop growth rate (CGR) was calculated on the basis of dry matter accumulation by using following formula:

$$\text{Crop growth rate (CGR)} = \frac{(W2 - W1)}{(t2 - t1)} \quad (\text{g/cm}^2/\text{ day})$$

Where, W_1 = weight of dry matter per cm^2 at time t_1, W_2 = weight of dry matter per cm^2 at time t_2.

The leaves of 1 m row length plants were separated, cleaned and leaf area was recorded by using leaf area meter (LI-COR 3100) at 30 DAS and at harvest to pearlmillet and 40 DAS and at harvest to mustard. Leaf area index (LAI) was calculated by dividing leaf surface area by land surface area. The dry matter of plant sample of 1-m row length was weighed after drying in an electric oven at 65 $\pm$ 2°C temperature. The experimental plots of pearlmillet and mustard were harvested on 16 and 8 October 2005 and 2006 and 20 and 12 February 2005-06 and 2006-07, respectively. The yield recorded and pooled on the basis of net plot (3.0 × 2.1 m) harvested and threshed.

Soil sampling and analysis

The composite soil samples were collected from 0 to 30 cm soil depth before the start of experiment and after harvesting of mustard crop in both the years of field experiments. These soil samples were air dried ground and passed through 2 mm sieve and analyzed for total N, available P and carbon were calculated separately from each plot after harvest of the crop. Nitrogen concentration in grain and Stover was estimated by modified Kjeldhal's method (Jackson, 1958). Phosphorus content in the plant samples was determined by Vanado-molybdo-phosphoric yellow colour method (Jackson, 1958). The uptake of nutrients (kg/ha) was computed by using the following formula:

$$\text{Uptake of nutrients (kg/ha)} = \frac{\text{Concentration of nutrient (\%) x Dry matter of plant parts (kg/ha)}}{100}$$

Soil moisture was determined at 30 days interval from four soil depths: 0-30 31-60, 61-90 and 91-120 cm commencing from sowing to harvest with the help of tube auger. Seasonal consumptive use of water for the entire growing season of the crop was estimated adding total soil moisture depletion by the crop during different measurement periods of crop growth and calculated from soil moisture determination. Soil moisture percentage (w/w) was determined after oven drying the samples at 105°C temperature for 24 h by gravimetric method. Consumptive use of water was worked out from the above soil moisture data. The consumptive use (CU) of water by the crop under different treatments was computed by using the formula described by Dastane (1972):

$$CU = \left[\sum_{K=1}^{N} (Ep + 0.6) + \sum_{i=1}^{n} \frac{M1i - M2i}{100} \times ASi \times Di + ER \right]$$

Where, CU = consumptive use of water (mm); Ep = evaporation from the USWB class A open pan (mm); 0.6 = a constant used to obtain ET value from the Ep value for the given period of time; M_{1i} = soil moisture percentage at the time of first sampling in the layer; M_{2i} = soil moisture percentage at the time of second sampling in the ith layer; Asi = apparent specific gravity of the i^{th} layer of the soil (g/cm^3); D*i* = depth of i^{th} layer of the soil (mm); ER = effective rainfall (during the crop growth period). Water use efficiency in terms of marke produce was worked out by the following formula:

$$\text{Water use efficiency (kg grain /ha mm)} = \frac{\text{Grain yield (kg/ha)}}{\text{Consumptive use of water (mm)}}$$

Energy and carbon efficiency analysis

Energy efficiency, energy production and energy intensity were calculated by using the following formulae as suggested by Mittal and Dhawan (1988) and Singh et al. (1997b):

$$\text{Energy efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Net energy (MJ/ha)} = \text{Energy output (MJ/ha)} - \text{Energy output (MJ/ha)}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Output of grain and byproduct (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy intensity (in economic terms MJ/INR)} = \frac{\text{Energy output (MJ/ha)}}{\text{Cost of cultivation (INR/ha)}}$$

The primary data collected on various inputs and management practices for both the crops were used for computation of energy consumption, and it's various ratios for each crop of this cropping system. The energy output from the economic and by-product yield was also estimated. After threshing the grains were separated and by-product yield was estimated. The damage of output was very negligible due to natural calamities and pests. Thus damage or waste is not included. While CE = C_o / C_i where; CE= Carbon efficiency, C_o= Carbon output and C_i= Carbon input given by (Lal, 2004). Total carbon input was calculated as the sum of the carbon equivalent of all inputs used for crop production (Table 2) while total carbon output was computed as the sum of the carbon equivalent of grain, straw and root biomass produced by crop. Carbon equivalent of inputs as well outputs was calculated by using globally prescribed values by different scientists.

Economics

The economics of cultivation was worked out on the basis of prevailing market price of produce and cost of inputs.

$$\text{Gross returns (US \$/ha)} = \text{Economic yield} \times \text{Market price of produce}$$

$$\text{Net return (US \$/ha)} = \text{Gross return} - \text{Cost of cultivation}$$

$$\text{Benefit: cost ratio} = \frac{\text{Net return}}{\text{Cost of cultivation}}$$

Table 2. Energy conversion factor for different inputs and outputs.

S/N	Particulars	Units	Equivalent energy (MJ)	Remarks
A	**Inputs**			
	Human labour			
1	Adult man	Man-hour	1.96	
	Woman	Woman-hour	1.57	
2	Animals	Bullock-pair/day	64.56	
3	Diesel	Liter	56.3	Including cost of lubricants
4	Electricity	Kwh	11.93	
	Machinery			
5	Electric motor	kg	64.8	Including self propelled machines
	Farm machinery	kg	62.7	
	Chemical fertilizers			
6	Nitrogen	kg	60.60	
	Phosphate (P_2O_5)	kg	11.10	
	Potash (K_2O)	kg	6.7	
7	Farm yard manure (FYM)	kg	0.3	Dry weight basis
8	Chemicals			
	Superior chemicals	kg	120	Requires dilution at the time of application
9	Seed		As output of the crop production system	
B	**Output**			
1	Main product			
	Pearlmillet	kg	14.7	Dry weight basis
	Mustard	kg	14.7	Dry weight basis
2	By-Product			
	Stover/stalk	Kg	12.5	Dry weight basis

Table 3. Nutrient concentration (%) and amount added by FYM (6 t/ha, dry weight basis) in the field experiment (averaged over 2 years)

Nutrients (%)	Content (%)	Nutrient added (kg ha^{-1})
N	0.53	31.8
P	0.22	13.2
K	0.59	35.4

The cost of inputs as well as price of produce varied in different years as follows:

Cost of inputs: 11.50 to 11.75 kg^{-1}N as urea, INR 30 kg^{-1} P_2O_5 as single super phosphate and INR 200 t^{-1} of FYM. Price of produce: INR 5.25 to 5.40 kg^{-1} pearlmillet grain; INR 0.40 kg^{-1} of pearlmillet stover; INR 17.15 kg^{-1} of mustard seeds and INR 0.20 kg^{-1} of mustard stalk (INR: Indian national rupees.)

