African Journal of Microbiology Research Vol. 6(23), pp. 5052-5061, 21 June, 2012
Available online at http://www.academicjournals.org/AJMR
DOI: 10.5897/AJMR12.764
ISSN 1996-0808 ©2012 Academic Journals

Full Length Research Paper

Carbon footprint and economic sustainability of pearl millet-mustard system under different tillage and nutrient management practices in moisture stress conditions

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Accepted 15 May, 2012

Pearlmillet (*Pennisetum glaucum* L.) – mustard (*Brassica juncea* L.) is an important cropping system of limited water and marginal land areas grown under improper crop establishment and imbalanced fertilization. Conservation tillage with integrated nutrient management (INM) has potential to improve productivity, maintain soil health and economic sustainability. In present study the response of different tillage and INM on yield, production efficiency, carbon sustainability index (CSI) and economics of pearlmillet and mustard grown during 2005-2006 and 2006-2007 at IARI, New Delhi(India) was evaluated. During all the season's ridge-furrow sowing resulted considerable improvement in growth and yield of pearlmillet and mustard. Pearlmillet and mustard produced higher yield (2.62 and 1.21 t ha^{-1}), pearlmillet equivalent yield (PEY) (6.52 t ha^{-1}) and production efficiency (31.04 kg ha^{-1} day^{-1}) when sown in ridge-furrow. Application of 30 kg N and 20 kg P_2O_5ha^{-1} along with FYM @ 6 t ha^{-1} recorded higher yield (2.75 and 1.31 t ha^{-1}) of pearlmillet and mustard, respectively as their residual effect. However, in mustard application of 60 kg N and 40 kg P_2O_5 ha^{-1} resulted highest yield (1.30 t ha^{-1}), PEY (6.66 t ha^{-1}) and production efficiency (31.74 kg ha^{-1} day^{-1}). Net returns and CSI were highest (US $572.4 & 21.92 and 603.4 & 20.02 ha^{-1}) in ridge and furrow and preceding application of 30 kg N and 20 kg P_2O_5 ha^{-1} along with FYM @ 6 t ha^{-1}, respectively. In mustard CSI was highest in control (21.84) and net returns (US $ 571.7 ha^{-1}) were highest with highest nutrient level. This study indicates that pearlmillet and mustard can be grown under ridge furrow sowing with INM for sustaining soil health and higher farm profitability.

Key words: Carbon sustainability index, economic returns, equivalent yield, farm yard manure, production efficiency, residual effect.

INTRODUCTION

In India pearlmillet and mustard are important food grain and oil seed crops and predominantly grown on sandy loam to loamy soils covering an area of 7.4 and 8.4 mha of which (>70%) is rain dependent, respectively. Despite the importance of these crops in food and oilseed production for growing populations of semi-arid tropic (SAT) region of India, productivity of these crops has remained low and unstable owing to crop establishment, nutrient management, climatic and soil-related constraints

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Pearlmillet-mustard cropping system is reported to cover an area of 9.37 lakh ha, and contributes about 3.5% of national food basket (Yadav, 1996). Tillage of cropping lands has led to decline in soil organic carbon (SOC) and soil total nitrogen (STN) (Houghton et al., 1983; Dalal and Mayer, 1986) while conservation tillage based ridge-furrow crop establishment has the potential to reduce the SOC and STN decline and also improve productivity of pearlmillet-mustard system with respect to crop yield by way of improved soil physical properties and enhanced soil organic C (Nyakatawa et al., 2001). Under low rainfall conditions, ridges may help in conservation and availability of moisture for a relatively longer time while under high rainfall areas these furrows may help drained out of excess water from the crop root zone, improved soil temperature, aeration and nutrient availability and also enhanced the depth of crop root zone. Therefore, proper land configuration (ridge and furrow) may help in realizing significantly higher productivity of this cropping sequence (Kaushik and Gautam, 1991; Shaikh et al., 1994; Khan and Agarwal, 1985, 1988; Rathi et al., 2003; Parihar et al., 2009). Farmers of semi-arid tropic region are resource poor and the different crops grown in a definite sequence may require differential and balanced application of nutrient through organic as well as inorganic sources (Solaiappan, 2002). Because in such situations continuous use of inorganic fertilizers may adversely affects the long-term soil fertility.

However, judicious combination of manures and chemical fertilizers depending upon the availability, nature and properties of the soil and crops to be grown would not only maximize the crop production and improve the quality of agricultural produces but would also helps in maintaining the soil fertility (Kaushik and Gautam, 1991; Shaikh et al., 1994; Parihar et al., 2010), optimum productivity and overall health and quality of the soil for posterity (Singh et al., 1981) and also to sustain the system productivity (Singh and Yadav, 1992). Due to continuous decline in factor productivity from present day's intensive agricultural production systems the use of organic manures and inorganic fertilizers in integrated manner is essentially required. Organic manures have significant direct and residual effect on productivity and soil health. The use of organic manure improves soil organic matter, long term soil fertility and crop productivity on sustainable basis is the need of the hour. The beneficial effects of organic manures to improve soil structure; fertility as well as plant growth and yield have been emphasized (Murwira et al., 1995; Esse et al., 2001; Katkar et al., 2002). Residual effect of organic manures, namely farm yard manure (FYM) may be more pronounced, as only a part of its nutrients is available to the first crop and remaining portion of nutrients will be available to the succeeding crop in sequence (Hegde, 1998).

