Agronomic and economic performances of different cropping systems in a hot, arid environment: A case study from North-western Rajasthan, India

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ABSTRACT

A four-year field experiment was conducted in order to assess the productivity and economic potential of five cropping systems, with two tillage (conventional and deep) and four nutrient management [no application, farm yard manure (FYM) at 5 t ha^{-1}, chemical fertilizer (CF), FYM at 5 t ha^{-1} + CF] treatments in a hot, arid environment at Bikaner, India. Pearl millet [*Pennisetum glaucum* (L.) R. Br], cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.] and moth bean [*Vigna aconitifolia* (Jacq.) Marechal] were grown in five rotations. The five rotations were: moth bean—pearl millet, cluster bean—pearl millet, moth bean—cluster bean, pearl millet—pearl millet and pearl millet + cluster bean—pearl millet + cluster bean. The moth bean—cluster bean cropping system recorded 21—148%, 36—246% and 33—178% higher equivalent yields, return and water use efficiency, respectively than other cropping systems. Deep tillage increased equivalent yields by 20% higher than conventional tillage. The combined application of CF and FYM recorded 15 and 32% higher equivalent yields than their respective sole application. In this hot, arid ecosystem, a legume—legume system was more productive and profitable than other systems, and higher crop yields could be achieved by combining deep tillage with the integrated use of CF and FYM.

1. Introduction

A key question facing agricultural scientists in the 21st century is how to produce sufficient amounts of food, feed and farm income while protecting and improving environmental quality (Robertson and Swinton, 2005). Approximately 854 million people are food-insecure globally (Borlaug, 2007). There are warnings of even bigger challenges to food security by 2050 when the present population of 6.7 billion reaches 9.5 billion, before stabilizing at about 10 billion by the end of the 21st century (Lal, 2009). Food insecurity is also related to a worldwide decrease in per capita arable land (Horrigan et al., 2002), the decline in production capacity of soils (Lal, 2009), a decrease in renewable freshwater supply (Barnett et al., 2005) and projected changes in the climate (Parry et al., 2004).

Land and water, the two basic inputs of agricultural production, are becoming scarce. Worldwide per capita arable land decreased from 0.40 to 0.25 ha between 1961 and 1999 (Horrigan et al., 2002).

The agricultural production of biomass for food and fiber uses about 86% of the world's available freshwater (Hoekstra and Chapagain, 2007). In many parts of the world, the use of water for agriculture competes with other uses, such as urban supply and industrial activities (Falkenmark and RockstrÖm, 2004). In the future, higher agricultural production must come from the natural resource base that is currently available. This requires a process of sustainable intensification by increasing land use and water use efficiency (FAO, 2005). The problem of ensuring an adequate supply of agricultural products and protecting natural resources is particularly acute in arid regions, which cover around 32% of world's land area and is home to about 21.2% of the human population (Safriel and Adeel, 2005). These regions are characterized by low precipitation, highly variable rainfall patterns, high evapotranspiration rates, poor soils, severe land degradation processes, a short crop growing season and low crop yields (Groombridge, 1998; Heathcote, 1983).

Identification of suitable cropping systems that make the best use of available resources and provide higher yields is important if the diverse needs of farming communities and environmental sustainability in arid regions are to be catered for (Joshi et al., 2009). Water use efficiency (WUE) and nutrient uptake, along with

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profitability and productivity, are important criteria when comprehensively assessing cropping systems. Management inputs interact with cropping systems and dictate their efficiencies (Riedell et al., 1998). Water is the most critical input for crop production in rainfed arid regions and the proper conservation and use of rainwater is very important if sustainable crop production is to be realized (Faroda et al., 2007). Crop management practices that efficiently utilize rainwater are essential if higher crop productivity in rainfed hot, arid regions is to be achieved.

The Indian hot, arid region covers 31.7 million ha (Fig. 1) and is characterized by low (100–400 mm y^{-1}) and erratic (coefficient of variation > 50%) rainfall, high evapotranspiration (1600–2000 mm y^{-1}) and strong winds (Rao and Singh, 1998). Soils are coarse textured, deficient in organic matter and nitrogen (N) and have poor moisture retention capacities (Gupta et al., 2000). Water resources and vegetation cover are therefore low and the average productivity of crops in this region is very low (<0.5 t ha^{-1}). High biotic pressure (human and livestock numbers have increased from 5.87 million and 13.80 million in 1950 to 22.50 million and 27.50 million in 2001, respectively) has resulted in the overexploitation of resources and poses a serious threat to the sustainability of the region (Gupta and Narain, 2003).

To date, very little information is available regarding the agronomic and economic performance of contrasting cropping systems in the hot, arid region of India. There is a lack of information pertaining to the comprehensive assessment of cropping systems in the region. Earlier research conducted in the region dealt with the component crops of cropping systems and mostly focused on a narrow range of criteria, e.g. yields, returns and the effect on soil properties of different cropping systems (Rao et al., 1995; Saxena et al., 1997). The present experiment was conducted with the objective of assessing yields, returns, water use efficiency and nutrient uptake of five cropping systems. This paper reports the results of a four year long field experiment that tested the hypothesis that a legume–legume rotation could provide yields, WUE and net returns that matched or exceeded those from millet–millet and legume–millet rotations. Crop yields are reduced by water and nutrient deficiencies in hot, arid environments, so this study also tested the hypothesis that tillage and nutrient management could also improve crop yields. An appropriate tillage system can increase water availability for crops by increasing infiltration, water storage in the soil profile (Gupta et al., 2000) and root growth of the crops (Gajri et al., 1994). Alleviating nutrient deficiencies is an important way of enhancing the productivity and water use efficiency of crops

in arid regions (Faroda et al., 2007; Joshi et al., 2009). The results from this study facilitate the selection of efficient cropping systems, tillage and nutrient management options in iso-agroclimatic regions of the world.

2. Materials and methods

2.1. Location

The experiment was conducted between 2004 and 2007 at the Central Arid Zone Research Institute, Regional Research Station, Bikaner, India (28°4′ N; 74°3′ E; 238.3 m above mean sea level) located in the northwestern part of the Indian Thar Desert (Fig. 1). The climate of the experimental site is hot and arid and mean annual rainfall is 286 mm. The weather data for the crop growing seasons during the four year experiment are presented in Fig. 2. The soil at the site is loamy sand (Typic Torripssamentes). Soil samples taken at the beginning of the experiment at 20 cm depth on 10 July 2004 indicated a mean pH of 8.5, a mean organic carbon content (Walkley and Black procedure) of 0.1%, a mean available phosphorus (P) content (Olsen's procedure) of 8.4 kg ha^{-1}, and a mean available potassium (K) content (1 N ammonium acetate method) of 234.1 kg ha^{-1}.

2.2. Treatments and experimental designs

There were two tillage treatments: conventional (CT: 15 cm deep), and deep (DT: > 25 cm deep) tillage. The five cropping systems tested used three crops: pearl millet [*Pennisetum glaucum* (L.) R. Br], moth bean [*Vigna aconitifolia* (Jacq.) Marechal] and cluster bean [*Cyamopsis tetragonoloba* (L.) Taub.]. The rotations followed were: moth bean–pearl millet (hereafter, MB–PM), cluster bean–pearl millet (CB–PM), moth bean–cluster bean (MB–CB), pearl millet–pearl millet (PM–PM), and pearl millet + cluster bean–pearl millet + cluster bean (PM + CB–PM + CB). There were four nutrient management treatments: no application (0 or control); farm yard manure (FYM) applied at 5 t ha^{-1}; a chemical fertilizer application of N and P at 10 and 20 kg ha^{-1} for legumes (i.e. moth bean and cluster bean) and 20 and 10 kg ha^{-1} for pearl millet and pearl millet + cluster bean intercrop (CF) and combined use of FYM and chemical fertilizer (FYM + CF).

The present study was conducted with a factorial experiment in a split–plot design along with three replications. Tillage treatments were taken in main plots. Factorial experiments (5 × 4) with five cropping systems and four nutrient management treatments were
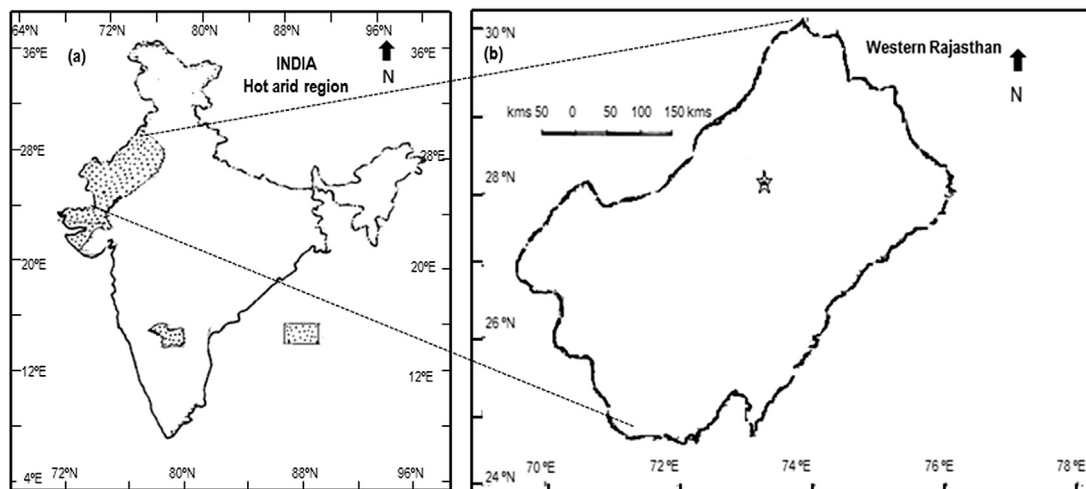

Fig. 1. (a) Extent of hot arid region in India (shaded part of map); (b) the northwestern Rajasthan and the black star indicate the location of the experimental site.
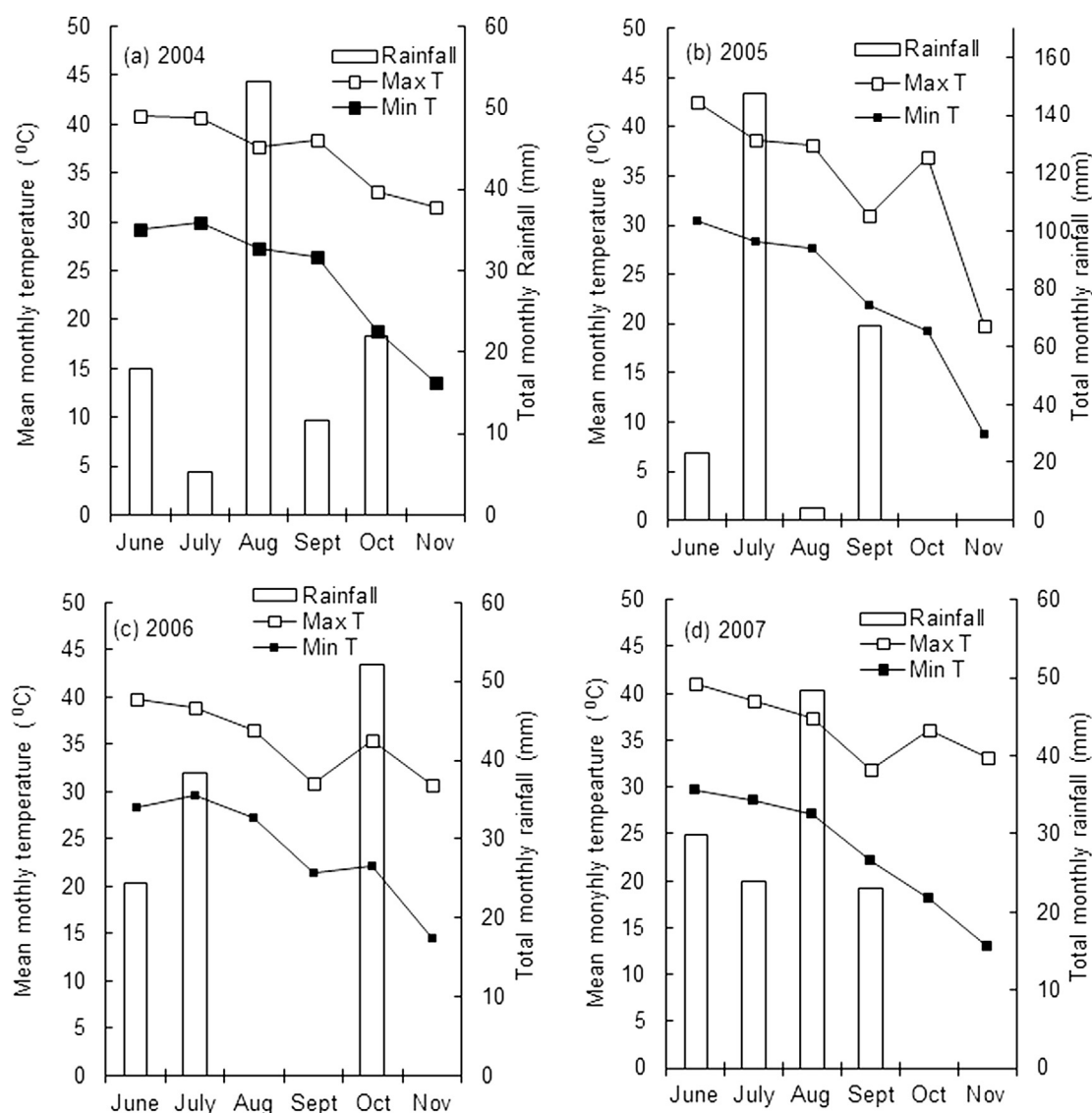
Fig. 2. Monthly rainfall, and mean maximum and minimum temperatures over the four year study period at Bikaner (India).

taken in sub-plots. Size of main plot was 138.0 × 3.5 m, whereas sub-plot was 5.0 × 3.5 m with 2 m gap in between. Each sub-plot was bordered with an earth dike of 30 cm in height. Overall, 20 sub-plots were randomly laid out in each main plot, which resulted in to a total of 120 sub-plots for the whole experiment. Main plots and sub-plots were randomly assigned during first year of the study. Thereafter, individual sub-plot with a particular tillage × cropping system × nutrient management treatments combinations was assigned with the same experimental unit during successive years.

2.3. Crop management practices and yield measurements

Crop cultivars, seeding rates, spacing and fertilizer application rates are shown in Table 1. After receiving adequate monsoon rain, the land was prepared by a tractor-drawn disc harrow and disc plow in plots assigned to conventional and deep tillage treatments, respectively. The well-decomposed FYM (containing 0.34 ± 0.04% N, 0.19 ± 0.02% P and 0.41 ± 0.05% K) was spread uniformly in plots as per treatment prior to tillage. The cultivars of moth bean, cluster bean and pearl millet used were "RMO − 40

Table 1
Management practices for the individual crops grown in this study.