Data analysis

The analysis of variance was done in RBD and split-plot design to pearlmillet and mustard, respectively for various observations recorded during experimentation as described by Gomez and Gomez (1984). The results were presented at 5% of significance (P=0.05). The critical difference (CD) values were calculated to compare the various treatments mean.

RESULTS AND DISCUSSION

Growth parameters of pearlmillet and mustard

The growth parameters indicated significant differences with respect to plant height, leaf area index (LAI), dry matter accumulation and crop growth rate (CGR) of pearlmillet and mustard cropping sequence. The pearlmillet and mustard at harvest recorded significantly superior values of plant height, LAI, dry matter accumulation and CGR with ridge and furrow sowing method than that of flat sowing. The improvement in growth attributes could be due to ridge and furrow sowing method maintains favorably moisture condition in the soil for relatively longer duration. These results were in close conformity with the results of Kantwa et al. (2005).

Table 4. Effect of nutrient management and tillage on plant height, leaf area index, dry matter accumulation and total number of tillers of pearlmillet (pooled over two years).

Treatments	Plant height (cm) Days after sowing		Leaf area index Days after sowing		Dry matter accumulation (g plant^{-1}) days after sowing		Total no. of tillers/m row length Days after sowing	
	30	Harvest	30	Harvest	30	Harvest	30	Harvest
Tillage practices								
Flat sowing	61.2	168.2	1.51	1.05	12.8	50.6	21.6	18.7
Ridge and furrow sowing	63.7	184.9	1.59	1.17	13.4	57.9	24.4	22.1
SEm $\pm$	1.22	4.17	0.03	0.03	0.39	1.29	0.76	0.50
CD (P=0.05)	NS	12.38	NS	0.09	NS	3.82	2.24	1.49
Nutrient management								
Control	54.7	162.1	1.42	0.88	10.0	45.1	17.7	16.48
30 kg N + 20 kg P_2O_5 ha^{-1}	62.3	173.7	1.56	1.07	13.2	52.8	21.3	19.86
60 kg N + 40 kg P_2O_5 ha^{-1}	66.4	186.4	1.61	1.25	14.4	59.7	27.5	22.9
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	66.1	187.7	1.62	1.28	14.3	60.3	276	22.7
FYM at 6 t ha^{-1}	62.6	172.7	1.55	1.09	13.7	53.5	20.9	20.2
SEm $\pm$	1.93	6.59	0.04	0.05	0.61	2.03	1.19	0.79
CD (P=0.05)	5.75	19.40	0.12	0.14	1.82	6.04	3.55	2.35

Integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha to preceding pearlmillet exhibited a measurable improvement in growth attributes and recorded significantly higher values of plant height, leaf area index, dry matter accumulation of both the crops and crop growth rate of mustard than that of control, 30 kg N + 20 kg P_2O_5/ha and FYM at 6 t/ha alone, and being on par with 60 kg N + 40 kg P_2O_5/ha (Tables 4 and 5). Application of farm yard manure (FYM) in combination with other chemical fertilizers like urea and single super phosphate proved better. This might be due to the role of FYM in enhancing soil health and quality and also biological properties including nutrient and water holding capacity thereby improving water relation and root growth. Moreover, FYM has synergistic relationship with urea and single super phosphate, thereby helping in mineralization of applied nitrogen and phosphorus, which might have helped in increased growth parameters of pearlmillet (Yakadri and Gautam, 2001) and mustard (Lal et al., 1996). The plant height, dry matter accumulation, LAI and CGR of mustard increased with increasing directly applied fertility levels at all growth stages which might be attributed to moisture availability for longer period resulting in balanced nutrient application (Table 5). The beneficial effect of fertilizers on LAI and dry matter accumulation was also observed by Cheema et al. (2001).

Seed (economic yield) and straw (by-product yield) yields of pearlmillet and mustard

Economic (seed and by-product (straw) yields of pearlmillet-mustard cropping system significantly improved in ridge and furrow sowing method as compared with flat sowing (Table 6). The increase in seed and straw yields of system under ridge and furrow sowing method was 12.9 and 13.4%, respectively over the flat sowing which was due to significant improvement in growth parameters of both the crops of the system. These results were in close conformity with the results of Kantwa et al. (2006). The superiority of ridge and furrow sowing method could be ascribed to conservation of moisture during post-monsoon period and proper drainage of excess water coupled with adequate aeration at the time of excess rainfall, seed and straw yields of pearlmillet-mustard cropping system significantly influenced by nutrient management to preceding pearlmillet crop (Table 6). Integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha recorded significantly higher seed and straw yield of pearlmillet-mustard cropping sequence over control, 30 kg N + 20 kg P_2O_5/ha and sole application of FYM at 6 t/ha, and being on par with 60 kg N + 40 kg P_2O_5/ha. The increment in seed and straw yields was 36.3 and 30.8, 15.2 and 13.3 and 14.6 and 12%) over control, 30 kg N + 20 kg P_2O_5/ha and FYM at 6 t/ha, respectively. Similar results were also reported by Satyajeet et al. (2007). This increment in seed and straw yield might be due to beneficial effect of combined use of organic sources and inorganic fertilizers could be attributed to the fact that after proper decomposition and mineralization, the manure supplied available plant nutrients in balanced proportion directly to the plants and also had solubilizing effect on fixed form of nutrients in soil. The directly applied nutrients 60 kg N + 40 kg P_2O_5/ha, recorded significantly higher seed and straw yield of pearlmillet-

Table 5. Effect of nutrient management and tillage on plant height, dry matter accumulation, leaf area index and crop growth rate of mustard (Pooled over two years).