Agricultural practices also have major impact on global carbon cycle and leading to increase in the global temperature during 20th century by 0.6 ± 0.2°C at an average rate of increase of 0.17°C per decade since 1950 (Dubey and Lal, 2009). Hence, crop production practices which leads to less carbon emission are more desirable for sustainability and environmental safety from any production system. Tillage is the major contributor in carbon emission; hence conservation agricultural based tillage practices will lead to less carbon load from agriculture production system in the environment. Keeping this background in mind, an investigation was undertaken to study the effect of land configuration and effect of prilled urea nitrogen, single super phosphate phosphorus and FYM application alone and their different combinations for N and P management on the performance of pearlmillet-mustard cropping system in terms of production potential, economic viability and carbon based sustainability index.

MATERIALS AND METHODS

Climate, soil and crops

Field experiments were carried out at the research farm of Indian Agricultural Research Institute, New Delhi during 2005-2006 and 2006-2007 under limited irrigation conditions. The Institute farm is located at 28°58'N latitude and 77°10'E longitude with an elevation of 228 m above mean sea level. The average maximum and minimum temperature during the pearlmillet growing season (July-October) was 29.4-36.4°C and 12.8-27.8°C, respectively and during mustard growing season (October-February) it was 19.1-24°C and 3.1-20°C, respectively. The average rainfall received during pearlmillet and mustard growing seasons was 455.5 and 45.2 mm, respectively (Figure 1). The region is characterized as SAT climate (Sehgal et al., 1992).

The experimental soil was sandy loam in texture having 62.4% sand, 18.7% silt and 18.9% clay contents. Chemical analysis of nutrients for the experimental soil were conducted by using the Subbiah and Asija (1956) procedure for determination of available N, Olsen's method for available P (Olsen et al., 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 experimental soil was analysed as low in available nitrogen (135.7 kg N ha^{-1}), medium in available phosphorus (13.20 kg P ha^{-1}) and potassium (181.40 kg ha^{-1}) and low in organic carbon content (0.40%). The pH of the soil was 7.9 and determined in soil water suspension in the ratio of 1:2.5 with glass electrode pH meter.

Experimental set-up and management

The experiment consisted of ten treatment combinations for pearlmillet (rainy season) of two land configurations: flat sowing and ridge and furrow sowing and five fertility levels – F_0: no nutrient (control), F_1: 30 N + 20 P_2O_5 kg ha^{-1}; F_2: 60 N + 40 P_2O_5 kg ha^{-1}; F_3: 30 N + 20 P_2O_5 kg ha^{-1} + FYM @ 6t ha^{-1} and F_4: FYM @ 6 t ha^{-1} alone. The trial was laid out in randomized block design (RBD) (for pearlmillet) with three replications and split plot design (SPD) for mustard (winter season). All preceding treatments were splitted into three direct applied nutrient levels to succeeding mustard were M_0: Control; M_1: 30 N + 20 P_2O_5 kg ha^{-1}and M_2: 60 N + 40 P_2O_5 kg ha^{-1}. Pearlmillet: 'Pusa composite-383' high yielding variety developed at