Crop	Cultivar	Seed rate (kg ha^{-1})	Spacing (cm)	Nutrient rate N:P (kg ha^{-1})[a]
Pearl millet	HHB − 67	4.5	50 × 10	20:10
Cluster bean	RGC − 936	20.0	35 × 10	10:20
Moth bean	RMO − 40	15.0	35 × 10	10:20
Pearl millet + cluster bean (1:2 ratio)	HHB − 67 and RGC − 936	1.5 + 14.0	35 × 10	20:10

[a] Chemical fertilizer application does not apply to all treatments.

(Rajasthan Moth − 40)", "RGC − 936 (Rajasthan Guar Cultivar − 936)" and "HHB − 67 (Haryana Hybrid Bajra − 67)", respectively. "RMO − 40" is an early maturing cultivar which matures in 60—65 days, has synchronous maturity, a plant height of 35—40 cm and is recommended for western Rajasthan. "RGC − 936" is an early maturing, branched, dwarf, drought hardy and a medium grain size cultivar. "HHB − 67" matures in 75 days with an average plant height of 140—195 cm. The crops were sown with a hand plow. In the case of the PM + CB−PM + CB cropping system, the row ratio of PM and CB was 1:2. The crops were sown on 2 August, 28 July, 25 July and 1 August in 2004, 2005, 2006 and 2007, respectively. Urea and single super-phosphate fertilizers were used to supply N and P, respectively. Life-saving irrigation was applied during long dry spells (10 September, 2004; 25 August, 2005; 20 August, 2006 and 14 September, 2007). The water was applied at the rate of 500 m^3 ha^{-1} per irrigation by a sprinkler. Crop yields of seed and straw were determined at the physiological maturity stage of each plot, excluding the two border rows of each sub-plot. Seeds were separated manually after harvesting. Sub-samples of main yield (seed) and by-products (straw) were oven-dried to a constant weight at 70 °C.

2.4. Determination of productivity, profitability and WUE

In order to compare the productivity of different rotations, the main product yields (seed) were converted into cluster bean equivalent yield (CEY) on a price basis using the formula (Biswas et al., 2006):

$$CEY(of\ crop\ x) = Yx(Px/Pc) \tag{1}$$

where Yx is the yield of crop x (kg ha^{-1}), Px is the price of crop x, and Pc is the price of cluster beans. The prevailing prices of crop produce in the local market were used to calculate CEY. The selling price of moth bean, cluster bean and pearl millet seed was Rs.14.80, 15.25 and 5.50 kg^{-1} respectively in 2004. In 2005, the selling price of cluster bean and pearl millet was Rs 15.50 and 6.50 kg^{-1} respectively. In 2006, the selling price of moth bean, cluster bean and pearl millet seed was Rs.25.50, 17.40 and 7.50 kg^{-1} respectively and in 2007, the selling price of cluster bean and pearl millet was Rs 17.00 and 7.00 kg^{-1} respectively. The CEY for each year was calculated separately.

Total biomass yields (BY) were measured by totaling the seed and straw yields of the individual crops. Production efficiencies (i.e. PE$_{CEY}$ and PE$_{BY}$) were computed by dividing the CEY and BY of each crop with the duration of each crops in a rotation (Tomar and Tewari, 1990). Crop production costs and returns were calculated on the basis of prevailing market prices for inputs and outputs. Net returns (NR) were calculated by subtracting production costs from the gross value of the produce (main and by-products) for each of the crops. The benefit—cost ratios (BCRs) were calculated by dividing the net returns by the production costs for the crops. Monetary efficiency (ME) was calculated by dividing the net return (NR) by the duration of the crop in a rotation.

Water use was computed as described by Ali et al. (2007). Soil water content was measured gravimetrically just before seeding and after harvest at 1.5 m depth. Soil samples were taken with a tube auger. Evapotranspiration (ET) values were used to compute the water use. ET was estimated using a standard water balance equation:

$$P + I + U = R + D \pm \Delta W + ET \tag{2}$$

where, P = precipitation (mm), I = amount of irrigation (mm), U = upward flux (mm), R = surface runoff (mm), D = water lost by deep percolation (mm), ΔW = change in soil water storage between planting and harvesting of the crop and ET = crop evapotranspiration (ET).

It was assumed that there was negligible upward flux (U) beyond the measured depth. This is because the level of the water table near the experimental field was never closer than 3.0 m. Surface runoff (R) was assumed to be zero as the soil at the experimental site was sandy, had a good infiltration rate and each sub-plot was protected by a 35 cm bund. Deep percolation (D) was assumed to be negligible since the water storage capacity of soil at the experimental site was high and normally exceeded the rainfall volume required to saturate that capacity or storage. Therefore, U, R and D were taken as zero. Thus, Eq. (3) reduces to the following form for calculating ET:

$$ET = I + P \pm \Delta W \tag{3}$$

The value of ET was considered to be equivalent to the volume of water used (WU) by the crops.

The WUEs for CEY and above ground BY were calculated using the formulas:

$$WUE_{CEY} = CEY(kg)/WU(mm) \tag{4}$$

$$WUE_{BY} = above\ ground\ BY(kg)/WU(mm) \tag{5}$$

where, WUE$_{CEY}$ is the water use efficiency in terms of CEY and WUE$_{BY}$ is the water use efficiency in terms of BY.

2.5. Plant chemical analysis

Plant samples (both seed and straw) were taken at crop harvests each year. Samples were oven-dried, ground and analyzed for N, P, and K contents using the Kjeldahl method, the vanadium molybdate color method using a spectrophotometer and a flame photometer after digestion by mixed perchloric and nitric acids (Jackson, 1973), respectively. The nutrient content of the seed and straw were multiplied with their respective yields in order to calculate the nutrient uptake by the seed and straw. The nutrient uptake by the seed and straw were added together in order to determine the total uptake of a nutrient by the whole plant. The N, P and K uptakes were added together in order to calculate the total nutrient (TN) uptake by a crop.

2.6. Data analysis

Data were analyzed using analysis of variance (ANOVA). Analysis of variance of the experimental data was carried out as per experimental split-plot design with factorial experiment in sub-plot (Gomez and Gomez, 1984). Data from each year were analyzed separately. Three main factors of experiment e.g. tillage, cropping systems and nutrient management were considered as fixed. In case of significant F test in ANOVA with 5% significance level ($P < 0.05$), the means were compared using the least significant difference (LSD) test at $\alpha = 0.05$. The tillage × cropping system (T × CS) and nutrient management × cropping system (NM × CS) interactions were detected significant for most of measured trait and are reported here. The tillage × nutrient management (T × NM) and tillage × cropping system × nutrient management (T × CS × NM) interactions were not detected significant for any trait measured. Throughout this paper means are shown as μ ± SE.

3. Results

3.1. Weather conditions

Temperature conditions during the crop growing periods between 2004 and 2007 did not deviate markedly, with the exceptions of September 2004 and 2007, which were warmer than September 2005 and 2006 (Fig. 2). However, variation in rainfall during the 2004–2007 crop-growing periods was marked (Fig. 2). For example, July 2004 and 2005 and August 2005 and 2006 were exceptionally dry. The rainfall distribution was erratic, particularly during 2005 and 2006.

3.2. Cropping system performance

3.2.1. Productivity and production efficiency

The CEYs were significantly different ($P < 0.05$) between cropping systems, tillage and nutrient management treatments for all years (Table 2). The T × CS and NM × CS interactions were significant for CEYs in all years (Fig. 3, Table 6). The MB–CB system had the greatest CEY compared to the other systems in 2005 and 2007. The millet–millet (PM–PM) system had the lowest CEY in all years. The pearl millet had a higher yield in legume–millet systems (CB–

PM, MB–PM) compared to the millet–millet (PM–PM) system. Mean CEYs across all tillage, nutrient management treatments and years were highest for MB–CB (630.6 kg ha^{-1} y^{-1}) followed by PM + CB–PM + CB (519.0 kg ha^{-1} y^{-1}), CB–PM (455.2 kg ha^{-1} y^{-1}), MB–PM (430.6 kg ha^{-1} y^{-1}) and PM–PM (254.0 kg ha^{-1} y^{-1}). The legume–legume (MB–CB) system had 21.5–46.4% higher CEYs compared to the legume–millet (CB–PM, MB–PM, PM + CB–PM + CB) systems and 148.3% higher CEYs than the millet–millet (PM–PM) system.

The BYs were significantly affected ($P < 0.05$) by the cropping system, tillage and nutrient management treatments (Table 2). The T × CS and NM × CS interactions were significant for BY in all years (Fig. 3; Table 6). The CB–PM system recorded the highest BYs in 2005 and 2007. The PM + CB–PM + CB system had the highest BYs in 2004 and 2006. The MB–CB system had the lowest BYs in three (2005, 2006, 2007) of the four years studied. Mean BYs across all tillage, nutrient management treatments and years ranged between 1908.0 and 2460.4 kg ha^{-1} y^{-1}. BYs were higher for the PM + CB–PM + CB and CB–PM systems (2424.5 and 2460.8 kg ha^{-1} y^{-1}, respectively), lowest for the MB–CB (1908.0 kg ha^{-1} y^{-1}) system and intermediate for the MB–PM and PM–PM systems (2116.3 and 2379.2 kg ha^{-1} y^{-1}, respectively).

Table 2
Main effects of cropping system, tillage and nutrient management on cluster bean equivalent yield (CEY), biomass yield (BY) and production efficiency (PE) in 2004, 2005, 2006 and 2007.

	2004	2005	2006	2007	2004	2005	2006	2007
	Cluster bean equivalent yield (kg ha^{-1})				Biomass yield (kg ha^{-1})			
Cropping system								
MB–PM[2]	391.6 ± 18.3[c1]	276.1 ± 8.5[d]	726.4 ± 40.8[a]	328.1 ± 9.6[c]	1633.3 ± 71.5[d]	2634.3 ± 70.8[b]	1134.7 ± 71.5[c]	3062.9 ± 53.1[b]
CB–PM	540.4 ± 19.7[a]	301.2 ± 7.8[c]	642.1 ± 26.8[b]	337.2 ± 12.1[c]	2315.4 ± 43.3[a]	2795.1 ± 53.4[a]	1610.4 ± 60.6[b]	3122.2 ± 76.8[a]
MB–CB	397.6 ± 16.3[c]	592.9 ± 28.8[a]	716.6 ± 35.8[a]	815.2 ± 44.0[a]	1780.5 ± 63.0[c]	1789.2 ± 30.3[d]	1145.0 ± 58.2[c]	2917.4 ± 94.1[bc]
PM–PM	192.0 ± 11.0[d]	258.3 ± 8.0[d]	263.4 ± 18.1[d]	302.2 ± 10.4[c]	2030.0 ± 118.5[b]	2489.4 ± 62.9[c]	2088.5 ± 91.2[a]	2908.9 ± 99.6[c]
PM + CB–PM + CB	445.9 ± 22.9[b]	504.5 ± 18.0[b]	519.5 ± 27.0[c]	606.2 ± 23.0[b]	2349.7 ± 88.6[a]	2510.0 ± 92.2[c]	2098.8 ± 89.3[a]	2739.7 ± 68.3[d]
LSD ($P = 0.05$)	12.9	25.7	34.8	41.7	92.8	97.0	112.0	171.6
Tillage								
Conventional	367.7 ± 17.8[b]	365.5 ± 17.5[b]	484.4 ± 24.6[b]	444.4 ± 26.1[a]	1894.2 ± 67.7[b]	2342.2 ± 53.3[b]	1333.8 ± 60.3[b]	2776.6 ± 57.3[b]
Deep	420.0 ± 19.6[a]	407.8 ± 23.3[a]	662.8 ± 30.8[a]	511.1 ± 33.2[a]	2149.4 ± 67.3[a]	2545.1 ± 70.2[a]	1897.1 ± 89.3[a]	3123.9 ± 71.7[a]
LSD ($P = 0.05$)	17.8	26.7	103.3	NS	109.0	102.3	431.5	180.1
Nutrient management								
0[3]	289.2 ± 20.4[d]	316.9 ± 19.7[d]	428.4 ± 28.3[d]	387.5 ± 31.1[d]	1513.8 ± 66.6[d]	2090.9 ± 53.8[d]	1176.9 ± 82.7[d]	2438.2 ± 76.2[d]
FYM	361.0 ± 22.6[c]	354.7 ± 23.3[c]	533.5 ± 36.0[c]	449.1 ± 34.7[c]	1898.9 ± 68.3[c]	2312.1 ± 69.9[c]	1502.4 ± 98.5[c]	2806.7 ± 49.4[c]
CF	415.8 ± 21.1[b]	405.0 ± 25.9[b]	624.0 ± 41.2[b]	508.5 ± 44.7[b]	2115.7 ± 66.1[b]	2594.9 ± 77.2[b]	1758.1 ± 99.8[b]	3105.3 ± 59.9[b]
FYM + CF	507.9 ± 26.4[a]	469.9 ± 38.0[a]	708.4 ± 48.8[a]	567.8 ± 52.5[a]	2558.7 ± 78.5[a]	2776.7 ± 91.6[a]	2024.5 ± 116.[a]	3450.7 ± 86.3[a]
LSD ($P = 0.05$)	15.9	22.9	31.1	37.3	83.0	86.8	100.2	153.4
	Production efficiency (CEY kg ha^{-1} d^{-1})				Production efficiency (BY kg ha^{-1} d^{-1})			
Cropping system								
MB–PM	5.8 ± 0.3[b]	3.1 ± 0.1[cd]	9.7 ± 0.6[a]	3.6 ± 0.1[c]	24.4 ± 1.2[b]	29.3 ± 0.9[a]	15.1 ± 1.1[c]	33.0 ± 0.8[a]
CB–PM	6.4 ± 0.2[a]	3.3 ± 0.1[c]	7.6 ± 0.3[b]	3.7 ± 0.1[c]	27.2 ± 0.9[a]	31.1 ± 0.8[a]	19.2 ± 0.8[b]	33.9 ± 1.3[a]
MB–CB	5.9 ± 0.3[b]	6.7 ± 0.4[a]	9.6 ± 0.5[a]	9.1 ± 0.5[a]	26.6 ± 1.0[a]	20.3 ± 0.3[c]	15.3 ± 0.8[c]	32.4 ± 1.6[ab]
PM–PM	2.2 ± 0.1[d]	2.9 ± 0.1[d]	3.0 ± 0.2[d]	3.3 ± 0.1[c]	23.6 ± 1.4[b]	27.7 ± 0.8[b]	23.7 ± 1.7[a]	31.6 ± 1.1[b]
PM + CB–PM + CB	5.2 ± 0.3[c]	5.6 ± 0.2[b]	5.9 ± 0.3[c]	6.6 ± 0.3[b]	27.3 ± 1.3[a]	27.9 ± 1.0[b]	23.8 ± 1.4[a]	29.8 ± 0.9[c]
LSD ($P = 0.05$)	0.2	0.3	0.4	0.5	1.2	1.1	1.3	1.9
Tillage								
Conventional	4.8 ± 0.2[b]	4.1 ± 0.2[b]	6.0 ± 0.3[b]	4.9 ± 0.3[a]	24.2 ± 0.7[b]	26.1 ± 0.6[b]	16.1 ± 0.5[b]	30.3 ± 0.6[b]
Deep	5.5 ± 0.3[a]	4.6 ± 0.3[a]	8.3 ± 0.4[a]	5.6 ± 0.4[a]	27.5 ± 0.7[a]	28.4 ± 0.8[a]	22.8 ± 0.7[a]	34.1 ± 0.8[a]
LSD ($P = 0.05$)	0.2	0.3	1.2	NS	1.3	1.1	5.1	0.9
Nutrient management								
0	3.7 ± 0.3[d]	3.5 ± 0.2[d]	5.3 ± 0.4[d]	4.2 ± 0.3[d]	19.4 ± 0.7[d]	23.3 ± 0.6[d]	14.1 ± 0.9[d]	26.6 ± 0.8[d]
FYM	4.7 ± 0.3[c]	4.0 ± 0.3[c]	6.7 ± 0.5[c]	4.9 ± 0.4[c]	24.3 ± 0.7[c]	25.8 ± 0.8[c]	18.1 ± 1.0[c]	30.6 ± 0.5[c]
CF	5.4 ± 0.3[b]	4.5 ± 0.3[b]	7.8 ± 0.6[b]	5.6 ± 0.5[b]	27.0 ± 0.6[b]	28.9 ± 0.8[b]	21.2 ± 1.1[b]	33.9 ± 0.7[b]
FYM + CF	6.6 ± 0.4[a]	5.3 ± 0.4[a]	8.8 ± 0.7[a]	6.2 ± 0.6[a]	32.6 ± 0.5[a]	31.0 ± 1.0[a]	24.4 ± 1.2[a]	37.7 ± 1.0[a]
LSD ($P = 0.05$)	0.2	0.2	0.3	0.4	1.0	1.0	1.2	1.7