Treatments	Plant height (cm) Days after sowing		Dry matter accumulation (g plant^{-1}) Days after sowing		Leaf area index Days after sowing		Crop growth rate (g day^{-1} cm^{-2}) Days after sowing	
	30	Harvest	30	Harvest	30	Harvest	40-80	81-120
Tillage practices								
Flat sowing	21.5	130.3	3.8	77.3	0.51	1.04	0.576	1.260
Ridge & furrow sowing	23.2	142.0	4.1	85.4	0.62	1.21	0.687	1.344
CD (P=0.05)	0.95	4.15	0.16	2.94	0.03	0.04	0.020	0.068
Nutrient management								
Control	18.2	116.3	3.2	64.8	0.44	0.92	0.511	1.029
30 kg N + 20 kg P_2O_5 ha^{-1}	22.0	134.8	3.8	80.3	0.55	1.10	0.613	1.300
60 kg N + 40 kg P_2O_5 ha^{-1}	24.7	145.6	4.4	88.8	0.62	1.23	0.701	1.404
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	25.0	146.9	4.6	91.1	0.63	1.25	0.704	1.459
FYM at 6 t ha^{-1}	22.0	137.1	3.8	81.7	0.57	1.13	0.629	1.319
CD (P=0.05)	1.50	6.57	0.26	4.65	0.03	0.07	0.033	0.108
Direct applied nutrients								
Control	19.5	122.3	3.5	74.8	0.49	0.99	0.578	1.153
30 kg N + 20 kg P_2O_5 ha^{-1}	22.3	137.9	4.1	81.9	0.56	1.14	0.633	1.312
60 kg N + 40 kg P_2O_5 ha^{-1}	25.3	148.3	4.3	89.3	0.63	1.26	0.684	1.440
CD (P=0.05)	1.80	6.64	0.25	4.52	0.03	0.06	0.041	0.106

Table 6. Effect of nutrient management and tillage on energy output-input relationship of pearlmillet-mustard cropping system (pooled over two years).

Treatments	Economic yield (kg ha^{-1})	By-product yield (kg ha^{-1})	Energy output (MJ ha^{-1})	Energy efficiency (Output-input ratio)	Net energy (MJ ha^{-1})	Energy productivity (kg MJ^{-1})	Energy intensity (MJ INR^{-1})
Tillage practices							
Flat sowing	3337	9206	164132	12.09	150423	0.925	16.54
Ridge and furrow sowing	3768	10443	185927	13.00	171248	0.995	17.63
CD (P=0.05)	131.32	428.81	6516	0.47	6516	0.041	0.63
Nutrient management							
Control	2922	8284	146503	12.64	134785	0.965	16.42
30 kg N + 20 kg P_2O_5 ha^{-1}	3458	9566	170401	12.49	156657	0.955	17.29
60 kg N + 40 kg P_2O_5 ha^{-1}	3886	10818	192349	12.29	176551	0.940	17.80
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	3982	10839	194023	12.55	178448	0.960	16.97
FYM at 6 t ha^{-1}	3475	9614	171257	12.78	157737	0.980	16.93
CD (P=0.05)	207.75	678.01	10303	NS	10303	NS	1.01
Direct applied nutrients							
Control	3341	9283	165150	13.74	153122	1.050	17.86
30 kg N + 20 kg P_2O_5 ha^{-1}	3601	9964	177485	12.61	163398	0.965	17.41
60 kg N + 40 kg P_2O_5 ha^{-1}	3692	10226	182097	11.28	165986	0.865	15.98
CD (P=0.05)	68.87	266.7	4108	0.295	4108	0.022	0.040

mustard cropping system over control and 30 kg N + 20 kg P_2O_5/ha. The increase in seed and straw yield with increased fertility levels have been earlier reported by Katiyar et al. (2003).

Table 7. Carbon efficiency (CE) of pearlmillet and mustard grown in sequence under different tillage and nutrient management practices during 2005-06 and 2006-07.

Treatments	Pearlmillet		Mustard	
	2005	2006	2005-06	2006-07
Tillage practices				
Flat sowing	29.44	25.24	11.18	11.96
Ridge and furrow sowing	34.72	30.72	13.81	15.57
CD (P=0.05)	1.85	1.54	0.64	0.44
Nutrient management				
Control	41.18	35.01	10.17	11.48
30 kg N + 20 kg P_2O_5 ha^{-1}	32.29	28.84	11.83	13.43
60 kg N + 40 kg P_2O_5 ha^{-1}	26.98	23.60	13.87	15.08
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	27.60	23.94	14.41	15.44
FYM at 6 t ha^{-1}	32.36	28.51	12.21	13.41
CD (P=0.05)	2.92	2.43	1.01	0.69
Direct applied nutrients				
Control	-	-	13.85	15.94
30 kg N + 20 kg P_2O_5 ha^{-1}	-	-	12.85	13.84
60 kg N + 40 kg P_2O_5 ha^{-1}	-	-	10.80	11.51
CD (P=0.05)	-	-	0.76	0.86

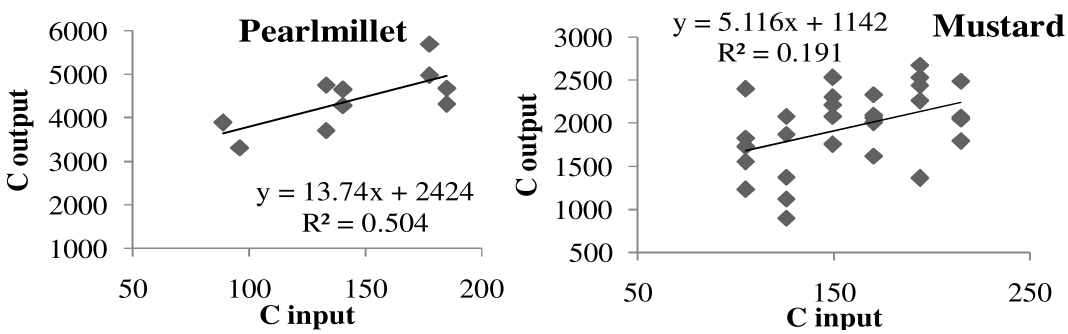

Figure 2. Correlation between total C output (Y-axis) and total C input (X-axis) in pearlmillet and mustard crops grown in sequence under various tillage and nutrient management practices.