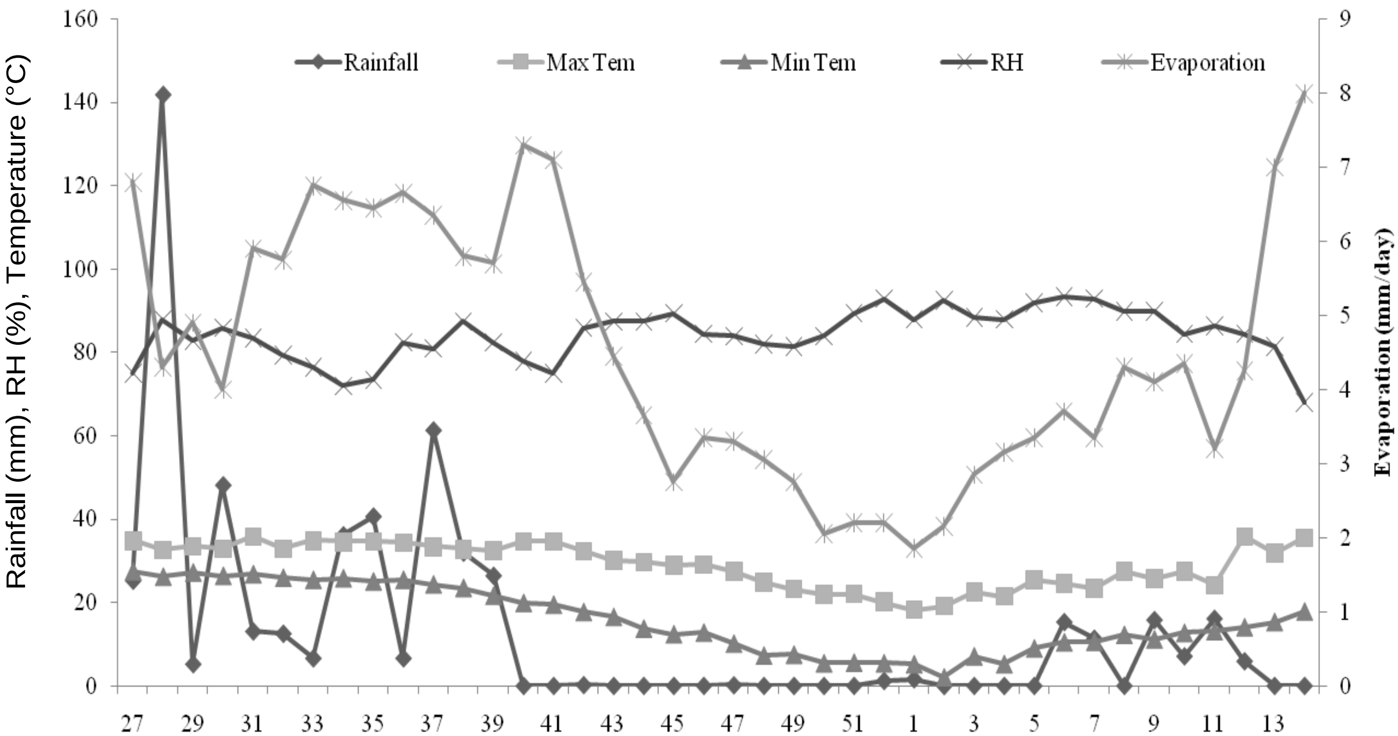

Figure 1. Weather parameters during cropping period (mean of two years).

Table 1. Nutrient composition of farm yard manure (FYM) used in the experiment (averaged over 2 years).

Nutrients	Content
N%	0.53
P%	0.22
K%	0.59
Fe (mg kg^{-1})	2100.00
Zn (mg kg^{-1})	61.0
B (mg kg^{-1})	2.2
Mo (mg kg^{-1})	0.75

Indian Agricultural Research Institute, New Delhi is resistant to shattering, lodging and downy mildew and suitable for early, normal and late-sown conditions and highly responsive to N. Its average grain yield is 2.17 t ha^{-1}, medium maturity variety. It is suitable for rainfed as well as irrigated areas of high and low fertility. Ear heads are medium bold and rod-shaped.

Mustard: 'Pusa Agrini' variety is also developed at Indian Agricultural Research Institute, New Delhi is early maturity, which is low water requiring and tolerant to high temperatures at seedling stage, escapes white rust, alternaria blight, other disease and insects. Its seed is light-brown and medium-size having test weight of about 4.5 g and oil content is 39-40%. Average yield is 1.7-1.8 t/ha with potential up to 3.0 t/ha. The variety performs well under early, timely as well as late sown conditions.

The pearlmillet cultivar (Pusa composite-383) was sown with spacing of 50 × 15 cm in the first fortnight of July each year and that of mustard variety 'Pusa Agrini' at the spacing of 45 × 15 cm in second fortnight of October during both the experimental years. Half dose of N was applied as basal and remaining half was top dressed at ear formation stage in case of pearlmillet and at pre-bloom stage in case of mustard through prilled urea. The phosphorus and potash were applied as basal dose to both pearlmillet and mustard using single super phosphate and muriate of potash, respectively. Well-rotten farm yard manure (cattle dung with litters) obtained from the nearby dairy farm was applied before sowing and incorporated into the soil. The nutrient composition of FYM as analyzed in the laboratory is presented in Table 1. The pearlmillet crop was irrigated at 25 days after sowing (DAS). However, succeeding mustard was irrigated at most critical stage namely, flowering stage (60 DAS). Production efficiency in terms of kg $ha^{-1}day^{-1}$ was calculated by total seed equivalent yield (SEY) of pearlmillet-mustard cropping system divided by total duration of the crop in a sequence (Tomar and Tiwari, 1990).

The carbon based sustainability index of individual crops and cropping system was calculated by using constants for input and output as used by Dubey (2008). Economic sustainability of the system was calculated using prevailing cost of input and output

Table 2. Effect of different tillage and nutrient management practices on growth performance of pearlmillet (averaged over 2 years).

Treatments	Plant height (cm)	Leaf area index	Dry matter accumulation (g plant^{-1})	Total no. of tillers m^{-1} row length
Tillage practices				
L_1 : Flat sowing	148.21	4.91	38.99	20.24
L_2 : Ridge & furrow sowing	159.78	5.34	43.52	23.20
SEm $\pm$	3.24	0.11	1.01	0.51
CD (P=0.05)	9.31	0.41	3.03	1.51
Nutrient management				
F_0 : Control	138.12	4.37	35.44	17.01
F_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	150.03	4.98	40.68	20.79
F_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	165.74	5.65	50.16	24.87
F_3 : 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1}	166.43	5.66	48.96	24.90
F_4 : FYM @ 6 t ha^{-1}	149.68	4.97	40.56	21.02
SEm $\pm$	5.12	0.22	1.62	0.80
CD (P=0.05)	15.20	0.65	4.79	2.38

produced in the production of pearlmillet and mustard during both years. The carbon based sustainability index (CSI) was calculated using following formula (Lal, 2004):

$$Cs = (Co - Ci) / Ci$$

Cs – Sustainability Index
Co – Carbon Output
Ci – Carbon Input

Data obtained from pearlmillet and mustard crops for consecutive two years were pooled and statistically analyzed using the F-test as per the procedure given by Gomez and Gomez (1984). LSD at P=0.05 were used to determine the significance between treatment means.