Values are mean ± 1 S.E.
[1] Values followed by the same letter in the same column within each main treatment were not significantly different according to the LSD test at $P = 0.05$ significant level.
[2] The MB–PM, CB–PM, MB–CB, PM–PM and PM + CB–PM + CB stands for Mothbean–Pearlmillet, Clusterbean–Pearlmillet, Mothbean–Clusterbean, Pearlmillet–Pearlmillet and Pearlmillet + Clusterbean–Pearlmillet + Clusterbean cropping systems, respectively.
[3] The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.

Fig. 3. Tillage system × cropping system interactions (T × CS) for (a) CEY, (b) BY, (c) PE$_{CEY}$, (d) PE$_{BY}$, (e) NR and (f) ME averaged across all nutrient management treatments. Vertical bars indicate mean ± 1 SE. Different letters indicate significant differences (p < 0.05) among treatments in a given year. (CT and DT refer to conventional and deep tillage, respectively.) The C1, C2, C3, C4 and C5 stands for mothbean–pearl millet, clusterbean–pearl millet, mothbean–clusterbean, pearlmillet–pearlmillet and pearlmillet + clusterbean–pearlmillet + clusterbean cropping systems, respectively).

Table 3
Main effects of cropping system, tillage and nutrient management on gross return (GR), net return (NR), benefit: cost ratio (BCR) and monetary efficiency (ME) in 2004, 2005, 2006 and 2007.

	2004	2005	2006	2007	2004	2005	2006	2007
	Gross return (Rs. ha^{-1})				Net return (Rs. ha^{-1})			
Cropping system								
MB–PM[2]	7799.80 ± 421.2[c1]	7244.7 ± 25.8[c]	13590.4 ± 804.4[a]	8947.8 ± 234.0[c]	2250.2 ± 342.2[b]	1799.6 ± 161.4[d]	7840.7 ± 729.1[a]	3446.7 ± 185.1[c]
CB–PM	10886.2 ± 369.3[a]	7786.7 ± 201.9[b]	12615.0 ± 543.0[b]	9164.4 ± 329.1[c]	3982.3 ± 294.4[a]	2341.6 ± 142.3[c]	5290.0 ± 467.1[b]	3663.2 ± 271.1[c]
MB–CB	8095.0 ± 333.8[c]	10984.6 ± 472.0[a]	13444.1 ± 755.3[a]	16985.0 ± 882.1[a]	2545.4 ± 257.7[b]	6171.1 ± 397.1[a]	7694.4 ± 672.5[a]	12112.8 ± 806.9[a]
PM–PM	5219.8 ± 311.0[d]	6815.3 ± 205.1[c]	6843.7 ± 480.6[d]	8456.0 ± 291.4[d]	1119.7 ± 247.4[c]	1370.1 ± 161.4[d]	2783.4 ± 416.2[c]	2964.5 ± 238.1[c]
PM + CB–PM + CB	9494.7 ± 469.9[b]	10640.0 ± 377.4[a]	11225.1 ± 594.4[c]	13102.6 ± 470.7[b]	3794.8 ± 399.9[a]	4550.1 ± 318.8[b]	5024.9 ± 519.9[b]	7515.5 ± 411.1[b]
LSD (P = 0.05)	345.6	450.6	627.9	806.0	345.6	450.6	627.9	806.0
Tillage								
Conventional	7748.0 ± 324.9[b]	8257.1 ± 248.6[b]	9711.1 ± 416.0[b]	10570.2 ± 449.2[b]	2387.4 ± 226.2[b]	3009.3 ± 238.0[b]	4099.1 ± 332.3[b]	5382.6 ± 456.5[b]
Deep	8850.1 ± 348.3[a]	9131.4 ± 338.4[a]	13376.3 ± 501.1[a]	12096.0 ± 580.5[a]	3089.5 ± 242.7[a]	3483.7 ± 32.6[a]	7354.3 ± 419.8[a]	6498.4 ± 589.1[a]
LSD (P = 0.05)	368.5	491.9	2234.8	1222.7	368.5	491.9	2234.8	1222.7
Nutrient management								
0[3]	6146.6 ± 371.8[d]	7255.0 ± 281.7[d]	8565.0 ± 484.0[d]	9210.3 ± 520.2[d]	1080.1 ± 222.2[d]	2317.2 ± 290.7[c]	3275.2 ± 364.3[d]	4325.9 ± 542.8[d]
FYM	7690.3 ± 403.4[c]	8079.3 ± 317.2[c]	10747.4 ± 586.5[c]	10695.6 ± 566.3[c]	2123.8 ± 254.7[c]	2591.5 ± 321.7[c]	4907.5 ± 478.5[c]	5261.2 ± 596.8[c]
CF	8730.0 ± 355.4[b]	9149.1 ± 331.3[b]	12565.7 ± 658.0[b]	12023.6 ± 750.9[b]	3175.3 ± 218.8[b]	3741.3 ± 332.6[b]	6771.5 ± 557.6[b]	6672.9 ± 782.7[b]
FYM + CF	10629.4 ± 415.9[a]	10293.8 ± 479.8[a]	14296.6 ± 781.1[a]	13402.8 ± 913.7[a]	4574.7 ± 259.4[a]	4336.0 ± 508.5[a]	7952.4 ± 682.6[a]	7502.1 ± 947.3[a]
LSD (P = 0.05)	309.1	403.1	601.8	720.9	309.1	403.1	601.8	720.9
	B:C ratio				Monetary efficiency (Rs. ha^{-1} d^{-1})			
Cropping system								
MB–PM	0.39 ± 0.06[d]	0.33 ± 0.03[d]	1.33 ± 0.11[a]	0.62 ± 0.03[c]	33.6 ± 5.1[c]	20.0 ± 1.8[d]	104.5 ± 9.7[a]	37.5 ± 2.0[c]
CB–PM	0.57 ± 0.04[b]	0.43 ± 0.02[c]	0.71 ± 0.06[bc]	0.66 ± 0.04[c]	46.9 ± 3.5[a]	26.0 ± 1.6[c]	63.0 ± 5.6[b]	39.8 ± 2.9[c]
MB–CB	0.45 ± 0.04[c]	1.27 ± 0.06[a]	1.31 ± 0.10[a]	2.45 ± 0.14[a]	38.0 ± 3.8[b]	70.1 ± 4.5[a]	102.6 ± 9.0[a]	134.6 ± 9.0[a]
PM–PM	0.26 ± 0.06[e]	0.25 ± 0.03[d]	0.66 ± 0.09[c]	0.53 ± 0.04[c]	13.0 ± 2.9[d]	15.2 ± 1.8[d]	31.6 ± 4.7[c]	32.2 ± 2.6[c]
PM + CB–PM + CB	0.65 ± 0.06[a]	0.74 ± 0.04[b]	0.79 ± 0.08[b]	1.34 ± 0.06[b]	44.1 ± 4.7[a]	50.6 ± 3.5[b]	57.1 ± 5.9[b]	81.7 ± 4.5[b]
LSD (P = 0.05)	0.06	0.08	0.12	0.16	4.6	5.0	8.5	8.8
Tillage								
Conventional	0.42 ± 0.04[b]	0.58 ± 0.05[b]	0.71 ± 0.06[b]	1.06 ± 0.09[a]	30.4 ± 2.8[b]	33.7 ± 2.7[b]	51.7 ± 4.5[b]	59.0 ± 5.1[b]
Deep	0.51 ± 0.04[a]	0.62 ± 0.06[a]	1.21 ± 0.06[a]	1.18 ± 0.11[a]	39.8 ± 3.0[a]	39.0 ± 3.7[a]	91.9 ± 5.8[a]	71.3 ± 6.6[a]
LSD (P = 0.05)	0.01	0.10	0.42	NS	1.5	5.5	26.7	13.6
Nutrient management								
0	0.19 ± 0.04[d]	0.48 ± 0.07[b]	0.61 ± 0.07[c]	0.91 ± 0.12[b]	13.6 ± 2.7[d]	26.0 ± 3.3[c]	40.9 ± 4.7[d]	47.4 ± 6.0[d]
FYM	0.36 ± 0.04[c]	0.48 ± 0.07[b]	0.83 ± 0.06[b]	0.99 ± 0.12[b]	27.3 ± 3.1[c]	29.0 ± 3.6[c]	61.6 ± 6.5[c]	57.7 ± 6.6[c]
CF	0.56 ± 0.03[b]	0.70 ± 0.07[a]	1.16 ± 0.09[a]	1.28 ± 0.16[a]	41.0 ± 2.8[b]	41.9 ± 3.8[b]	85.0 ± 7.8[b]	73.2 ± 8.7[b]
FYM + CF	0.74 ± 0.03[a]	0.74 ± 0.10[a]	1.25 ± 0.10[a]	1.30 ± 0.18[a]	58.6 ± 3.1[a]	48.6 ± 5.8[a]	99.6 ± 9.6[a]	82.3 ± 10.6[a]
LSD (P = 0.05)	0.05	0.07	0.11	0.14	4.1	4.5	7.6	7.9

Values are mean ± 1 S.E.
[1]Values followed by the same letter in the same column within each main treatment were not significantly different according to the LSD test at P = 0.05 significant level.
[2]The MB–PM, CB–PM, MB–CB, PM–PM and PM + CB–PM + CB stands for Mothbean–Pearlmillet, Clusterbean–Pearlmillet, Mothbean–Clusterbean, Pearlmillet–Pearlmillet and Pearlmillet + Clusterbean–Pearlmillet + Clusterbean cropping systems, respectively.
[3]The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.
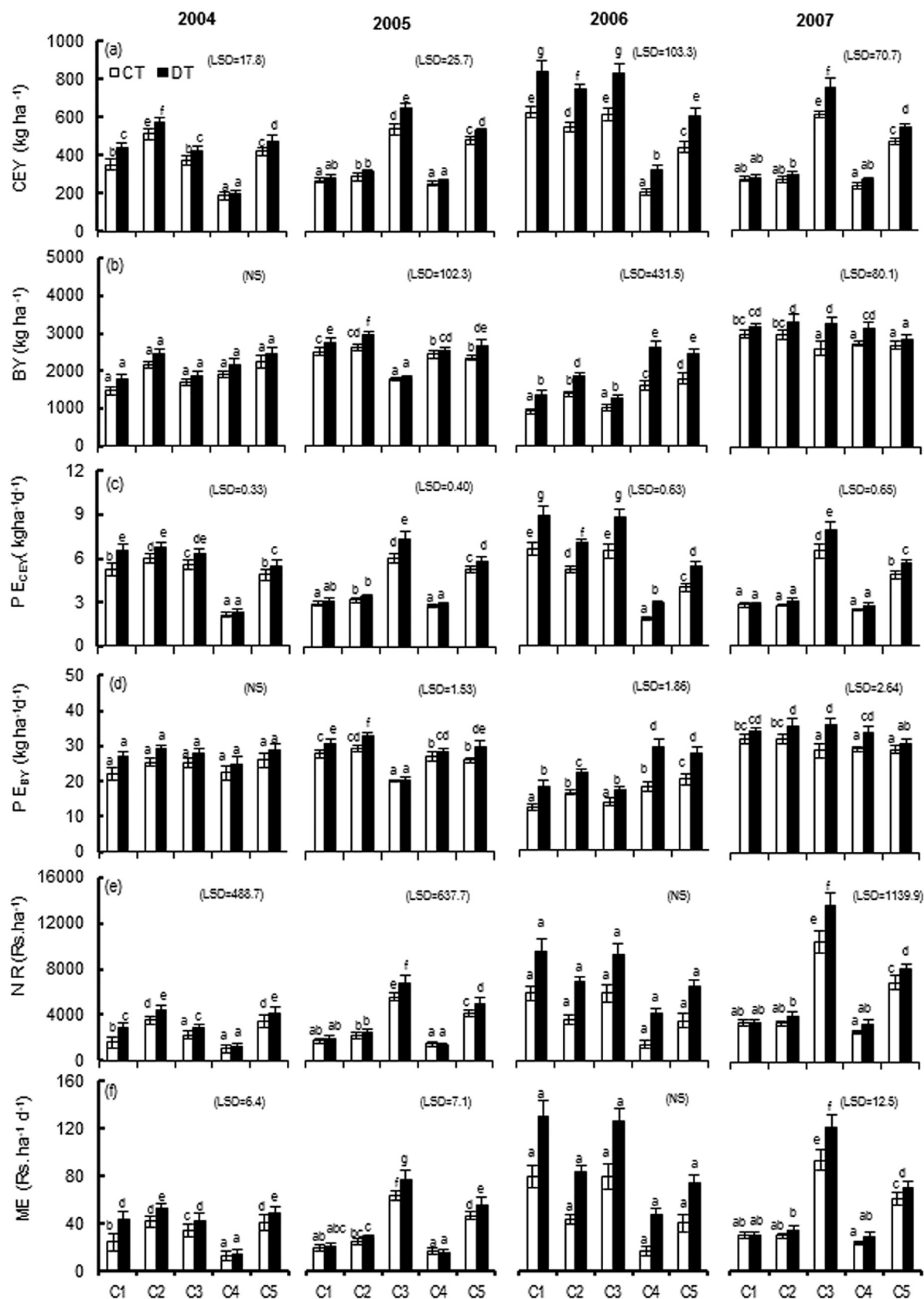
The PE$_{CEY}$ and PE$_{BY}$ were significantly different ($P < 0.05$) between the cropping system, tillage and nutrient management treatments (Table 2). The T × CS and NM × CS interactions were significant for PE$_{CEY}$ in all years (Fig. 3 and Table 6), and for PE$_{BY}$ in three of the four years studied. The MB–CB system had a higher ($P < 0.05$) PE$_{CEY}$ compared to the other systems in three of the four years studied. The PM–PM system had the lowest PE$_{CEY}$ in all years. Mean PE$_{CEY}$ across all tillage, nutrient management treatments and years was highest for MB–CB (7.8 kg ha^{-1} d^{-1}), intermediate for MB–PM, CB–PM and PM + CB–PM + CB (5.2–5.8 kg ha^{-1} d^{-1}) and lowest for PM–PM (2.9 kg ha^{-1} d^{-1}). The CB–PM system had the greatest PE$_{BY}$ in three of the four years studied. In contrast to PE$_{CEY}$, the MB–CB system had the lowest ($P < 0.05$) PE$_{BY}$ compared to the other systems in 2005 and 2006. Mean PE$_{BY}$ across all tillage, nutrient management treatments and years ranged between 23.7 and 27.9 kg ha^{-1} d^{-1}, being highest for CB–PM followed by PM + CB–PM + CB, PM–PM, MB–PM and MB–CB.