Energy pattern and carbon efficiency of pearlmillet-mustard cropping system

Total energy output, energy efficiency, net energy productivity and energy intensity of pearlmillet-mustard cropping system were significantly influenced due to ridge and furrow sowing method over the flat sowing. The ridge and furrow sowing method recorded (13.3, 7.5, 13.8, 7.6 and 6.6%) higher energy output, energy efficiency, net energy, energy productivity, energy intensity, respectively (Table 6) and carbon efficiency (17.9, 21.7, 23.5 and 30.2%) higher in individual crops of the system (Table 7) during both the years over to flat sowing method of crop establishment. Similar results were also reported by Mandal et al. (2002). This might be due to carbon inputs and outputs were remarkably influenced by the tillage and nutrient management practices (Dubey and Lal, 2009; Parihar et al., 2012). Nutrient management to preceding pearlmillet crop in pearlmillet-mustard cropping system shows different effect on different energy parameters. The total energy output and net energy were recorded maximum with integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha and lowest with control, While the carbon efficiency shows the reverse trend as it is maximum with control (41.2, 35.0 and 13.8,15.9) and lowest (26.9, 23.6 and 10.8, 11.5) with highest level of direct applied nutrient 60 kg N + 40 kg P_2O_5/ha in both the crops (Table 7 and Figure 2) during both years of study. This might be due to low input use in control and highest level of input use in maximum level of direct applied nutrient (Dubey and Lal, 2009). The increment in total energy was 32.4, 13.9 and 13.3% over control, 30 kg N + 20 kg P_2O_5/ha and sole application of FYM at 6 t/ha (Table 6), while the energy efficiency (12.78 MJ/ha) and energy productivity (0.98 MJ/ha) was maximum with sole application of FYM at 6 t/ha and

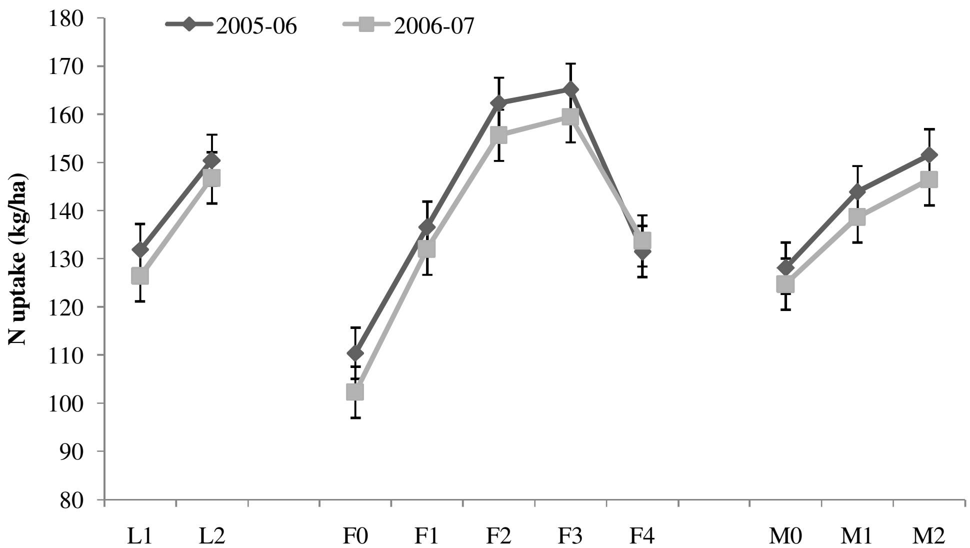

Figure 3. Total N uptake of pearlmillet-mustard cropping system under different crop establishment and nutrient management practices.

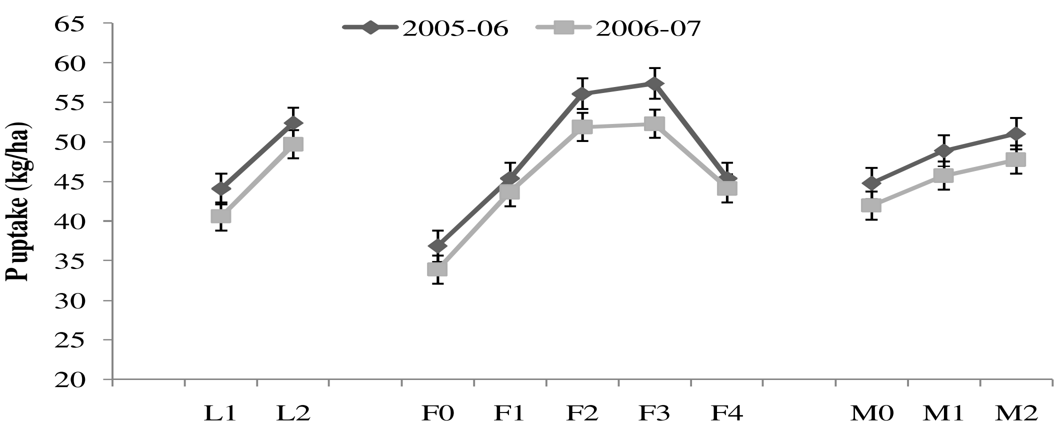

Figure 4. Total P uptake of pearlmillet-mustard cropping system under different crop establishment and nutrient management practices.

lowest with 60 kg N + 40 kg P_2O_5/ha. However, the energy intensity was maximum (17.8 MJ/INR) with60 kg N + 40 kg P_2O_5/ha and lowest (16.4 MJ/INR) with control. These results are in close conformity with those of Mahendra Pal et al. (1985).