RESULTS AND DISCUSSION

Pearlmillet growth and yield

Land configuration effect

Growth attributes of pearlmillet namely plant height, leaf area index (LAI), total number of tillers per meter row length and dry matter accumulation were significantly influenced by land configuration (ridge and furrow sowing) (Table 2). Plant height, LAI total number of tillers and dry matter accumulation increased significantly with ridge and furrow sowing over flat sowing. The improvement in growth attributes could be ascribed due to maintained favorable moisture condition in the soil for relatively longer duration by ridge and furrow sowing. Besides this ridge and furrow sowing system also attributed to adequate drainage and aeration in soil during high rainfall period which promote root growth in rhizosphere. It also helps in moisture conservation during the period of scanty rainfall. The enhanced nutrient supply together with favorable moisture condition created conducive environment for plant growth and development (Kantwa et al., 2005). The yield attributes and yield of pearlmillet was influenced by land configuration namely, flat sowing and ridge and furrow sowing (Table 3). Ridge and furrow sowing resulted in better development of yield attributes, namely, number of earhead per metre row length and length of ear head which resulted significant increase in yields namely grain, stover and biological yield of pearl millet. Singh and Verma (1996) also reported the similar findings. This could be attributed to improvement in growth attributes through adequate availability of moisture and nutrients which in turn favorably influenced number of physiological processes like transpiration, photosynthesis and build up of food material. Increase in yield attributes in pearlmillet ultimately led to increased yields in ridge and furrow planting over flat sowing.

Nutrient management effect

All the growth attributes of pearlmillet namely plant height, LAI, total number of tillers per meter row length and dry matter accumulation were significantly influenced by prilled urea, single super phosphate and farm yard manure sources of nitrogen and phosphorus (Table 2). Plant height, LAI, total number of tillers and dry matter accumulation were significantly higher with 30 kg N integrated applied through prilled urea and 20 kg P_2O_5 ha^{-1} through single super phosphate and FYM @ 6 t ha^{-1} over control, 30 kg N + 20 kg P_2O_5 ha^{-1} and sole application of FYM @ 6 t ha^{-1}, but remained on par with 60 kg N + 40 kg P_2O_5 ha^{-1}. The highest values of all the growth attributes was observed with integrated application of 30 kg N and 20 kg P_2O_5 ha^{-1} along with FYM @ 6 t ha^{-1} followed by 60 kg N and 40 kg P_2O_5 ha^{-1}. Both these two treatments were found on par with each

Table 3. Effect of different tillage and nutrient management practices on yield attributes and yields of pearlmillet (averaged over 2 years).

Treatments	No. of earheads/m row length	Length of earhead (cm)	Grain yield (t ha^{-1})	Stover yield (t ha^{-1})	Biological yield (t ha^{-1})	HI (%)
Tillage practices						
L_1 : Flat sowing	12.94	25.20	2.33	6.35	8.63	27.02
L_2 : Ridge & furrow sowing	14.75	28.62	2.63	7.31	9.93	26.44
SEm $\pm$	0.42	9.98	0.46	1.25	1.63	0.26
CD (P=0.05)	1.25	2.90	1.36	3.72	4.85	NS
Nutrient management						
F_0 : Control	10.07	22.51	2.06	5.80	7.86	26.38
F_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	13.43	26.63	2.44	6.65	9.10	26.87
F_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	16.33	29.54	2.69	7.45	10.06	26.68
F_3 : 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1}	16.01	29.21	2.75	7.54	10.26	26.62
F_4 : FYM @ 6 t ha^{-1}	13.39	26.61	2.43	6.59	9.02	27.08
SEm $\pm$	0.66	1.54	0.72	1.98	2.58	0.41
CD (P=0.05)	1.97	4.58	2.15	5.70	7.66	NS

other. This could be ascribed to higher and continuous nutrient availability from these sources of nitrogen and phosphorus up to the crop maturity. Higher nutrient availability improved the growth attributes and photosynthetic activities of plant (Padole et al., 1998; Bhagchand and Gautam, 2000).

The yield attributes and yield of pearlmillet was also influenced by the application of prilled urea, single super phosphate and farm yard manure (Table 3). Successive doses of nitrogen and phosphorus increased the yield attributes namely, number of ear heads per meter row length and length of ear head and yield namely grain, stover and biological yield of pearlmillet considerably (Sharma and Gupta, 2002). Integrated application of 30 kg N and 20 kg P_2O_5 ha^{-1} along with FYM @ 6 t ha^{-1} (F_3) produced significantly higher yield over control, 30 kg N + 20 kg P_2O_5 ha^{-1} and sole application of FYM @ 6 t ha^{-1} and being on par with 60 kg N + 40 kg P_2O_5 ha^{-1} (Kumar and Gautam, 2004). This could be due to efficient utilization and availability of nutrients from combined sources of either organic or inorganic fertilizers. In addition to major nutrients, the availability of micronutrients is also increased due to application of FYM which is helpful for better growth and development and which ultimately resulted in higher yield (Taneja et al., 1981; Hooda et al., 1996; Bhagchand and Gautam, 2000).