3.2.2. Economics

Cropping system, tillage and nutrient management treatments all had significant effects ($P < 0.05$) on returns, BCR and ME in all years (Table 3). The T × CS interaction was significant for NR and ME in 2004, 2005 and 2007 (Fig. 3). The NM × CS interaction was significant for NR and ME in all years (Table 6).

Averaged across tillage and nutrient management treatments, the MB–CB system showed significantly higher ($P < 0.05$) NRs, BCRs and MEs in 2005 and 2007 (Table 3). The MB–PM and MB–CB systems recorded significantly higher NR, BCR and ME values compared to the other systems in 2006. Averaged over 2004–2007, the MB–CB system recorded 36.6, 86.7, 86.0 and 246.3% higher NRs than the PM + CB–PM + CB, CB–PM, MB–PM and PM–PM systems, respectively. In 2004, the PM + CB–PM + CB system had the highest BCR. Mean ME across all tillage, nutrient management treatments and years ranged between Rs. 23.0 and 86.3 ha^{-1} d^{-1}, being highest for MB–CB followed by PM + CB–PM + CB, MB–PM, CB–PM and PM–PM. Mean BCR was highest for MB–CB, lowest for PM–PM and intermediate for the other systems.

3.2.3. Total water use and WUE

WU and WUEs (WUE$_{CEY}$, WUE$_{BY}$) were significantly different ($P < 0.05$) between the cropping systems. Tillage and nutrient management had a significant influence on WU and WUE in all years (Table 4). The T × CS interaction was significant for WU and WUE in all years (Fig. 4). The NM × CS interaction was significant for WU only in 2007 and for WUE in all years (Table 7). The MB–

Table 4
Main effects of cropping system, tillage and nutrient management on water use (WU) and water use efficiencies (WUEs) in 2004, 2005, 2006 and 2007.

	2004	2005	2006	2007
	Water use (mm)			
Cropping system				
MB–PM	155.8 ± 0.7^a	257.1 ± 1.9^b	156.1 ± 0.9^a	174.6 ± 2.0^b
CB–PM	175.4 ± 0.5^c	264.8 ± 1.7^c	180.5 ± 0.4^d	185.8 ± 0.8^d
MB–CB	157.0 ± 0.8^a	249.5 ± 2.0^a	158.8 ± 0.6^b	162.3 ± 0.7^a
PM–PM	171.1 ± 0.8^b	258.7 ± 1.8^b	180.8 ± 0.4^d	185.5 ± 0.4^d
PM + CB–PM + CB	171.9 ± 0.7^b	258.9 ± 1.4^b	178.0 ± 0.6^c	181.5 ± 0.7^c
LSD ($P = 0.05$)	1.5	3.1	1.4	1.3
Tillage				
Conventional	164.2 ± 0.7^a	255.7 ± 1.6^a	169.7 ± 1.5^a	175.5 ± 1.4^a
Deep	168.3 ± 0.6^b	259.8 ± 1.1^b	172.0 ± 1.4^b	180.4 ± 1.9^b
LSD ($P = 0.05$)	3.3	2.1	2.2	1.4
Nutrient management				
0	164.3 ± 1.5^a	251.4 ± 1.3^a	169.4 ± 2.2^a	174.3 ± 2.0^a
FYM	165.9 ± 1.6^b	256.4 ± 5.5^a	170.7 ± 2.1^b	178.0 ± 1.8^b
CF	166.8 ± 1.7^{bc}	259.0 ± 1.7^c	171.0 ± 2.1^b	179.0 ± 1.9^b
FYM + CF	167.9 ± 1.7^c	264.3 ± 1.9^d	172.3 ± 2.0^c	180.5 ± 1.7^c
LSD ($P = 0.05$)	1.3	2.8	1.2	1.1
	WUE (CEY kg ha^{-1} mm^{-1})			
Cropping system				
MB–PM	2.51 ± 0.14^b	1.07 ± 0.03^{ab}	4.63 ± 0.25^d	1.88 ± 0.05^b
CB–PM	3.08 ± 0.11^c	1.14 ± 0.03^b	3.56 ± 0.14^c	1.81 ± 0.06^{ab}
MB–CB	2.53 ± 0.11^b	2.37 ± 0.11^d	4.51 ± 0.24^d	5.02 ± 0.27^d
PM–PM	1.12 ± 0.07^a	1.00 ± 0.03^a	1.46 ± 0.10^a	1.63 ± 0.06^a
PM + CB–PM + CB	2.59 ± 0.13^b	1.95 ± 0.07^c	2.91 ± 0.15^b	3.34 ± 0.13^c
LSD ($P = 0.05$)	0.11	0.10	0.21	0.25
Tillage				
Conventional	2.23 ± 0.14^a	1.44 ± 0.07^a	2.91 ± 0.16^a	2.58 ± 0.17^a
Deep	2.50 ± 0.11^b	1.57 ± 0.09^b	3.92 ± 0.20^b	2.89 ± 0.21^a
LSD ($P = 0.05$)	0.14	0.11	0.62	NS
Nutrient management				
0	1.76 ± 0.12^a	1.26 ± 0.08^a	2.56 ± 0.18^a	2.24 ± 0.19^a
FYM	2.17 ± 0.13^b	1.39 ± 0.09^b	3.18 ± 0.23^b	2.57 ± 0.22^b
CF	2.50 ± 0.12^c	1.57 ± 0.11^c	3.72 ± 0.27^c	2.91 ± 0.29^c
FYM + CF	3.03 ± 0.15^d	1.79 ± 0.15^d	4.18 ± 0.30^d	3.27 ± 0.32^d
LSD ($P = 0.05$)	0.09	0.09	0.19	0.22
	WUE (BY kg ha^{-1} mm^{-1})			
Cropping system				
MB–PM	10.5 ± 0.50^a	10.2 ± 0.26^c	7.2 ± 0.48^a	17.5 ± 0.32^c
CB–PM	13.2 ± 0.40^c	10.5 ± 0.22^c	8.9 ± 0.36^b	16.8 ± 0.58^b
MB–CB	11.3 ± 0.40^b	7.2 ± 0.12^a	7.2 ± 0.37^a	17.9 ± 0.85^c
PM–PM	11.8 ± 0.67^b	9.6 ± 0.12^b	11.6 ± 0.84^c	15.7 ± 0.54^a
PM + CB–PM + CB	13.6 ± 0.65^c	9.7 ± 0.37^b	11.8 ± 0.66^c	15.1 ± 0.45^a
LSD ($P = 0.05$)	0.56	0.42	0.65	0.93
Tillage				
Conventional	11.5 ± 0.36^a	9.1 ± 0.18^a	7.8 ± 0.31^a	15.8 ± 0.33^a
Deep	12.7 ± 0.35^b	9.8 ± 0.25^b	10.9 ± 0.46^b	17.4 ± 0.41^b
LSD ($P = 0.05$)	0.61	0.48	2.53	1.59
Nutrient management				
0	9.2 ± 0.34^a	8.3 ± 0.19^a	6.8 ± 0.42^a	14.0 ± 0.44^a
FYM	11.4 ± 0.34^b	9.0 ± 0.25^b	8.7 ± 0.51^b	15.8 ± 0.26^b
CF	12.6 ± 0.31^c	10.0 ± 0.28^c	10.2 ± 0.57^c	17.4 ± 0.38^c
FYM + CF	15.2 ± 0.35^d	10.5 ± 0.36^d	11.6 ± 0.64^d	19.2 ± 0.54^d
LSD ($P = 0.05$)	0.50	0.37	0.58	0.84

Values are mean ± 1 S.E.
[1]Values followed by the same letter in the same column within each main treatment were not significantly different according to the LSD test at $P = 0.05$ significant level.
[2]The MB–PM, CB–PM, MB–CB, PM–PM and PM + CB–PM + CB stands for Mothbean–Pearlmillet, Clusterbean–Pearlmillet, Mothbean–Clusterbean, Pearlmillet–Pearlmillet and Pearlmillet + Clusterbean–Pearlmillet + Clusterbean cropping systems, respectively.
[3]The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.

CB cropping system had the lowest WU compared to the other cropping systems in three of the four years studied. In 2006, MB–PM had the lowest WU compared to the other systems. Averaged over 2004–2007, mean WU for the cropping systems ranged from 185.9 to 201.6 mm, being greatest for CB–PM followed by PM–PM, PM + CB–PM + CB, MB–PM and MB–CB (Table 4).

The MB–CB system had the greatest ($P < 0.05$) WUE$_{CEY}$ compared to the other cropping systems in 2005 and 2007. In 2006, the MB–PM and MB–CB systems had higher WUE$_{CEY}$ values compared to the other systems. The PM–PM system had the lowest WUE$_{CEY}$ in all years. Averaged across tillage, nutrient management treatments and years, the mean WUE$_{CEY}$ was highest for MB–CB (3.61 kg ha^{-1} mm^{-1}), followed by PM + CB–PM + CB

Table 5
Main effects of cropping system, tillage and nutrient management on nutrient uptake in 2004, 2005, 2006 and 2007.