Directly applied nutrients have significant influence on all the energy parameters of pearlmillet-mustard cropping system. The energy output and net energy were highest in application of 60 kg N + 40 kg P_2O_5/ha. While the energy efficiency (that is, the ratio of energy output to energy input), energy productivity and energy intensity were shown reverse trend with increasing fertility levels and observed highest with control and lowest with highest fertility level (60 kg N + 40 kg P_2O_5/ha) (Table 3). Similar results were also observed by Baishya and Sharma (1990).

Total N and P uptake and dynamics

The crop establishment with ridge and furrow sowing revealed significantly higher total uptake of N and P in both the years of investigation (Figures 3 and 4) mainly because of higher economic yield and biomass production resulting from enhanced nutrient uptake over flat sowing (Rathore et al., 2008). Integrated application of 30 kg N + 8.8 kg P + FYM at 6 t/ha through urea, single super phosphate and farm yard manure markedly increased the total N and P uptake of individual crops over control, 30 kg N + 8.8 kg P/ha (through urea and single super phosphate) and FYM at 6 t/ha and being on par with 60 kg N + 17.6 kg P/ha through urea and single super phosphate (Figures 3 and 4) in both years of investigation. Nutrient application directly to mustard, 60

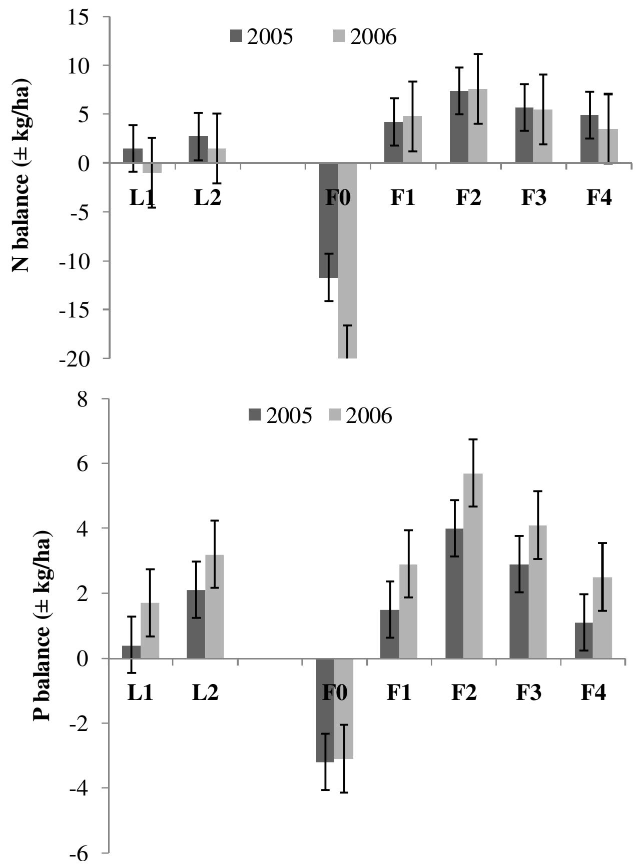

Figure 5. Net change (gain/loss) of nitrogen and phosphorus in pearlmillet-mustard cropping system under different treatments after harvest of pearlmillet.

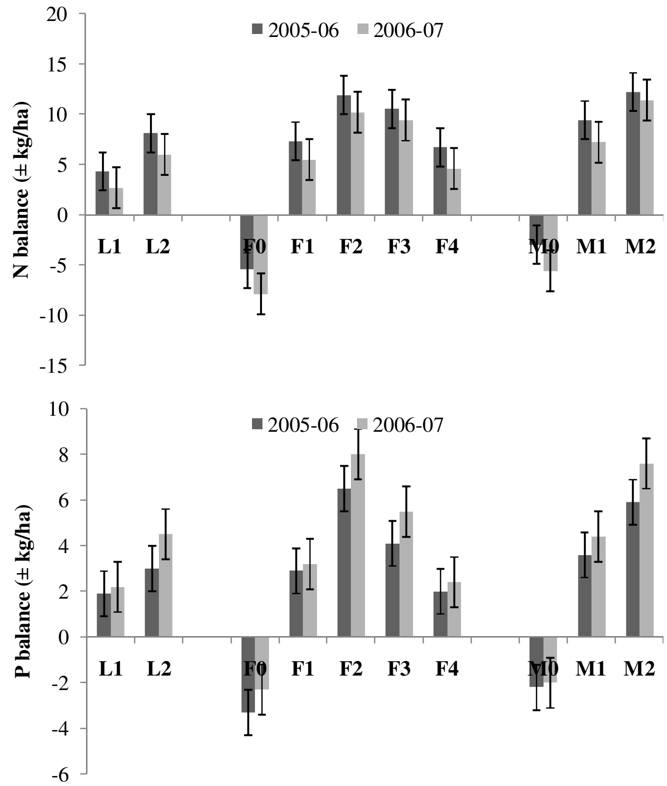

Figure 6. Net change (gain/loss) of nitrogen and phosphorus in pearlmillet-mustard cropping system under different treatments after harvest of mustard.

kg N + 17.6 kg P/ha through urea and single super phosphate significantly increased the total N and P uptake of mustard over control and 30 kg N + 8.8 kg P/ha in both the years of study. The increase in dry matter yield together with higher concentration of N and P finally led to higher uptake of N and P with individual crops (pearlmillet and mustard) of the system. The added N and P increased the availability of N and P to plants, which in turn might have resulted in profuse shoot and root growth, thereby activating greater absorption of N and P from the soil and improving the grain/seed and stover/stalk yields. The present trend of increased nutrient uptake is in line with those of Satyajeet et al (2007).