Direct and residual effect on mustard

Growth parameters

The residual effect of preceding treatments on growth attributes of mustard namely plant height; dry matter accumulation, number of branches (primary and secondary) and LAI with inclusion of FYM with chemical fertilizer in preceding crop of pearlmillet. The residual effect of integrated application of 30 kg N + 20 kg P_2O_5 ha^{-1} + FYM @ 6 t ha^{-1} (F_3) gave maximum plant height, number of branches, leaf area index and dry matter accumulation to succeeding mustard crop (Prasad and Shukla, 1991; Lal et al., 1996).

Direct application of 60 kg N + 40 kg P_2O_5 ha^{-1} (M_2) to mustard exerted significant effect over control (M_0) and 30 kg N + 20 kg P_2O_5 ha^{-1} (M_1) on all growth attributes namely plant height, number of branches, dry matter accumulation and leaf area index (Table 4). Nitrogen is a vitally important element in plant nutrient, a basic constituent of plant life and an integral part of chlorophyll, which is primary absorber of light green colour in plants (Das, 1999). Phosphorus encourages growth of roots and aerial parts through cell division, plays a pivotal role in energy transfer and oxidation reduction reactions and also prevent leaf fall and rolling of leaf margin and tips and chlorosis. Thus it helps in retaining more leaf area and contributes to dry matter production (Pandey and Sinha, 2002).

Yield attributes and yield

Residual effect of nitrogen and phosphorus in pearlmillet caused marked variation in yield attributes (siliquae plant^{-1}, seeds siliqua^{-1}, seed weight plant^{-1} and 1000-seed weight) and yields of succeeding mustard crop (Table 5). The siliquae plant^{-1}, seeds siliqua^{-1} and seed weight plant^{-1} varied significantly whereas, 1000-seed weight was non-significant due to residual effect of N and P management in pearlmillet. The highest values of all the yield attributes and seed yield of mustard was observed

Table 4. Effect of preceding and direct applied treatments on growth, yield attributes of mustard (averaged over 2 years).

Treatments	Plant height (cm) 80 DAS	Dry matter accumulation (g/plant) 80 DAS	Primary branches/plant	Secondary branches/plant	Leaf area index
Tillage practices					
L_1 : Flat sowing	120.94	26.88	7.14	11.95	1.55
L_2 : Ridge & furrow sowing	129.29	31.62	7.68	13.22	1.69
SEm $\pm$	1.42	0.28	0.11	0.21	0.017
CD (P=0.05)	4.22	0.83	NS	NS	0.055
Nutrient management					
F_0 : Control	106.84	23.61	5.88	9.52	1.01
F_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	122.05	28.33	7.17	12.19	1.59
F_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	134.40	32.59	8.20	14.01	1.92
F_3 : 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1}	135.89	34.25	8.48	14.39	1.96
F_4 : FYM @ 6 t ha^{-1}	131.77	28.99	7.34	12.81	1.63
SEm $\pm$	2.25	0.44	0.18	0.33	0.03
CD (P=0.05)	6.67	1.31	0.52	0.98	0.85
Direct applied nutrients					
M_0 : Control	113.90	26.68	6.50	11.35	1.46
M_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	126.78	29.41	7.50	12.78	1.64
M_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	135.68	31.67	8.23	13.63	1.77
SEm $\pm$	2.50	0.56	0.21	0.38	0.02
CD (P=0.05)	7.60	1.60	0.59	1.08	0.057

Table 5. Effect of preceding and direct applied treatments on yield attributes and yields of mustard (averaged over 2 years).

Treatments	Siliquae $plant^{-1}$	Seeds $siliqua^{-1}$	Seed wt. $plant^{-1}$	1000-seed wt.	Seed yield (t ha^{-1})	Stalk yield (t ha^{-1})	Biological yield (t ha^{-1})	HI (%)
Tillage practices								
L_1 : Flat sowing	279.19	11.09	13.53	4.77	1.09	3.17	4.26	25.50
L_2 : Ridge & furrow sowing	297.10	12.04	13.96	4.89	1.21	3.47	4.68	25.83
SEm $\pm$	2.77	0.20	0.22	0.055	0.02	0.044	0.057	0.018
CD (P=0.05)	8.21	0.58	0.65	0.165	0.08	0.131	0.169	NS
Nutrient management								
F_0 : Control	237.84	10.11	10.28	4.74	0.94	2.75	3.70	25.52
F_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	282.53	11.39	13.49	4.78	1.10	3.18	4.28	25.57
F_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	315.47	12.50	15.50	4.88	1.27	3.63	4.90	25.85
F_3 : 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1}	317.69	12.30	15.67	4.91	1.31	3.75	5.06	25.81
F_4 : FYM @ 6 t ha^{-1}	287.18	11.52	13.79	4.84	1.12	3.27	4.39	25.59
SEm $\pm$	4.37	0.31	0.34	0.088	0.026	0.069	0.09	0.30
CD (P=0.05)	12.98	0.92	1.02	0.26	0.077	0.207	0.28	NS
Direct applied nutrients								
M_0 : Control	259.01	10.90	10.91	4.71	0.95	2.79	3.74	25.34
M_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	294.84	11.62	14.42	4.87	1.19	3.47	4.67	25.63
M_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	310.59	12.68	15.90	4.90	1.30	3.70	5.00	26.03
SEm $\pm$	4.03	0.34	0.46	0.07	0.024	0.070	0.08	0.26
CD (P=0.05)	11.52	0.95	1.30	0.20	0.07	0.207	0.25	NS

Table 6. Effect of different tillage and nutrient management practices on equivalent yield, production efficiency, economic returns and CSI of pearlmillet-mustard cropping system (averaged over 2 years).