	2004	2005	2006	2007	2004	2005	2006	2007
	N uptake (kg ha⁻¹)				P uptake (kg ha⁻¹)			
Cropping system								
MB–PM[2]	37.8 ± 1.7[b1]	20.1 ± 0.6[bc]	28.6 ± 1.8[a]	23.3 ± 0.6[c]	4.7 ± 0.3[bc]	2.1 ± 0.2[b]	3.8 ± 0.2[a]	2.4 ± 0.1[c]
CB–PM	33.4 ± 0.9[c]	21.6 ± 0.5[b]	29.6 ± 1.3[a]	24.6 ± 0.7[c]	6.0 ± 0.5[a]	2.3 ± 0.2[b]	4.0 ± 0.3[a]	2.5 ± 0.1[c]
MB–CB	40.3 ± 1.7[a]	30.8 ± 1.1[a]	29.2 ± 1.5[a]	48.4 ± 2.3[a]	5.1 ± 0.2[b]	4.0 ± 0.3[a]	3.9 ± 0.2[a]	6.6 ± 0.3[a]
PM–PM	16.0 ± 0.9[e]	19.4 ± 0.6[c]	17.5 ± 1.2[c]	22.2 ± 0.6[c]	1.7 ± 0.2[d]	2.1 ± 0.1[b]	1.8 ± 0.1[c]	2.2 ± 0.1[c]
PM + CB–PM + CB	28.8 ± 1.4[d]	30.3 ± 1.1[a]	23.4 ± 1.4[b]	33.9 ± 1.1[b]	4.3 ± 0.2[c]	3.7 ± 0.1[a]	2.2 ± 0.1[b]	3.4 ± 0.2[b]
LSD (P = 0.05)	1.8	1.9	1.6	2.2	0.7	0.3	0.4	0.3
Tillage								
Conventional	29.8 ± 1.3[a]	23.6 ± 0.9[a]	21.5 ± 1.3[a]	28.8 ± 3.6[b]	4.2 ± 0.3[a]	2.6 ± 0.1[a]	2.7 ± 0.2[b]	3.2 ± 0.2[a]
Deep	32.7 ± 1.4[b]	25.3 ± 1.0[a]	29.8 ± 1.6[b]	32.2 ± 4.1[a]	4.5 ± 0.2[a]	3.1 ± 0.2[a]	3.6 ± 0.2[a]	3.6 ± 0.3[a]
LSD (P = 0.05)	2.3	NS	6.8	NS	NS	NS	0.4	NS
Nutrient management								
0[3]	23.8 ± 1.5[d]	20.9 ± 1.1[d]	19.6 ± 1.5[d]	25.3 ± 4.3[c]	3.2 ± 0.2[d]	2.4 ± 0.2[c]	2.3 ± 0.2[d]	2.6 ± 0.2[d]
FYM	29.8 ± 1.9[c]	22.7 ± 1.1[c]	23.6 ± 1.8[c]	29.5 ± 5.1[b]	4.0 ± 0.3[c]	2.5 ± 0.1[c]	2.8 ± 0.2[c]	3.2 ± 0.3[c]
CF	32.3 ± 1.7[b]	25.4 ± 1.3[b]	27.4 ± 2.4[b]	33.3 ± 5.8[a]	4.8 ± 0.5[b]	2.9 ± 0.2[b]	3.5 ± 0.3[b]	3.6 ± 0.3[b]
FYM + CF	39.2 ± 1.8[a]	28.7 ± 1.5[a]	32.0 ± 2.3[a]	33.9 ± 6.4[a]	5.5 ± 0.3[a]	3.6 ± 0.3[a]	3.9 ± 0.2[a]	4.1 ± 0.4[a]
LSD (P = 0.05)	1.6	1.2	1.4	1.9	0.6	0.3	0.3	0.2
	K uptake (kg ha⁻¹)				Total N, P, K uptake (kg ha⁻¹)			
Cropping system								
MB–PM	12.1 ± 0.6[d]	29.0 ± 1.4[b]	7.4 ± 0.6[d]	34.4 ± 1.4[b]	54.7 ± 2.6[c]	51.2 ± 2.1[cd]	39.8 ± 2.6[d]	60.2 ± 2.0[cd]
CB–PM	26.9 ± 1.1[a]	32.6 ± 1.3[a]	17.2 ± 1.0[b]	38.1 ± 1.7[a]	66.3 ± 2.3[a]	56.5 ± 1.9[a]	50.8 ± 2.4[a]	65.2 ± 2.4[b]
MB–CB	13.6 ± 0.6[c]	19.6 ± 0.7[c]	7.3 ± 0.5[d]	37.6 ± 2.4[a]	59.0 ± 2.5[b]	54.4 ± 1.8[ab]	40.3 ± 2.2[cd]	92.6 ± 4.9[a]
PM–PM	22.1 ± 1.8[b]	28.0 ± 1.1[b]	22.8 ± 1.9[a]	32.8 ± 1.2[b]	39.8 ± 2.8[d]	49.5 ± 1.7[d]	42.1 ± 3.1[bc]	57.2 ± 1.7[de]
PM + CB–PM + CB	27.5 ± 1.8[a]	18.1 ± 0.7[d]	9.2 ± 0.7[c]	18.5 ± 0.7[c]	60.6 ± 3.4[b]	52.0 ± 1.8[bc]	34.8 ± 2.1[e]	55.7 ± 1.7[e]
LSD (P = 0.05)	1.2	1.4	1.3	2.2	3.0	2.5	2.7	4.1
Tillage								
Conventional	19.3 ± 1.1[a]	24.3 ± 0.9[a]	10.4 ± 0.8[b]	30.3 ± 1.2[b]	53.3 ± 2.0[a]	50.5 ± 1.0[b]	34.7 ± 1.3[b]	62.4 ± 2.2[b]
Deep	21.6 ± 1.2[a]	26.6 ± 1.0[a]	15.1 ± 1.1[a]	34.2 ± 1.5[a]	58.8 ± 2.1[a]	55.0 ± 1.3[a]	48.5 ± 1.6[a]	70.0 ± 2.6[a]
LSD (P = 0.05)	NS	NS	3.7	1.1	NS	2.7	10.9	4.9
Nutrient management								
0	13.5 ± 0.9[d]	19.5 ± 0.7[d]	8.8 ± 0.9[d]	24.3 ± 1.2[d]	40.5 ± 2.1[d]	42.7 ± 0.9[d]	30.6 ± 1.7[d]	52.2 ± 2.2[d]
FYM	18.6 ± 1.2[c]	24.6 ± 1.1[c]	11.0 ± 1.1[c]	30.6 ± 1.1[c]	52.4 ± 2.4[c]	49.8 ± 0.9[c]	37.4 ± 1.5[c]	63.2 ± 2.2[c]
CF	22.3 ± 1.4[b]	28.0 ± 1.3[b]	14.2 ± 1.5[b]	35.1 ± 1.8[b]	59.4 ± 1.8[b]	56.3 ± 0.8[b]	45.1 ± 1.9[b]	72.1 ± 3.6[b]
FYM + CF	27.3 ± 1.8[a]	29.8 ± 1.5[a]	17.1 ± 1.8[a]	39.1 ± 2.0[a]	72.0 ± 1.8[a]	62.1 ± 1.6[a]	53.1 ± 2.2[a]	77.2 ± 3.9[a]
LSD (P = 0.05)	1.1	1.3	1.1	1.9	2.6	2.3	2.4	3.6

Values are mean ± 1 S.E.
[1]Values followed by the same letter in the same column within each main treatment were not significantly different according to the LSD test at P = 0.05 significant level.
[2]The MB–PM, CB–PM, MB–CB, PM–PM and PM + CB–PM + CB stands for Mothbean–Pearlmillet, Clusterbean–Pearlmillet, Mothbean–Clusterbean, Pearlmillet–Pearlmillet and Pearlmillet + Clusterbean–Pearlmillet + Clusterbean cropping systems, respectively.
[3]The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.

(2.70 kg ha⁻¹ mm⁻¹), CB–PM (2.52 kg ha⁻¹ mm⁻¹), MB–PM (2.40 kg ha⁻¹ mm⁻¹) and PM–PM (1.30 kg ha⁻¹ mm⁻¹).

The CB–PM system had the highest WUE_{BY} in 2004. The PM–PM and PM + CB–PM + CB systems had the highest WUE_{BY} in 2006 and 2007 and the CB–PM system had the highest WUE_{BY} in 2005. Averaged across tillage, nutrient management treatments and years, the mean WUE_{BY} varied from 11.4 to 12.6 kg ha⁻¹ mm⁻¹. Mean WUE_{BY} values were highest for the PM + CB–PM + CB, PM–PM and CB–PM systems, intermediate for MB–PM and lowest for MB–CB. The legume–millet (CB–PM, MB–PM and PM + CB–PM + CB) and millet–millet (PM–PM) cropping systems had higher WUE_{BY} values than the legume–legume (MB–CB) system. In contrast to WUE_{CEY}, the mean WUE_{BY} values were lowest for the MB–CB system.

3.2.4. Nutrient uptake

Nutrient uptake was significantly different ($P < 0.05$) between cropping systems (Table 5). Nutrient management treatments had a significant influence on nutrient uptake (N, P, K, and TN) in all years. The T × CS and NM × CS interactions were significant for total nutrient (TN) uptake in three of the four years studied (Fig. 3 and Table 7). The MB–CB system recorded the greatest N uptake in three of the four years studied. The MB–CB system recorded a

higher N uptake than the PM–PM and PM + CB–PM + CB systems in all years (Table 5). The MB–CB system had the highest P uptake in two of the four years studied (2005 and 2007). The PM–PM system recorded the lowest N and P uptake in all years. The CB–PM system had the highest K uptake in 2004, 2005 and 2007. The PM–PM system recorded the highest K uptake in 2006. The MB–CB system had a higher TN uptake than the MB–PM, PM–PM and PM + CB–PM + CB systems in 2005 and 2007 and the CB–PM system recorded the highest TN uptake in 2004 and 2006. Mean TN uptake by the different cropping systems ranged between 47.2 and 61.6 kg ha⁻¹ y⁻¹ and was highest for the MB–CB and CB–PM systems, intermediate for MB–PM and PM + CB–PM + CB and lowest for the PM–PM system.

3.3. Tillage effects

Tillage and the T × CS interaction had significant effects on the agronomic and economic performance of the cropping systems. DT had significantly higher ($P < 0.05$) CEY than CT in 2004, 2005 and 2006 (Table 2). The increases in CEY for DT over CT were 14.2, 11.6, 36.8 and 15.0% in 2004, 2005, 2006 and 2007, respectively. Averaged across cropping systems, nutrient management treatments and years, the increase in mean CEY with DT was 20.4%

Table 6
Interaction effects of nutrient management and cropping system (NM × CS) on yield, production efficiency (PE), net return (NR) and monetary efficiency (ME) in 2004, 2005, 2006 and 2007.

Cropping system	2004				2005			
	0[2]	FYM	CF	FYM + CF	0	FYM	CF	FYM + CF
Cluster bean equivalent yield (kg ha^{-1})								
MB–PM[3]	267.7 ± 20.8[c1]	353.7 ± 28.4[e]	429.4 ± 28.6[g]	515.2 ± 18.9[i]	226.0 ± 7.3[a]	261.3 ± 15.0[ab]	289.8 ± 5.0[b]	327.2 ± 9.7[c]
CB–PM	453.3 ± 17.1[g]	501.7 ± 15.8[hi]	526.7 ± 15.4[i]	680.0 ± 23.4[k]	262.0 ± 13.1[ab]	288.7 ± 17.8[b]	310.8 ± 10.3[bc]	343.7 ± 11.2[c]
MB–CB	291.6 ± 10.5[cd]	374.4 ± 19.8[e]	430.3 ± 18.5[g]	494.1 ± 12.9[hi]	460.7 ± 14.7[de]	518.2 ± 31.2[f]	609.8 ± 24.3[g]	783.0 ± 41.9[h]
PM–PM	126.8 ± 7.5[a]	157.5 ± 6.0[a]	217.4 ± 7.1[b]	266.3 ± 5.5[c]	217.5 ± 6.6[a]	230.4 ± 6.5[a]	288.5 ± 9.2[b]	296.7 ± 9.0[bc]
PM + CB	306.7 ± 18.0[d]	417.9 ± 19.1[f]	475.0 ± 19.7[gh]	583.8 ± 16.1[j]	418.5 ± 18.1[d]	475.2 ± 16.0[ef]	526.0 ± 11.7[f]	598.8 ± 26.0[g]
LSD (P = 0.05)	(2004: 35.6)				(2005: 51.4)			
Biomass yield (kg ha^{-1})								
MB–PM	1184.5 ± 68.2[a]	1587.2 ± 98.7[c]	1670.5 ± 93.1[c]	2090.8 ± 56.6[de]	2151.4 ± 91.1[cd]	2548.8 ± 98.5[f]	2781.7 ± 56.5[g]	3055.7 ± 90.6[ij]
CB–PM	2056.8 ± 93.2[de]	2233.5 ± 81.5[ef]	2251.5 ± 50.2[f]	2720.0 ± 92.5[gh]	2436.5 ± 98.8[ef]	2704.0 ± 67.5[g]	2903.3 ± 97.5[hi]	3136.7 ± 98.4[j]
MB–CB	1381.8 ± 33.7[b]	1699.7 ± 91.3[c]	1909.5 ± 80.6[d]	2131.0 ± 52.9[ef]	1670.7 ± 31.3[c]	1696.5 ± 36.7[a]	1833.2 ± 20.5[ab]	1956.3 ± 60.7[bc]
PM–PM	1384.0 ± 68.8[b]	1705.8 ± 46.1[c]	2153.2 ± 74.0[ef]	2877.0 ± 80.6[hi]	2074.5 ± 58.3[c]	2268.5 ± 67.0[de]	2782.0 ± 56.7[gh]	2833.2 ± 53.0[gh]
PM + CB	1561.7 ± 60.7[bc]	2268.5 ± 98.7[f]	2594.0 ± 38.6[g]	2974.5 ± 96.4[i]	2121.5 ± 42.2[cd]	2342.5 ± 52.1[de]	2674.3 ± 65.8[f]	2901.8 ± 79.7[h]
LSD (P = 0.05)	(2004: 185.6)				(2005: 194.1)			
Production efficiency (CEY kg ha^{-1} d^{-1})								
MB–PM	4.0 ± 1.48[d]	5.3 ± 0.31[fg]	6.4 ± 0.42[ij]	7.7 ± 0.43[kl]	2.5 ± 0.08[a]	2.9 ± 0.17[ab]	3.2 ± 0.06[bc]	3.6 ± 0.11[cd]
CB–PM	5.3 ± 0.28[fg]	5.9 ± 0.20[hi]	6.2 ± 0.19[i]	8.0 ± 0.18[l]	2.9 ± 0.15[ab]	3.2 ± 0.20[bc]	3.5 ± 0.11[bcd]	3.8 ± 0.12[d]
MB–CB	4.4 ± 0.28[de]	5.6 ± 0.16[gh]	6.4 ± 0.30[ij]	7.4 ± 0.28[k]	5.2 ± 0.17[e]	5.9 ± 0.35[g]	6.9 ± 0.28[h]	8.9 ± 0.70[i]
PM–PM	1.5 ± 0.19[a]	1.8 ± 0.09[a]	2.5 ± 0.07[b]	3.1 ± 0.08[c]	2.4 ± 0.07[a]	2.6 ± 0.07[a]	3.2 ± 0.10[bc]	3.3 ± 0.10[bcd]
PM + CB	3.6 ± 0.06[c]	4.9 ± 0.21[ef]	5.5 ± 0.22[gh]	6.8 ± 0.23[j]	4.7 ± 0.20[e]	5.3 ± 0.18[ef]	5.8 ± 0.13[fg]	6.7 ± 0.51[h]
LSD (P = 0.05)	(2004: 0.5)				(2005: 0.6)			
Production efficiency (BY kg ha^{-1} d^{-1})								
MB–PM	17.7 ± 1.02[ab]	23.7 ± 2.08[d]	24.9 ± 1.69[de]	31.2 ± 0.84[gh]	23.9 ± 1.01[cd]	28.3 ± 1.13[gh]	30.9 ± 0.63[hij]	34.0 ± 1.01[klm]
CB–PM	24.2 ± 1.90[de]	26.3 ± 0.96[ef]	26.5 ± 0.59[ef]	32.0 ± 1.42[gh]	27.1 ± 1.10[efg]	30.0 ± 0.75[hi]	32.3 ± 1.19[kl]	34.9 ± 1.15[lm]
MB–CB	20.6 ± 0.50[c]	25.4 ± 1.36[de]	28.5 ± 1.20[fg]	31.8 ± 0.79[gh]	19.0 ± 0.29[a]	19.3 ± 0.42[a]	20.8 ± 0.23[ab]	22.2 ± 0.69[bc]
PM–PM	16.1 ± 0.80[a]	19.8 ± 0.54[bc]	25.0 ± 0.86[de]	33.5 ± 0.94[hi]	23.1 ± 0.65[cd]	25.2 ± 0.74[de]	30.9 ± 0.63[hij]	31.5 ± 0.59[hijk]
PM + CB	18.2 ± 0.71[abc]	26.4 ± 1.38[ef]	30.2 ± 0.45[g]	34.6 ± 1.24[i]	23.6 ± 0.47[cd]	26.0 ± 0.58[ef]	29.7 ± 0.73[ghi]	32.2 ± 3.11[kl]
LSD (P = 0.05)	(2004: 2.4)				(2005: 2.2)			
Net return (Rs ha^{-1} y^{-1})								
MB–PM	397.2 ± 325.9[ab]	1676.0 ± 492.8[cd]	2813.4 ± 452.3[ef]	4114.3 ± 299.9[h]	976.4 ± 198.1[ab]	1443.8 ± 286.3[abc]	2235.6 ± 119.0[cde]	2542.5 ± 185.6[def]
CB–PM	2911.4 ± 373.5[f]	3339.7 ± 260.6[fg]	3685.0 ± 257.0[gh]	5993.0 ± 427.5[j]	1833.7 ± 244.6[bcd]	2003.0 ± 247.5[cde]	2668.6 ± 227.7[def]	2861.1 ± 227.7[ef]
MB–CB	993.6 ± 163.0[bc]	2124.6 ± 338.3[ef]	3178.2 ± 302.5[f]	3885.0 ± 181.8[gh]	4694.3 ± 222.7[hi]	4988.1 ± 144.8[i]	6471.5 ± 442.7[k]	8530.6 ± 280.9[l]
PM–PM	−119.9 ± 68.8[a]	210.1 ± 75.0[a]	1621.6 ± 178.2[cd]	2766.8 ± 110.5[ef]	759.6 ± 87.1[a]	654.2 ± 137.1[a]	2221.1 ± 148.3[cde]	1845.5 ± 153.1[bcd]
PM + CB	1218.3 ± 271.7[c]	3268.5 ± 347.2[fg]	4578.4 ± 238.7[i]	6114.2 ± 330.6[j]	3322.1 ± 219.0[fg]	3868.6 ± 297.6[gh]	5109.5 ± 270.8[ij]	5900.2 ± 166.8[jk]
LSD (P = 0.05)	(2004: 35.6)				(2005: 901.3)			
Monetary efficiency (Rs. ha^{-1} d^{-1})								
MB–PM	5.9 ± 1.9[ab]	25.0 ± 3.1[cd]	42.0 ± 6.8[fg]	61.4 ± 4.5[ij]	10.8 ± 2.2[ab]	16.0 ± 3.2[abc]	24.8 ± 1.3[cde]	28.3 ± 2.0[def]
CB–PM	34.3 ± 4.4[d]	39.3 ± 7.4[efg]	43.4 ± 3.0[fg]	70.5 ± 5.0[j]	20.4 ± 2.7[bcd]	22.3 ± 2.8[cde]	29.7 ± 2.5[def]	31.8 ± 2.5[ef]
MB–CB	14.8 ± 2.4[b]	31.7 ± 5.0[de]	47.4 ± 4.5[gh]	58.0 ± 2.7[i]	53.3 ± 1.6[h]	56.7 ± 5.0[hi]	73.5 ± 3.2[j]	96.9 ± 9.9[k]
PM–PM	−1.4 ± 1.0[a]	2.4 ± 0.9[a]	18.9 ± 1.4[c]	32.2 ± 1.3[de]	8.4 ± 1.5[a]	7.3 ± 1.6[a]	24.7 ± 1.7[cde]	20.5 ± 2.4[bcd]
PM + CB	14.2 ± 3.2[b]	38.0 ± 4.0[ef]	53.2 ± 2.8[hi]	71.1 ± 5.1[k]	36.9 ± 3.3[fg]	43.0 ± 3.0[g]	56.8 ± 1.9[hi]	65.6 ± 3.4[ij]
LSD (P = 0.05)	(2004: 9.1)				(2005: 10.1)			