The soil status in respect of available N and P in pearlmillet-mustard cropping system showed discernible improvement due to sowing in ridge and furrow over flat sowing method. It could be attributed because both the crops are nutrient exhaustive crops and removes greater amount of N and P from soil. After two years, of experimentation it was observed that soil available N and P after pearlmillet markedly improved with the increase in applied nutrients (N and P) to pearlmillet crop (Table 10 and Figures 5 and 6). Application of 60 kg N + 17.6 kg P/ha through urea and single super phosphate, being on par with 30 kg N + 8.8 kg P + FYM at 6 t/ha through urea, SSP and farm yard manure and higher over control, 30 kg N + 8.8 kg P/ha and FYM at 6 t/ha alone. Negative balance of N and P were observed in control plot only (Table 10 and Figures 5 and 6).The soil available N and P after mustard improved significantly with successive increase in the rate of applied nutrients (N and P) to pearlmillet. Application of 60 kg N + 17.6 kg P/ha through urea and single super phosphate to pearlmillet being on par with 30 kg N + 8.8 kg P + FYM at 6 t/ha through urea, single super phosphate and farm yard manure, recorded higher soil available N and P after mustard over control, 30 kg N + 8.8 kg P/ha through urea and single super phosphate and FYM at 6 t/ha alone. Application of N and P directly to mustard at 60 kg N + 17.6 kg P/ha through urea and single super phosphate recorded the maximum available N and P in soil after mustard, being markedly higher over the control and 30 kg N + 8.8 kg P/ha through urea and single super phosphate. This could be explained in terms of poor N and P utilization. Moreover, since the excessive dose of fertilizer N and P does not result into luxury consumption, the unutilized portion goes into the soil system and become unavailable fraction of soil N mainly because of its fast losses through leaching, percolation and volatilization and the unavailable fraction

Table 8. Effect of nutrient management and tillage on consumptive use, rate of moisture use and moisture use efficiency of pearlmillet and mustard in cropping system (pooled over two years).

Treatments	Consumptive use (mm)		Moisture use rate (mm day^{-1})		Moisture use efficiency (kg ha^{-1} mm)	
	Pearlmillet	Mustard	Pearlmillet	Mustard	Pearlmillet	Mustard
Tillage practices						
Flat sowing	274.0	200.7	3.22	1.71	8.47	5.38
Ridge and furrow sowing	289.1	210.7	3.40	1.79	9.07	5.71
CD (P=0.05)	12.94	3.16	0.15	0.027	0.58	0.24
Nutrient management						
Control	257.2	190.6	3.03	1.62	8.01	4.93
30 kg N + 20 kg P_2O_5 ha^{-1}	277.1	203.1	3.26	1.73	8.82	5.38
60 kg N + 40 kg P_2O_5 ha^{-1}	295.6	213.1	3.48	1.81	9.13	5.94
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	299.3	215.6	3.52	1.83	9.17	6.05
FYM at 6 t ha^{-1}	278.7	2060	3.28	1.75	8.74	5.42
CD (P=0.05)	20.46	5.00	0.24	0.044	0.92	0.38
Direct applied nutrients						
Control	-	192.4	-	1.64	-	4.91
30 kg N + 20 kg P_2O_5 ha^{-1}	-	207.9	-	1.77	-	5.73
60 kg N + 40 kg P_2O_5 ha^{-1}	-	216.6	-	1.84	-	5.99
CD (P=0.05)	-	5.58	-	0.049	-	0.38

Table 9. Effect of nutrient management and tillage on monetary returns of pearlmillet and mustard in pearlmillet-mustard cropping system

Treatments	Gross return (US $ ha^{-1})		Net return (US $ ha^{-1})		Net return US $$^{-1}$ invested	
	Pearlmillet	Mustard	Pearlmillet	Mustard	Pearlmillet	Mustard
Tillage practices						
Flat sowing	331.20	440.39	154.39	236.20	0.87	1.21
Ridge & furrow sowing	374.87	477.00	185.43	274.83	0.98	1.30
CD (P=0.05)	1869	19.08	18.52	1928	NS	NS
Nutrient management						
Control	295.14	371.62	136.55	172.99	0.86	0.85
30 kg N + 20 kg P_2O_5 ha^{-1}	347.23	431.63	171.32	233.00	0.97	1.17
60 kg N + 40 kg P_2O_5 ha^{-1}	377.92	504.02	187.65	304.28	0.95	1.52
30 kg N + 20 kg P_2O_5 + FYM at 6 t ha^{-1}	391.72	514.51	189.41	315.8	0.93	1.58
FYM at 6 t ha^{-1}	346.17	443.91	164.67	251.45	0.91	1.18
CD (P=0.05)	29.54	30.17	29.41	30.48	NS	0.17
Direct applied nutrients						
Control	-	374.53	-	196.98	-	1.10
30 kg N + 20 kg P_2O_5 ha^{-1}	-	472.15	-	272.85	-	1.37
60 kg N + 40 kg P_2O_5 ha^{-1}	-	512.74	-	296.73	-	1.31
CD (P=0.05)	-	27.72	-	28.83	-	0.15

of P mainly because of its inherent chemical nature of fast fixation in the soil. Singh and Sin (2003) also reported similar results. The negative balance of available N and P were observed in control plot only.

Consumptive use and moisture use efficiency

The pearlmillet and mustard with ridge and furrow sowing method had the higher moisture use rate (3.40 and 1.79 mm day^{-1}), consumptive use (289.1 and 210.7 mm) and water use efficiency (9.07 and 5.71 kg ha^{-1} mm), respectively (Table 8 and 9) over flat sowing method. This might be due to conservation of moisture in ridges and furrow. Similar results were also reported by Jadhav et al. (1994). Nutrient management to preceding pearlmillet crop also enhanced the consumptive use, moisture use efficiency and moisture use rate over control.

Table 10. Nitrogen and phosphorus balance in pearlmillet-mustard cropping system during 2005-6 and 2006-07 in different treatments.