Treatments	Pearl millet equivalent yield of system (t ha^{-1})	Production efficiency (kg $ha^{-1}day^{-1}$)	Cost of cultivation (US \$ ha^{-1})	Net returns (US \$ ha^{-1})	Net returns US $\$^{-1}$ invested	Carbon sustainability index (CSI)
Tillage practices						
L_1 : Flat sowing	5.84	27.81	236.37	501.86	2.11	17.60
L_2 : Ridge & furrow sowing	6.52	31.04	253.82	572.38	2.28	21.92
SEm $\pm$	0.05	0.27	-	-	-	0.25
CD (P=0.05)	0.16	0.79	-	-	-	0.76
Nutrient management						
F_0 : Control	5.13	24.45	212.82	433.17	2.03	20.00
F_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	5.97	28.43	235.42	521.62	2.22	19.95
F_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	6.77	32.26	258.00	601.12	2.36	19.18
F_3 : 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1}	6.95	34.60	277.89	603.38	2.23	20.02
F_4 : FYM @ 6 t ha^{-1}	6.06	28.81	241.39	526.29	2.17	19.65
SEm $\pm$	0.08	0.41	-	-	-	0.40
CD (P=0.05)	0.26	1.26	-	-	-	NS
Direct applied nutrients						
M_0 : Control	5.55	26.43	219.74	480.62	2.18	21.84
M_1 : 30 kg N + 20 kg P_2O_5 ha^{-1}	6.32	30.09	242.32	559.05	2.29	19.85
M_2 : 60 kg N + 40 kg P_2O_5 ha^{-1}	6.66	31.74	273.26	571.67	2.11	17.59
SEm $\pm$	0.07	0.36	-	-	-	0.14
CD (P=0.05)	0.22	1.07	-	-	-	0.40

with residual effect of integrated application of 30 kg N and 20 kg P_2O_5 ha^{-1} coupled with FYM @ 6 t ha^{-1} (F_3), followed by 60 kg N + 40 kg P_2O_5 ha^{-1} (F_2). Increase in seed yield of mustard with residual effect of 30 kg N + 20 kg P_2O_5 ha^{-1} + FYM @ 6 t ha^{-1} (F_3) was 38.6% higher over residual control. In general, it was observed that residual effect of FYM either alone or in combination with prilled urea and single super phosphate was most pronounced on succeeding mustard over chemical fertilizers alone (Rao and Sharma, 1978; Sharma et al., 1997; Mishra and Giri, 2004; Satyajeet et al., 2007). The direct application of 60 kg N and 40 kg P_2O_5 ha^{-1} (M_2) to mustard gave maximum yield attributes and yield over control (M_0) and 30 kg N + 20 kg P_2O_5 ha^{-1} (M_1).

System productivity, production efficiency and economic returns of system

The significantly higher pearlmillet grain equivalent yield (6.52 t ha^{-1}), production efficiency (31.04 kg $ha^{-1}day^{-1}$), net returns (US \$ 572.4 ha^{-1}) and net returns per US \$ (2.28) (NRS US \$) invested in pearlmillet-mustard cropping system was recorded with ridge and furrow sowing. The highest grain equivalent yield (6.95 t ha^{-1}) of pearlmillet-mustard cropping system was recorded with integrated application of 30 kg N + 20 kg P_2O_5 + FYM @ 6 t ha^{-1} (F_3) to pearlmillet, which was 35.3, 16.4, 2.7 and 14.7% higher to control, 30 kg N + 20 kg P_2O_5 ha^{-1}, 60 kg N + 40 kg P_2O_5 ha^{-1} and sole application of FYM @ 6 t ha^{-1}, respectively (Table 6). Production efficiency followed the same trend as of pearlmillet grain equivalent yield. The highest production efficiency (34.6 kg $ha^{-1}day^{-1}$) was achieved with integrated application of 30 kg N + 20 kg P_2O_5 ha^{-1} + FYM @ 6 t ha^{-1} (F_3). This treatment combination also recorded the highest net return (US \$ 603.4 ha^{-1}). Unlike net returns, the net return per US \$ (NRP US \$) invested was highest (2.36) with the 60 kg N + 40 kg P_2O_5 ha^{-1} to pearlmillet followed by integrated application of 30 kg N + 20 kg P_2O_5 + FYM@ 6 t $ha^{-1}$and the lowest NRP US \$ value was recorded with control. Comparatively lower value of NRP US \$ invested with the treatments involving FYM were mainly due to the higher transportation charges involved. However, since the farmers are supposed to use their own FYM and family laborer, the benefit realized may be much higher