Values are mean ± 1S.E.
[1]For a parameter within a year values followed by the same letter are not significantly different at $p < 0.05$ according to LSD.
[2]The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.
[3]The MB–PM, CB–PM, MB–CB, PM–PM and PM + CB stands for Mothbean–Pearlmillet, Clusterbean–Pearlmillet, Mothbean–Clusterbean, Pearlmillet–Pearlmillet and Pearlmillet + Clusterbean–Pearlmillet + Clusterbean cropping systems, respectively.

compared to CT. The increase in CEY due to DT was highest for the MB–CB system and lowest for PM–PM, with other cropping systems being intermediate. The CEY of the MB–CB and PM + CB–PM + CB systems with DT were significantly higher than with CT in all years (Fig. 3). The difference in CEY for the PM–PM system with DT and CT were not significant in three out of the four years studied. DT had a higher BY than CT in all years (Table 2). DT gave 255.2, 202.9, 563.3, and 357.3 kg ha^{-1} higher BY than CT in 2004, 2005, 2006 and 2007, respectively. The T × CS interaction was significant for BY in 2005, 2006 and 2007 (Fig. 3). The BY of the MB–PM system with DT was higher than with CT in 2005 and 2006. The CB–PM and PM–PM systems had higher BYs with DT than with CT in 2005, 2006 and 2007. The BY of the MB–CB system was higher with DT compared to CT in 2006 and 2007. Averaged across cropping systems, nutrient management treatments and years, the increase in mean BY with DT was 344.7 kg ha^{-1} compared to using CT.

Tillage and the T × CS interaction significantly affected PEs. DT had a higher PE$_{CEY}$ in three of the four years studied (Table 2). Mean PE$_{CEY}$ values across the cropping systems and nutrient management treatments with DT were 14.6, 12.2, 38.3 and 14.3% higher than with CT in 2004, 2005, 2006 and 2007 respectively. The T × CS interaction was significant for PE$_{CEY}$ in all years. The PE$_{CEY}$ of the MB–CB and PM + CB–PM + CB systems were also higher with DT than with CT in all years. The PE$_{CEY}$ of the CB–PM and MB–PM systems were higher with DT than with CT in two of the four years studied. The differences in PE$_{CEY}$ for the PM–PM system between CT and DT were significant in 2006. DT gave a higher PE$_{BY}$ than CT in all years. The increase in PE$_{BY}$ with DT compared to CT was 3.3, 2.3, 6.7 and 3.8 kg ha^{-1} d^{-1} in 2004, 2005, 2006 and 2007, respectively. The T × CS interaction was significant for PE$_{BY}$ in three of the four years studied and the CB–PM and PM–PM systems had a higher PE$_{BY}$ with DT than with CT in 2005, 2006 and 2007. The MB–CB system recorded a higher PE$_{BY}$ with DT compared to CT in 2006 and 2007.

2006				2007			
0	FYM	CF	FYM + CF	0	FYM	CF	FYM + CF
Cluster bean equivalent yield (kg ha⁻¹)							
497.5 ± 40.5^d	695.8 ± 46.8^g	828.3 ± 51.5^{ij}	884.2 ± 91.1^{jk}	287.2 ± 6.0^{ab}	311.9 ± 6.9^{ab}	340.7 ± 4.2^{bc}	372.3 ± 28.0^{bc}
536.7 ± 35.7^{de}	600.0 ± 40.3^f	670.0 ± 54.3^{fg}	761.7 ± 54.4^h	283.8 ± 20.6^{ab}	318.8 ± 7.3^{ab}	350.7 ± 9.9^{bc}	395.5 ± 27.2^c
505.2 ± 38.5^d	646.3 ± 59.8^{fg}	789.0 ± 42.9^{hi}	925.8 ± 64.7^k	601.2 ± 79.4^{ef}	733.5 ± 47.7^g	906.2 ± 45.2^h	1019.9 ± 67.0^i
204.3 ± 31.7^a	230.0 ± 28.1^{ab}	278.2 ± 34.2^{bc}	341.2 ± 29.9^c	256.9 ± 22.6^a	296.4 ± 7.4^{ab}	305.8 ± 13.8^{ab}	349.8 ± 20.6^{bc}
398.2 ± 55.8^c	495.5 ± 44.2^d	554.6 ± 38.1^{de}	629.3 ± 34.7^f	499.3 ± 38.9^d	584.7 ± 28.7^e	639.0 ± 42.0^{ef}	701.7 ± 43.7^{fg}
(2005: 51.4)	(2006: 69.7)			(2007: 83.4)			
Biomass yield (kg ha⁻¹)							
764.6 ± 76.7^a	1047.5 ± 77.8^b	1256.0 ± 111.9^{bc}	1470.5 ± 193.8^{cd}	2641.4 ± 80.3^{bcd}	2950.0 ± 69.8^{def}	3215.7 ± 88.6^{fg}	3444.3 ± 123.3^h
1348.4 ± 104.7^{cd}	1521.0 ± 102.3^{de}	1667.8 ± 111.6^e	1904.3 ± 124.9^f	2546.8 ± 104.5^{bc}	2937.5 ± 94.9^{def}	3306.9 ± 125.8^g	3697.5 ± 199.1^i
817.2 ± 67.7^a	1054.0 ± 55.4^b	1266.9 ± 74.5^{bc}	1441.9 ± 101.6^{cd}	2137.4 ± 121.1^a	2659.2 ± 92.7^{cd}	3201.2 ± 109.0^{fg}	3671.9 ± 179.8^{hi}
1522.4 ± 232.3^{de}	1906.8 ± 244.3^f	2259.9 ± 297.3^g	2664.8 ± 276.4^h	2540.3 ± 124.0^b	2811.9 ± 69.5^{cd}	2951.1 ± 124.7^{def}	3332.6 ± 219.1^{gh}
1431.7 ± 141.8^{cd}	1982.6 ± 204.3^f	2339.9 ± 159.2^g	2640.9 ± 146.3^h	2325.1 ± 74.0^{ab}	2674.9 ± 63.8^{bcd}	2851.6 ± 98.7^{cde}	3107.5 ± 175.2^{efg}
	(2006: 224.1)			(2007: 343.1)			
Production efficiency (CEY kg ha⁻¹ d⁻¹)							
6.6 ± 0.54^e	9.3 ± 0.62^h	11.0 ± 0.69^{ij}	11.8 ± 1.21^{jk}	3.1 ± 0.07^{ab}	3.4 ± 0.07^{abc}	3.7 ± 0.05^{abc}	4.0 ± 0.03^{bc}
6.4 ± 0.42^{de}	7.1 ± 0.48^e	8.0 ± 0.65^{fg}	9.1 ± 0.65^h	3.1 ± 0.22^{ab}	3.5 ± 0.08^{abc}	3.8 ± 0.11^{bc}	4.3 ± 0.30^c
6.7 ± 0.51^e	8.6 ± 0.80^{gh}	10.5 ± 0.57^i	12.3 ± 0.86^k	6.7 ± 0.88^e	8.1 ± 0.53^g	10.1 ± 0.50^h	11.3 ± 0.74^i
2.3 ± 0.36^a	2.6 ± 0.32^a	3.2 ± 0.39^{ab}	3.9 ± 0.34^{bc}	2.8 ± 0.25^a	3.2 ± 0.08^{ab}	3.3 ± 0.15^{ab}	3.8 ± 0.22^{bc}
4.5 ± 0.63^{bc}	5.6 ± 0.50^d	6.3 ± 0.43^{de}	7.2 ± 0.39^{ef}	5.4 ± 0.42^d	6.4 ± 0.31^e	6.9 ± 0.46^{ef}	7.6 ± 0.48^{fg}
	(2006: 0.9)			(2007: 0.9)			
Production efficiency (BY kg ha⁻¹ d⁻¹)							
10.2 ± 1.02^a	14.0 ± 1.04^b	16.7 ± 1.49^{cd}	19.6 ± 2.58^{ef}	28.7 ± 0.87^a	32.1 ± 0.76^a	35.0 ± 0.96^a	37.4 ± 1.34^a
16.1 ± 1.25^{bc}	18.1 ± 1.22^{cde}	19.9 ± 1.33^{efg}	22.7 ± 1.49^h	27.7 ± 1.68^a	31.9 ± 1.68^a	35.9 ± 1.37^a	40.2 ± 2.16^a
10.9 ± 0.90^a	14.1 ± 0.74^b	16.9 ± 0.99^{cd}	19.2 ± 1.35^{def}	23.7 ± 2.46^a	29.5 ± 1.47^a	35.6 ± 1.21^a	40.8 ± 2.00^a
17.3 ± 2.64^{cde}	21.7 ± 2.78^{fgh}	25.7 ± 3.38^i	30.3 ± 3.14^j	27.6 ± 2.44^a	30.6 ± 0.76^a	32.1 ± 1.36^a	36.2 ± 2.38^a
16.3 ± 1.61^{bc}	22.5 ± 2.32^{gh}	26.6 ± 1.81^i	30.0 ± 1.66^j	25.3 ± 0.81^a	29.1 ± 0.69^a	31.0 ± 1.65^a	33.8 ± 1.90^a
	(2006: 2.6)			(2007: 0.9)			
Net return (Rs ha⁻¹ y⁻¹)							
4084.9 ± 689.3^d	7205.7 ± 804.5^g	9693.5 ± 936.6^{hi}	10378.7 ± 903.9^{hi}	2772.2 ± 133.7^{ab}	3011.6 ± 105.0^{ab}	3895.1 ± 134.1^{abc}	4107.9 ± 571.8^{bc}
3768.7 ± 633.1^{cd}	4483.5 ± 711.9^{de}	5823.5 ± 937.0ef	7084.4 ± 966.6^{fg}	2590.5 ± 490.9^{ab}	3090.2 ± 250.3^{ab}	4170.5 ± 306.1^{bc}	4801.7 ± 589.7^{cd}
4289.1 ± 646.8^d	6403.8 ± 955.0^{fg}	9066.5 ± 723.9^h	11018.0 ± 1108.5^i	8179.4 ± 1481.6^{fg}	10457.6 ± 828.5^h	13950.1 ± 723.6^i	15863.9 ± 1200.7^j
1597.7 ± 222.6^a	1991.2 ± 686.6^{ab}	3301.3 ± 455.2^{bcd}	4243.3 ± 757.9^d	2297.4 ± 632.6^a	2687.2 ± 151.4^{ab}	3127.1 ± 332.7^{ab}	3746.3 ± 526.4^{abc}
2635.7 ± 100.6^{abc}	4453.5 ± 905.0^d	5972.7 ± 727.4^{fg}	7037.8 ± 546.1^{fg}	5790.2 ± 617.8^{de}	7059.4 ± 450.8^{ef}	8221.6 ± 800.0^{fg}	8990.7 ± 487.4^{gh}
	(2006: 1345.7)			(2007: 1612.1)			
Monetary efficiency (Rs. ha⁻¹ d⁻¹)							
54.5 ± 9.2^{def}	96.1 ± 10.7^i	129.2 ± 12.5^{jk}	138.4 ± 12.7^{kl}	30.1 ± 1.5^{ab}	32.7 ± 1.1^{ab}	42.3 ± 1.5^{abc}	44.7 ± 6.2^{bc}
44.9 ± 9.4^{cde}	53.4 ± 12.5^{def}	69.3 ± 22.7^{fgh}	84.3 ± 7.5^{ghi}	28.2 ± 5.3^{ab}	33.6 ± 2.7^{ab}	45.3 ± 3.3^{bcd}	52.2 ± 6.4^{cd}
57.2 ± 8.5^{ef}	85.4 ± 11.2^{hi}	120.9 ± 11.5^j	146.9 ± 8.6^l	90.9 ± 11.5^h	116.2 ± 9.2^h	155.0 ± 8.0^i	176.3 ± 13.3^j
18.2 ± 2.7^a	22.6 ± 9.7^{ab}	37.5 ± 14.8^{bcd}	48.2 ± 8.2^{de}	25.0 ± 1.6^a	29.2 ± 1.6^{ab}	34.0 ± 3.6^{ab}	40.7 ± 5.7^{abc}
30.0 ± 7.8^{abc}	50.6 ± 9.7^{de}	67.9 ± 8.6^{fg}	80.0 ± 11.4^{ghi}	62.9 ± 6.9^{de}	76.7 ± 4.9^{ef}	89.4 ± 8.7^{fg}	97.7 ± 9.1^g
	(2006: 16.9)			(2007: 17.7)			

Tillage had a significant effect on return, BCR and ME in all years (Table 3). DT produced higher returns and a larger ME than CT in all years (Table 3). Averaged across cropping systems and nutrient management, DT produced a 29.4, 15.8, 79.4 and 20.7% higher NR than CT in 2004, 2005, 2006 and 2007, respectively. The T × CS interaction was significant for NR and ME in three of the four years studied. The NR and ME of the MB–CB and PM + CB–PM + CB systems with DT were higher than with CT in three of the four years studied. The MB–CB system with DT gave significantly higher NR and ME results than all the other tillage and CS combinations in 2005 and 2007.