Treatment	After pearlmillet				After mustard			
	Available N (kg/ha)		Available P (kg/ha)		Available N (kg/ha)		Available P (kg/ha)	
	2005	2006	2005	2006	2005-06	2006-07	2005-06	2006-07
Tillage practices								
L_1: Flat sowing	136.9	138.7	13.2	14.9	139.7	142.4	14.7	15.4
L_2: Ridge and furrow sowing	138.1	141.2	14.9	16.4	143.5	145.7	15.8	17.7
SEm ±	2.58	2.37	0.78	0.83	1.93	1.86	0.69	0.78
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Preceding nutrient management								
F_0: Control	123.7	119.5	9.6	10.1	130.0	131.8	9.5	10.9
F_1: 30 kg N + 20 kg P_2O_5/ha	139.6	144.5	14.3	16.1	142.7	145.2	15.7	16.4
F_2: 60 kg N + 40 kg P_2O_5/ha	142.8	147.3	16.8	18.9	147.3	149.9	19.3	21.2
F_3: 30 kg N + 20 kg P_2O_5ha + 6 tonne FYM/ha	141.1	145.2	15.7	17.3	145.9	149.1	16.9	18.7
F_4: 6 tonne FYM/ha	140.3	143.2	13.9	15.7	142.1	144.3	14.8	15.6
SEm ±	4.07	3.73	1.23	1.31	3.10	2.99	3.30	3.73
CD (P=0.05)	12.11	11.12	3.66	3.89	9.20	8.88	3.30	3.73
Direct nutrient management in mustard								
M_0: Control	-	-	-	-	132.4	134.1	10.6	11.2
M_1: 30 kg N + 20 kg P_2O_5/ha	-	-	-	-	144.8	146.9	16.4	17.6
M_2: 60 kg N + 40 kg P_2O_5/ha	-	-	-	-	147.6	154.1	18.7	20.8
SEm ±	-	-	-	-	1.02	0.97	0.38	0.41
CD (P=0.05)	-	-	-	-	2.91	2.77	1.08	1.17

Integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha recorded the maximum (9.17 and 6.05 kg ha^{-1} mm) moisture use efficiency by pearlmillet and mustard, respectively and all other fertility levels follow the order: 60 kg N + 40 kg P_2O_5/ha > Sole application of FYM at 6 t/ha > 30 kg N + 20 kg P_2O_5/ha > Control in consumptive use, moisture use efficiency and rate of moisture use (Table 8). Direct application of 60 kg N + 40 kg P_2O_5/ha to succeeding mustard crop recorded highest consumptive use (216.6 mm) moisture use efficiency (5.99 kg ha^{-1} mm) and rate of moisture and moisture use (1.84 mm day^{-1}) over other fertility levels viz. control and 30 kg N + 20 kg P_2O_5ha. It was because of higher biomass production per unit area. These results are in close conformity with the results of Prasad et al. (2003).

Economics

Results from pearlmillet-mustard system varied in different treatments not only due to variable effect of treatments on crop performance but also due to the fluctuating cost of the inputs F Net return from pearlmillet was highest in ridge and furrow sowing method over the flat sowing. The net return increased by 38.9, 10.6 and 15.0% with integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha over control, 30 kg N + 20 kg P_2O_5 and sole application of FYM at 6 t/ha. This increment in net return was due to increased productivity of pearlmillet. Net returns from mustard were also higher in ridge and furrow sowing method over flat sowing method. Integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha and being on par with 60 kg N + 40 kg P_2O_5/ha. This increment in net return was due to increased productivity of pearlmillet. Net returns from mustard were also higher in ridge and furrow sowing method over flat sowing method. Integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha to preceding pearlmillet recorded highest net return (US $ 315.9 ha^{-1}) to succeeding mustard crop over other preceding fertility levels. Direct application of 60 kg N + 40 kg P_2O_5/ha to mustard recorded maximum net return (US $ 296.7 ha^{-1}) over control and 30 kg N + 20 kg P_2O_5/ha (Table 9). Similar results were earlier observed by Satyajeet et al. (2007), Jat et al. (2011). Benefit:cost ratio was higher with ridge and furrow sowing of pearlmillet and mustard both respectively. Pearlmillet having highest benefit: cost ratio with fertility level of 30 kg N + 20 kg P_2O_5/ha, while it was highest in mustard with integrated application of 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha to preceding pearlmillet. Direct application of 60 kg N + 40 kg P_2O_5/ha to mustard recorded highest B: C ratio over control and 30 kg N + 20 kg P_2O_5/ha. These results are in close conformity with Bahera et al. (2007).

Conclusions

Crop establishment of pearlmillet-mustard system with ridge and furrow recorded significantly higher system productivity, economic yield, energy and carbon efficiencies. The integrated application of organic and inorganic fertilizers with 30 kg N + 20 kg P_2O_5 + FYM at 6 t/ha to pearlmillet resulted in significantly higher yields, energy, carbon efficiency, moisture use efficiency and economics of individual crops (pearlmillet and mustard) and system as a whole also saves nutrient and sustain soil fertility.

REFERENCES

Bahera UP, Sharma AR, Pandey HN (2007). Sustaining productivity of wheat-soybean cropping system through integrated nutrient management practices on the vertisols of central India. Plant Soil. 297:185-199.

Baishya A, Sharma GL (1990). Energy budgeting in rice-wheat cropping system. *Indian* J. Agron. 35(1,2):167-177.

Cheema MA, Malika MA, Hussain A, Shah SH, Basra SMA (2001). Effect of lime and rate of nitrogen and phosphorus application on the growth and the seed and oil yields of canola. J. Agron. Crop. Sci. 186:103-110.

Dastane NG (1972). A practical manual for water use research in agriculture. Poona (Maharashtra): Navbharat Prakashan. p. 120.

DiStefano JF, Gholz HL (1986) A proposed use of ion exchange resins to measure nitrogen mineralization and nitrification in intact soil cores. Commun. Soil. Sci. Plant Anal. 17:989-998.

Dubey A, Lal R (2009). Carbon Footprint and Sustainability of Agricultural Production Systems in Punjab, India, and Ohio, USA, J. Crop Improv. 23:332- 350. Economic Survey (2006-2007). Agriculture, Publications, Division, Ministry of Information and Broadcasting, Government of India.

Gomez KA, Gomez AA (1984). Statistical procedures for agricultural research. 2nd ed. New York, John Wiley and Sons.

Hadas A, Portnoy R (1994). Nitrogen and carbon net N mineralization rates of composed manures incubated in soil. J Environ. Qual. 23:1184-1189. Jackson ML (1958). Soil Chemical analysis, Asian Publication House, New Delhi. pp. 173-195.