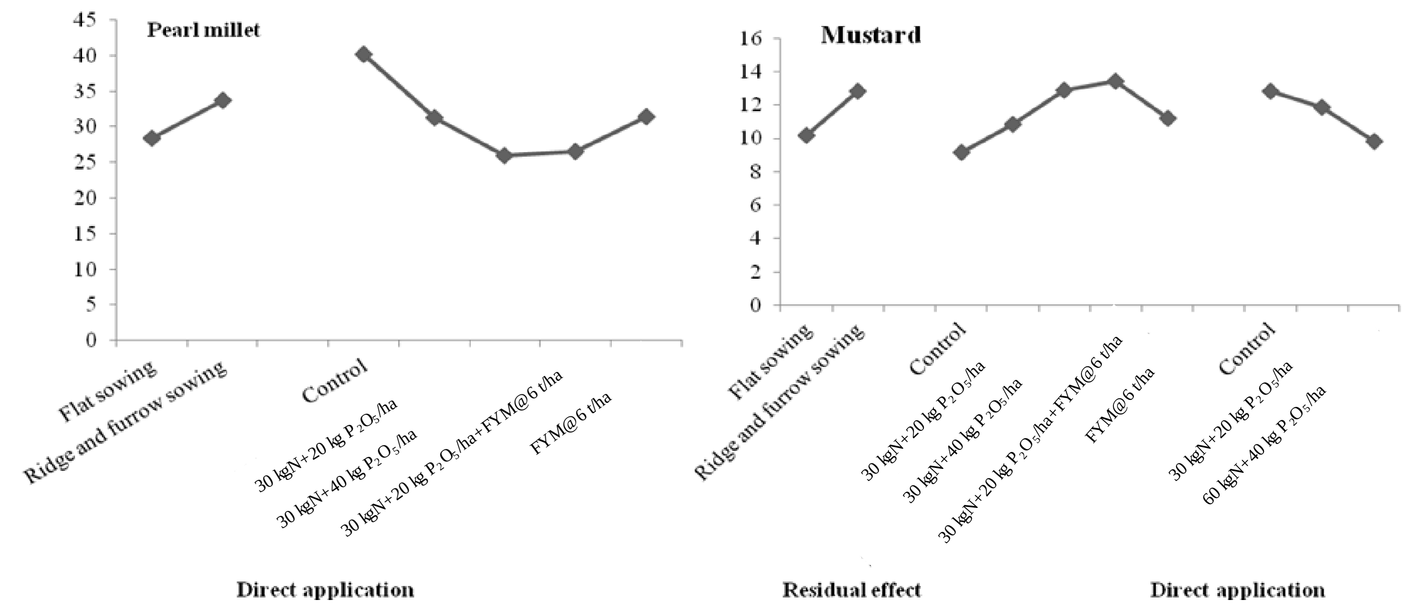

Figure 2. Carbon sustainability index of individual crops in pearl millet-mustard cropping system under various tillage and nutrient management practices (Average of two years).

improvement in soil health and quality.

Direct application of 60 kg N and 40 kg P_2O_5 ha^{-1} (M_2) to mustard recorded highest pearlmillet equivalent yield (6.66 t ha^{-1}) of pearlmillet-mustard system which was 20 and 5.4% higher compared to control and 30 kg N + 20 kg P_2O_5 ha^{-1} respectively (Table 6). Production efficiency followed the same trend as of pearlmillet grain equivalent yield. The highest production efficiency (31.74 kg $ha^{-1}day^{-1}$) was recorded with 60 kg N + 40 kg P_2O_5 ha^{-1} (M_2). The same treatment combination also recorded the highest net returns (US $ 571.7 ha^{-1}). Unlike net returns, the net return per US $ (NRS US $) invested was highest (2.29) with the application of 30 kg N + 20 kg P_2O_5 ha^{-1} followed by control.

System carbon sustainability index (CSI)

Ridge and furrow planting resulted to higher CSI over flat planting in terms of individual crops (Figure 2) and cropping system (Table 6). This might be due to efficient moisture conservation in ridge-furrow resulted in higher productivity of crops under moisture stress conditions. Integrated application of organic and inorganic sources of nutrients i.e. 30 kg N + 20 kg P_2O_5 + FYM@ 6 t ha^{-1} resulted higher CSI in succeeding crop (13.41) as well as the overall system CSI (20.02) as a whole over to all other sole applications. This might be due to more availability of micro as well as macro-nutrient throughout the crop period and accumulation of more carbon into biomass. Because pearlmillet crop is more efficient carbon accumulator and having efficient photosynthetic process due to its C_4 nature than mustard which resulted into more than double CSI. A significant positive correlation between C input and C output of the pearlmillet-mustard cropping system was also found during both the years of study (Figure 3). The individual crop yield was also significantly correlated with CSI of the respective crops (Figure 4).