Tillage and the T × CS interaction significantly affected WU in all years. The MB–PM, MB–CB and PM + CB–PM + CB systems had a higher WU with DT than CT in all years (Fig. 4). The CB–PM system recorded a higher WU with DT compared to CT in 2005, 2006 and 2007. The differences in WU using the PM–PM system with DT and CT were significant in 2004 and 2005. DT had a higher ($P < 0.05$) WUE$_{CEY}$ than CT in three of the four years studied (Table 4). The increases in WUE$_{CEY}$ with DT compared to CT were 12.1, 9.0, 34.7 and 12.0% in 2004, 2005, 2006 and 2007, respectively. The T × CS interaction was significant for WUE$_{CEY}$ in all years (Fig. 4). In 2004, the MB–CB, CB–PM and MB–CB systems had a higher WUE$_{CEY}$ using DT compared to using CT. In 2005, the CB–PM, MB–CB and

PM + CB–PM + CB systems recorded a higher WUE$_{CEY}$ using DT than with CT. All cropping systems had a higher WUE$_{CEY}$ with DT than with CT in 2006. In 2007, the PM–PM and MB–CB systems showed a higher WUE$_{CEY}$ using DT compared to CT. DT had a higher ($P < 0.05$) WUE$_{BY}$ than CT in all years. The increase in WUE$_{BY}$ with DT compared to CT ranged between 7.7 and 39.7% in 2004–2007. The T × CS interaction significantly affected WUE$_{BY}$ in three of the four years studied (Fig. 4). The CB–PM had a higher WUE$_{BY}$ with DT than with CT in 2005, 2006 and 2007. The WUE$_{BY}$ for the MB–PM, MB–CB, PM–PM, PM + CB–PM + CB systems were higher with DT than with CT in two of the four years studied.

A significant effect due to tillage on N and K uptake was detected in two of the four years studied. The effect was significant for P uptake only in 2006. The TN (combined N, P and K) uptake showed significant variation between tillage treatments in three out of the four years studied. Averaged across cropping systems, nutrient management and years, DT led to a 4.1, 0.5 and 3.3 kg ha⁻¹ y⁻¹ higher N, P and K uptake than did CT. The T × CS interaction was significant for total nutrient (N, P, K) uptake in 2004, 2006 and 2007 (Table 7). The TN uptake for the CB–PM and MB–CB systems with DT were higher than with CT in three of the four years studied. The PM–PM system with CT had the lowest nutrient uptake in all years.
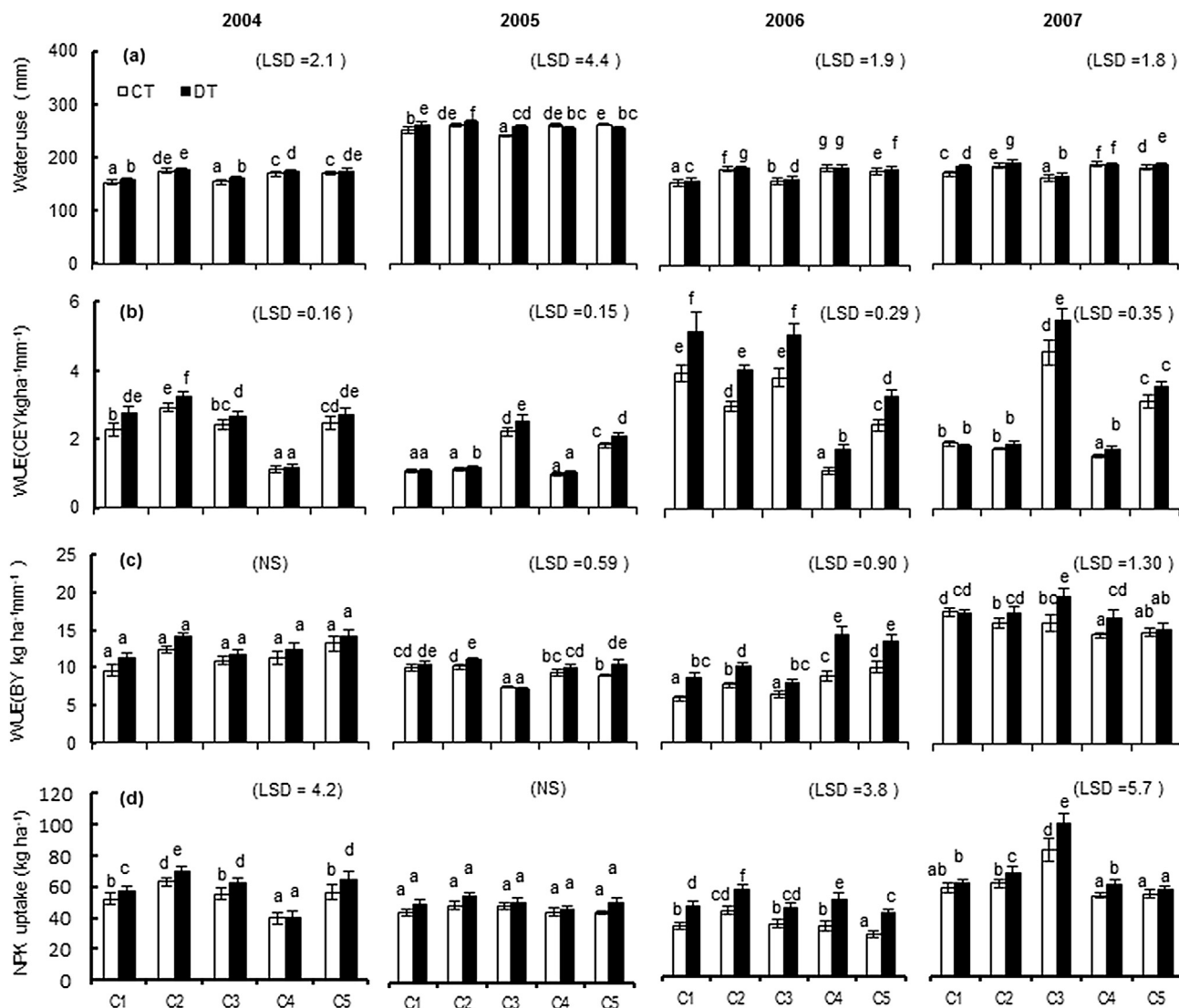
Fig. 4. Tillage system × cropping system interactions (T × CS) for (a) WU, (b) WUE$_{CEY}$, (c) WUE$_{BY}$ and (d) TN uptake averaged across all nutrient management treatments. Vertical bars indicate mean ± 1 SE. Different letters indicate significant differences ($p < 0.05$) among treatments in a given year. (CT and DT refer to conventional and deep tillage, respectively.) The C1, C2, C3, C4 and C5 stands for mothbean–pearl millet, clusterbean–pearl millet, mothbean–clusterbean, pearlmillet–pearlmillet and pearlmillet + clusterbean–pearlmillet + clusterbean cropping systems, respectively).

3.4. Nutrient management effects

NM and the NM × CS interaction had significant effects on yields, returns, water use and nutrient uptake. Averaged across tillage and cropping systems, a sole application of FYM or CF gave higher ($P < 0.05$) CEY and BY than no nutrient application (0 or control) in all years. FYM + CF had higher CEY and BY values than a sole application of each in all years. CF recorded 43.8, 27.8, 45.7 and 31.8% higher CEYs than the control in 2004, 2005, 2006 and 2007. The increase in CEYs with the addition of FYM and FYM + CF compared to the control ranged between 37.8 and 105.1 kg ha^{-1} and 153.0 and 280.0 kg ha^{-1}, respectively between 2004 and 2007. The NM × CS interaction was significant for CEY and BY in all years (Table 6). The MB–CB and PM + CB–PM + CB systems had higher CEYs with FYM than the control in all years. The MB–PM and CB–PM systems recorded higher CEYs with FYM than the control in 2004 and 2006. The differences in CEY between FYM and the control for the PM–PM system were non-significant in all years. All the cropping systems had a higher CEY with CF compared to the control in 2004 and 2006. In 2005, the MB–PM, MB–CB and PM–PM cropping systems recorded higher CEYs with CF compared to the control. In 2007, the MB–CB and PM + CB–PM + CB systems gave higher CEYs with CF than did the control. All the cropping systems had higher CEYs with FYM + CF compared to the control in all years. The CEYs of the MB–CB and PM + CB–PM + CB systems recorded with FYM + CF were higher than with a sole application of FYM or CF in all years. The CEYs of the CB–PM, MB–PM and PM–PM systems recorded when both FYM + CF were applied were higher than with just a sole application of FYM or CF in two of the four years studied. The MB–CB system with FYM + CF produced significantly higher CEYs compared to all other NM × CS combinations in three of the four years studied.

Averaged across all the tillage methods, cropping systems and years, the increase in mean BY with FYM, CF or FYM + CF were 325.1, 588.6 and 897.7 kg ha^{-1} more than the control, respectively. The NM × CS interaction was significant for BY in all years (Table 6). The PM–PM system had a higher BY with FYM than the control in all years. The differences in BY with FYM compared to the control

were significant in three of the four years studied for the MB–PM (2004, 2005 and 2006) and MB–CB (2004, 2006 and 2007) systems and in two of the four years studied for the CB–PM (2005 and 2007) and PM + CB–PM + CB (2004 and 2006) systems. All cropping systems had higher BYs with CF than the control in all years. With CF, the PM + CB–PM + CB and PM–PM systems had higher BYs than the other systems in all years. The PM + CB–PM + CB and CB–PM systems had higher ($P < 0.05$) BYs with FYM + CF compared to a sole application of FYM or CF in all years. The PM + CB–PM + CB and PM–PM systems with FYM + CF had the greatest BYs compared to the other systems in all years. In contrast to CEY, the improvement in BY with the application of nutrients was higher in the PM + CB–PM + CB and PM–PM systems than in all the other systems. Nutrient application had a significant effect on PEs. Averaged across all tillage and cropping systems, the application of FYM, CF and FYM + CF produced higher PEs than the control in all years (Table 2). The increase in mean PE_{CEY} with the application of FYM, CF and FYM + CF were 0.9, 1.7, and 2.6 kg ha^{-1} d^{-1} compared to the control, respectively. The PE_{CEY} of the MB–CB, PM + CB–PM + CB systems were higher ($P < 0.05$) with FYM or CF compared to the control in all years. The MB–CB system had a significantly higher PE_{CEY} with FYM + CF compared to the sole application of FYM or CF in all years and the MB–CB system had the greatest PE_{CEY} following an application of FYM + CF in three of the four years studied. PE_{BY} showed a significant response to application of FYM and/or CF. FYM + CF had a higher PE_{BY} than their sole application (FYM or CF) in all years. Averaged across tillage, cropping system and years, the mean PE_{BY} with applications of FYM, CF or FYM + CF were 19.8, 35.3 and 54.0% higher than the control, respectively. The NM × CS interaction for PE_{BY} was significant in three of the four years studied. The PM–PM and PM + CB–PM + CB systems, with combined application of FYM + CF, had higher PE_{BY}s than all the other systems in 2004 and 2006.

Nutrient application had significant effect on returns, BCRs and ME in all years (Table 3). FYM application produced higher ($P < 0.05$) returns, BCRs and MEs than the control in three of the four years studied (Table 3) .The returns, BCRs and MEs after the application of CF were higher than the control in all years. The increases in mean NR with the application of FYM, CF or FYM + CF were 45.0, 104.1 and 156.7% greater than the control, respectively. The NM × CS interaction was significant for NR and ME in all years (Table 6). The MB–PM, MB–CB and PM + CB–PM + CB systems had significantly higher NRs with FYM than the control in 2004 and 2006. Differences in NR between the FYM treatment and the control were non-significant for the PM–PM and CB–PM systems in all years. The MB–CB and PM + CB–PM + CB systems had higher NRs with CF than the control in all years and CB–PM, CB–PM and PM–PM systems recorded higher NRs with CF compared to the control in 2004, 2005 and 2006. Combined application of FYM + CF had a significantly higher NR than the control for the CB–PM, MB–CB and PM + CB–PM + CB systems in all years. The MB–CB with FYM + CF systems recorded higher NRs than all the other systems in three of the four years studied.

The NM had a significant effect on WU and WUE in all years (Table 4). The application of FYM or CF produced higher WU and WUE values than the control in all years. The WU and WUE values produced by a combined application of FYM + CF, were higher than a sole application of FYM and CF in all years. Averaged across tillage, cropping systems and years, the WUE_{CEY} following an application of FYM, CF or FYM + CF were 0.4, 0.7 and 1.1 kg ha^{-1} mm^{-1} higher than the control, respectively. The increases in WUE_{BY} were 1.7, 3.0 and 4.6 kg ha^{-1} mm^{-1}, respectively. The NM × CS interaction was significant for WUE in all years (Table 7). The WUEs of all the cropping systems were higher following an application of FYM + CF compared to a sole application of FYM in all years. The MB–CB

system with FYM + CF had a higher WUE_{CEY} than all the other systems in three out of the four years studied. The PM + CB–PM + CB and PM–PM systems with a combined application of FYM + CF recorded higher WUE_{BY}s than all the other systems in 2005 and 2006.