Jadhav BS, Bhosale AS, Patil BR (1994). Consumptive use, WUE and moisture extraction pattern in maize as influenced by irrigation scheduling, mulching and layouts. J. Soils. Crops 4(1):25-30.

Jat SL, Parihar CM, Singh AK, Jat ML, Jat RK (2011). Economic sustainability and water productivity of maize based cropping system under conservation agricultural practices. In: Proceeding of 5th World Congress on Conservation Agriculture, Incorporating the 3rd Farming systems Design Conference held at Brisbane, Australia from 26th to 29th September 2011. pp. 110-111

Jat ML, Gupta RK, Sharma SK, Gill MS, Dass S, Singh RP (2008). Evaluating conservation tillage systems under maize-wheat rotaion in Indo-Gangatic plains of India. In: Proceedings of the 10th Asian Regional Maize Workshop, 20 - 23 October 2008, Makassar, Indonesia. p. 7.

Kantwa SR, Ahlawat IPS, Gangaiah B (2005). Effect of land configuration, post-monsoon irrigation and phosphorus on performance of sole and intercropped pigeonpea (*Cajanus cajan*). Indian. J. Agron. 50(4):278-280.

Kantwa SR., Ahlawat, IPS, Gangaiah B (2006). Performance of sole and intercropped pigeonpea (*Cajanus cajan*) as influenced by land configuration, post monsoon irrigation and phosphorus fertilization. Indian. J. Agric. Sci. 76(10):635-637.

Katiyar AK, Chaudhary HP, Uttam SK (2003). Studies on the suitability of barley based intercropping system with mustard in relation to fertility level and moisture conservation practices under irrigated conditions in central Uttar Pradesh. *Bhartiya Krishi* Anusandhan Patrika. 18(1-2):65-67.

Kaushik SK, Gautam RC (1991). Effect of dryland practices and plant population on the productivity and moisture use efficiency of pearlmillet. Indian J Agron. 36(2):228-233.

Kolberg RL, Rouppet B, Westfall DG, Peterson GA (1997). Evaluation of an in situ net soil nitrogen mineralization method in dryland agroecosystems. Soil Sci.Soc. Am. J. 61: 504-508.

Lal R, Singh S, Yadav SK, Kumar A (1996). Growth of *Brassica* as affected by irrigation and nitrogen levels. Haryana. J. Agron. 12(1):23-28.

Lal R (2004). Carbon emissions from farm operations. Environ. Int. 30:981-990.

Mahendra Pal, Singh KA, Saxena JP, Singh HK (1985). Energetic of cropping systems. Indian J. Agron. 30(2):1-L(xi)

Mandal KG, Saha KP, Ghosh PK, Hati KM, Bandyopadhyay KK (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass. Bioener. 23:337-345.

Mittal JP, Dhawan KC (1988). Resarch manual on energy requirement in agriculture sector, ICAR, New Delhi, pp. 20-23.

Parihar CM, Jat SL, Singh AK, Jat ML (2011). Energy scenario and Water and productivity of maize based cropping system under conservation agriculture practices in South Asia. In: Proceeding of 5th World Congress on Conservation Agriculture, Incorporating the 3rd Farming systems Design Conference held at Brisbane, Australia from 26th to 29th September 2011. pp. 144-145.

Parihar CM, Rana KS, Jat ML, Jat SL, Parihar MD, Kantwa SR, Singh DK, Sharma S (2012). Carbon footprint and economic sustainability of pearl millet-mustard system under different tillage and nutrient management practices in moisture stress conditions. Afr J Microbiol Res. 6(23):5052-5061. DOI: 10.5897/AJMR12.764.

Prasad K, Chaudhary HP, Uttam SK (2003). Effect of fertility treatments on moisture use efficiency, yeidl and root development of rainfed mustard. Indian J. Soil .Conserv. 31:2007-2009.

Raison RJ, Connell MJ, Khanna PK (1987). Methodology for studying fluxes of soil inorganic-N in situ. Soil Biol. Biochem. 19:521-530.

Rathore BS, Rana VS, Nanwal RK (2008). Effect of plant density and fertility levels on growth and yield of pearlmillet (*Pennisetum glaucum*) hybrids under limited irrigation conditions in semi-arid environment. Indian. J. Agric. Sci. 78(1):667-670.

Satyajeet, Nanwal RK, Kumar P (2007). Residual nutrients in pearlmillet-mustard cropping system as influenced by integrated nutrient management treatments in sandy loam soils. Environ. Eco. 25(1):154-157.

Satyajeet, Nanwal RK (2007). Integrated nutrient management in pearlmillet-mustard cropping system. Indian J. Fert. 3(4):59-62, 76.

Singh MK, Pal SK, Thakur R, Verma UN (1997a). Energy input-output relationship of cropping systems. Indian. J. Agric. Sci. 67(6):262-264.

Singh S, Mittal JP, Verma SR (1997b). Energy requirements for production of major crops in India. *Agric* Mechanization in Asia, Afri.Latin.Am.28(4):13-17.

Singh Yadvinder, Singh Bijay (2003). Integrated plant nutrient supply systems for sustainable rice-wheat rotation. In: Nutrient management for sustainable rice-wheat cropping system Yadvinder-Singh, Bijay-Singh, Nayyar VK, Jagmohan Singh (eds.) National Agricultural Technology Project, Indian Council of Agricultural Research, New Delhi and Punjab Agricultural University, Ludhiana, India, pp. 237-252.

Tandon SK, Singh S (2009). Energy Balance in Conservation Agriculture and Conventional Farming: a Comparison. In: proceedings of *4th World Congress on Conservation Agriculture* - February 4-7, 2009 held at New Delhi, India. pp. 156-166.

Yadav RL, Paroda RS, Chadha KL (1996). Cropping System (eds.). In: 50 years of Crop Science Research in India. ICAR, New Delhi. pp. 117-128.

Yakadri M, Gautam RC (2001). Dry matter accumulation and uptake of N and P by pearlmillet (*Pennisetum glaucum*) intercropping with groundnut in relation to fertilizer levels under dryland conditions. Agric. Sci. Digest. 21(1):43-45.