Conclusions

Response of pearlmillet-mustard cropping system to conservation agriculture based crop establishment /land configuration systems and integrated nutrient management was studied during 2005-2006 and 2006-2007, and results of present study showed that the conservation agriculture based ridge and furrow system of crop establishment gave higher productivity and reported significantly higher growth attributes, yield attributes, yields, pearlmillet equivalent yield, production efficiency, net returns, net returns per US $ (NRP US $) invested and CSI. It can also be concluded that nutrients are better utilized by pearlmillet-mustard cropping system if organic FYM and inorganic (prilled urea and single super phosphate) sources of fertilizer are applied in judicious combinations and as a result higher growth, yield attributes and yields of pearlmillet was achieved from integrated application of fertilizer nitrogen and phosphorus and farm yard manure. It also showed a marked residual influence on growth, yield attributes and yields of succeeding mustard crop and gave maximum equivalent yield, net returns, production efficiency and

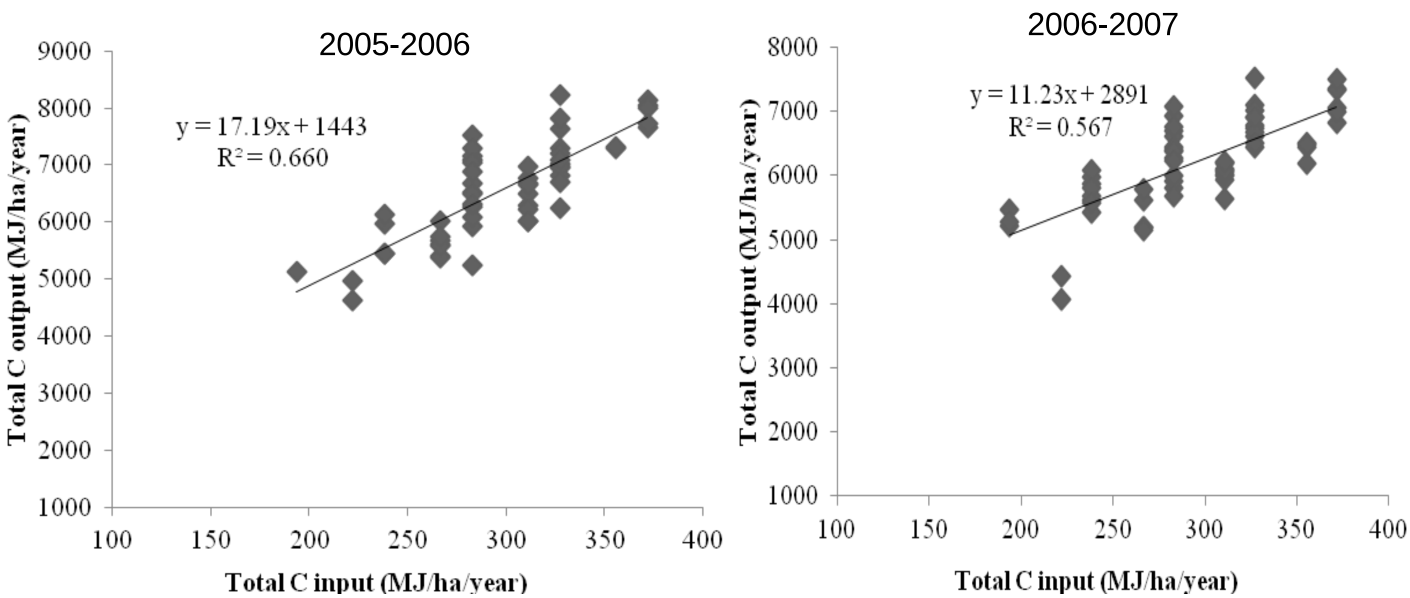

Figure 3. Correlation between total C output (Y-axis) and total C input (X-axis) in pearl millet-mustard cropping system under various tillage and nutrient management practices.

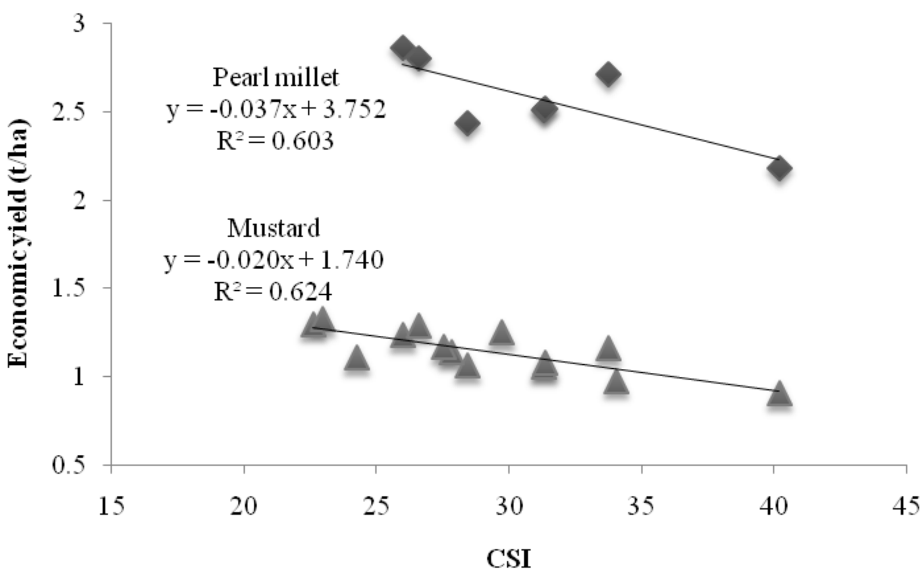

Figure 4. Correlation between crop productivity (Y-axis) t/ha and carbon sustainability index (X-axis) in pearlmillet-mustard cropping system under various tillage and nutrient management practices (Average of two years).

carbon footprint of pearlmillet-mustard cropping system.

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