Nutrient application had significant effect on N, P, K and TN uptake in all years (Table 5). Averaged across tillage and cropping systems, the FYM, CF and FYM + CF treatments produced significantly higher N, P, K and TN uptakes than the control in all years. The FYM + CF treatment recorded higher nutrient uptakes than sole applications of FYM or CF. The NM × CS interaction was significant for TN uptake in three of the four years studied (Table 7). The PM–PM and PM + CB–PM + CB systems with FYM had higher TN uptakes than the control in three of the four years studied (2004, 2005 and 2007). The MB–PM, CB–PM and MB–CB systems with FYM recorded higher TN uptakes than the control in two of the four years studied. All the cropping systems had higher TN uptakes with CF compared to the control in 2004, 2005 and 2007. The MB–CB system with FYM + CF had the highest TN uptake compared to all the other systems in three of the four years studied.

4. Discussion

In a broad sense, a cropping system describes both a temporal sequence of crops and the management practices adopted to grow them. The ideal combination of these components is specific to the soil and individual eco-regions and thus has to be researched and fine-tuned under site specific conditions. The choice of an appropriate cropping system is critical to maintaining/enhancing agronomic sustainability and soil quality (Lal, 2007) and helps, to a considerable extent, to sustain agriculture in arid environments by improving yield, returns, resource utilization and soil quality (Joshi et al., 2009).

Because of the very short rainy season (50–60 days) and low moisture-retention capacity of the soils, the crop growing period in the Indian hot, arid region varies from <6 to 12 weeks (Rao and Singh, 1998). The better yields of the legume–legume (MB–CB) system compared to the legume–millet and millet–millet (PM–PM) systems (Table 2) could be attributed to the ability of legumes to complete development prior to plant-available soil moisture being exhausted. Rao et al. (1994) reported that short duration pulses are suitable crops for regions with a mean annual rainfall of 250–300 mm and an 8–10 week growing season, whereas pearl millet is suitable for regions with a mean annual rainfall of 300–400 mm and a 10–12 week growing season in the hot, arid region of Rajasthan. The late onset of the monsoon is another common weather feature of the region (Ramakrishna et al., 1992). During the present study, the first monsoon rain that was adequate for sowing was delayed by 15–20 d in three of the four years studied. Under the late sowing conditions, the reduction in seed yields was less with legumes than with millet. The substitution of millet by short-duration pulse and oilseed crops if the monsoon is delayed has been suggested for rainfed areas (Singh, 1995). In the present study, better seed yields under lower and delayed rainfall and higher selling prices for legume seed, relative to millet, were responsible for higher equivalent yields of the MB–CB system compared to systems that included millet. The results suggested that under low and delayed rainfall conditions, a legume–legume system gave a higher CEY compared to millet–millet and legume–millet systems. Low, erratic and high inter-annual variability in rainfall are major factors influencing crop yields in the northwestern hot, arid region of India (Rao and Singh, 1998). The provision of life-saving irrigation is an important strategy towards achieving sustainable crop production in the region.

Table 7
Interaction effect of nutrient management and cropping system (NM × CS) on water use (WU), water use efficiency (WUE) and total nutrient uptake (TN) in 2004, 2005, 2006 and 2007.

Cropping system	2004				2005			
	0[2]	FYM	CF	FYM + CF	0	FYM	CF	FYM + CF
Water use (mm)								
MB−PM[3]	154.7 ± 1.4^{a1}	155.5 ± 1.6^{a}	155.8 ± 1.4^{a}	157.3 ± 1.5^{a}	249.8 ± 3.1^{a}	255.2 ± 2.6^{a}	257.3 ± 2.8^{a}	266.2 ± 3.6^{a}
CB−PM	173.2 ± 0.8^{a}	175.8 ± 0.5^{a}	175.7 ± 1.0^{a}	176.8 ± 0.9^{a}	256.7 ± 2.4^{a}	261.8 ± 1.5^{a}	266.7 ± 3.0^{a}	273.8 ± 2.5^{a}
MB−CB	155.5 ± 1.2^{a}	157.5 ± 1.9^{a}	157.0 ± 1.6^{a}	157.8 ± 1.9^{a}	245.5 ± 3.3^{a}	248.8 ± 4.2^{a}	249.7 ± 3.2^{a}	253.8 ± 4.5^{a}
PM−PM	167.7 ± 0.8^{a}	170.2 ± 1.5^{a}	172.3 ± 1.2^{a}	174.2 ± 1.7^{a}	252.2 ± 2.7^{a}	257.3 ± 2.8^{a}	260.2 ± 3.4^{a}	265.2 ± 3.5^{a}
PM + CB	170.5 ± 1.7^{a}	170.3 ± 1.3^{a}	173.3 ± 1.3^{a}	173.3 ± 1.1^{a}	253.0 ± 1.6^{a}	259.0 ± 2.7^{a}	261.2 ± 3.1^{a}	262.3 ± 1.9^{a}
LSD (P = 0.05)	(2004: NS)				(2005: NS)			
WUE (kg CEY ha⁻¹ mm⁻¹)								
MB−PM	1.73 ± 0.12^{d}	2.27 ± 0.16^{e}	2.75 ± 0.17^{gh}	3.27 ± 0.12^{k}	0.91 ± 0.03^{ab}	1.02 ± 0.06^{abc}	1.13 ± 0.02^{cd}	1.23 ± 0.02^{cd}
CB−PM	2.62 ± 0.10^{fg}	2.85 ± 0.09^{hi}	3.00 ± 0.08^{ij}	3.84 ± 0.12^{l}	1.02 ± 0.05^{abc}	1.10 ± 0.07^{bcd}	1.17 ± 0.04^{cd}	1.25 ± 0.03^{d}
MB−CB	1.87 ± 0.06^{d}	2.37 ± 0.11^{e}	2.74 ± 0.10^{gh}	3.13 ± 0.07^{jk}	1.88 ± 0.04^{f}	2.08 ± 0.12^{g}	2.44 ± 0.08^{h}	3.08 ± 0.21^{i}
PM−PM	0.76 ± 0.04^{a}	0.92 ± 0.03^{a}	1.26 ± 0.04^{b}	1.53 ± 0.04^{c}	0.86 ± 0.03^{a}	0.90 ± 0.03^{ab}	1.11 ± 0.05^{bcd}	1.12 ± 0.04^{cd}
PM + CB	1.80 ± 0.11^{d}	2.45 ± 0.10^{ef}	2.74 ± 0.11^{gh}	3.37 ± 0.13^{k}	1.65 ± 0.06^{e}	1.84 ± 0.08^{ef}	2.02 ± 0.07^{fg}	2.29 ± 0.05^{h}
LSD (P = 0.05)	(2004: 0.22)				(2005: 0.21)			
WUE (kg BY ha⁻¹ mm⁻¹)								
MB−PM	7.65 ± 0.39^{a}	10.17 ± 0.81^{cd}	10.69 ± 0.61^{d}	13.30 ± 0.39^{f}	8.61 ± 0.34^{d}	9.98 ± 0.34^{fg}	10.81 ± 0.20^{ghi}	11.47 ± 0.21^{i}
CB−PM	11.87 ± 0.92^{e}	12.70 ± 0.45^{ef}	12.81 ± 0.23^{ef}	15.38 ± 0.66^{g}	9.49 ± 0.37^{ef}	10.32 ± 0.23^{fgh}	10.90 ± 0.43^{hi}	11.45 ± 0.31^{i}
MB−CB	8.88 ± 0.18^{b}	10.79 ± 0.54^{d}	12.15 ± 0.43^{e}	13.51 ± 0.36^{f}	6.81 ± 0.16^{a}	6.83 ± 0.19^{a}	7.35 ± 0.13^{ab}	7.71 ± 0.24^{bc}
PM−PM	8.26 ± 0.41^{ab}	10.02 ± 0.23^{cd}	12.49 ± 0.41^{ef}	16.52 ± 0.42^{h}	8.23 ± 0.24^{cd}	8.83 ± 0.34^{d}	10.71 ± 0.31^{gh}	10.70 ± 0.27^{gh}
PM + CB	9.16 ± 0.33^{bc}	13.31 ± 0.65^{f}	14.97 ± 0.20^{g}	17.15 ± 0.21^{h}	8.38 ± 0.15^{cd}	9.06 ± 0.28^{de}	10.25 ± 0.33^{fg}	11.12 ± 0.31^{hi}
LSD (P = 0.05)	(2004: 1.13)				(2005: 0.84)			
Total nutrient (N, P, K) uptake (kg ha⁻¹ y⁻¹)								
MB−PM	38.7 ± 1.7^{cd}	54.7 ± 3.5^{e}	56.1 ± 3.2^{e}	69.2 ± 1.9^{i}	39.3 ± 2.0^{a}	47.9 ± 1.6^{bc}	54.1 ± 1.0^{def}	63.6 ± 3.2^{hi}
CB−PM	56.5 ± 3.1^{ef}	61.4 ± 2.2^{fgh}	66.8 ± 2.1^{hi}	80.4 ± 3.4^{j}	44.9 ± 2.0^{b}	55.4 ± 2.1^{def}	60.5 ± 2.2^{gh}	65.3 ± 2.5^{hi}
MB−CB	44.3 ± 2.2^{d}	56.5 ± 3.4^{ef}	63.2 ± 2.7^{gh}	71.9 ± 2.9^{i}	45.5 ± 0.8^{b}	48.6 ± 1.4^{bc}	57.1 ± 0.8^{efg}	66.4 ± 2.7^{i}
PM−PM	24.6 ± 1.2^{a}	31.1 ± 0.7^{b}	44.2 ± 0.9^{cd}	59.3 ± 2.0^{ef}	38.5 ± 1.4^{a}	46.1 ± 1.0^{b}	56.7 ± 1.1^{efg}	56.9 ± 0.9^{efg}
PM + CB	38.3 ± 1.8^{c}	58.2 ± 4.0^{ef}	66.8 ± 1.7^{hi}	79.2 ± 3.0^{j}	45.4 ± 1.3^{b}	51.3 ± 1.6^{cd}	53.0 ± 1.8^{de}	58.4 ± 6.1^{fg}
LSD (P = 0.05)	(2004: 5.9)				(2005: 5.0)			

Values are mean ± 1S.E.
[1]For a parameter within a year values followed by the same letter are not significantly different at $p < 0.05$ according to LSD.
[2]The 0, FYM, CF and FYM + CF stands for no application, farm yard manure application, chemical fertilizer application and combined application of farm yard manure and chemical fertilizer, respectively.
[3]The MB−PM, CB−PM, MB−CB, PM−PM and PM + CB stands for Mothbean−Pearlmillet, Clusterbean−Pearlmillet, Mothbean−Clusterbean, Pearlmillet−Pearlmillet and Pearlmillet + Clusterbean−Pearlmillet + Clusterbean cropping systems, respectively.

Mixed crop−livestock systems are the dominant forms of agricultural production in tropical and sub-tropical developing countries of the world. Livestock are important assets and play a critical role in maintaining the sustainability of most farming systems in the hot, arid region of India (Bhati and Joshi, 2007). Crop residues are the most important feed for ruminants in the small-holder, crop-livestock production systems of Asia and Africa and constitute 40−60% of animals' total dry matter intake (Rao and Hall, 2003). Therefore, the yield and quality of crop residues are important criteria used to assess the performance of cropping systems in an arid region. The straw of cluster bean (crude protein 8.9%) and moth bean (crude protein 9.7%) are more nutritious compared to pearl millet straw (crude protein 5.1%) (Singh and Saini, 2002). Although the straw yield of the MB−CB system was found to be lower than the millet−millet and legume−millet systems in the present study, the higher protein content of straw from legumes compensated for the lower yield compared to the millet−millet and millet−legume systems. The results demonstrated that the MB−CB system was better than millet based systems for supplying nutritious feed to livestock.

Although the PM−PM system incurred the minimum production cost, it also showed the lowest ME due to lower yields and the lower selling price of the seed compared to systems containing legumes (Table 3). Conversely, the MB−CB system had the highest returns and ME due to better equivalent yields.

The total amount of water used in the systems that included moth bean (i.e. MB−PM, MB−CB) was lower than in systems that included cluster bean and pearl millet as component crops

(Table 4). The higher WUE CEY of MB−CB compared to other systems might be attributed to its better equivalent yields. The results showed that legumes were more water use efficient in equivalent yields terms (CEY) than millet, which suggested that the selection of crops was important in optimizing water productivity in an arid region. The better WUEBY of the PM + CB−PM + CB, CB−PM and PM−PM systems could be due to the higher BY of cluster bean and pearl millet compared to moth bean.

The nutrient uptake of a cropping system is determined by the nutrient contents and yields of the component crops. The MB−CB system had the highest N and P uptake (Table 5). In contrast to N and P, uptake of K was higher for systems involving millet, possibly due to higher straw yields and the K contents of millet compared to legumes. The results suggested that the MB−CB system was more efficient in utilizing available N and P than systems involving millet.

There have been different and contradictory results for rainfed areas when crop yields under different tillage systems are compared. Some researchers have reported no differences in crop yields between tillage systems (Unger, 1994) while others have observed greater soil water storage, crop yields and WUEs under minimum and no tillage (Lawrence et al., 1994). Tillage has an important role in rainfall utilization by reducing runoff and evaporation and increasing moisture storage in the soil profile. In the present study, crop yields were higher under deep compared to conventional tillage (Fig. 3) and these results were consistent with the findings of Saxena et al. (1997). Gupta et al. (2000) reported 25.4−98.3% higher soil moisture storage for deep compared to no and shallow-tillage, respectively, in hot, arid regions. In the present

2006				2007			
0	FYM	CF	FYM + CF	0	FYM	CF	FYM + CF
Water use (mm)							
152.5 ± 2.1^a	156.5 ± 1.0^a	157.5 ± 2.3^a	158.0 ± 0.4^a	162.0 ± 4.2^{ab}	177.3 ± 1.9^c	178.8 ± 2.8^{cd}	180.3 ± 2.1^{de}
179.0 ± 1.0^a	180.3 ± 0.8^a	180.5 ± 1.0^a	182.0 ± 0.5^a	182.5 ± 1.2^{efg}	185.5 ± 1.9^{hi}	187.5 ± 1.6^i	187.7 ± 1.4^i
159.3 ± 1.1^a	157.5 ± 1.5^a	157.8 ± 1.0^a	160.5 ± 0.8^a	162.8 ± 1.2^{ab}	161.0 ± 1.7^a	161.3 ± 1.2^a	164.0 ± 0.9^b
179.7 ± 1.0^a	181.7 ± 0.8^a	181.3 ± 0.6^a	180.7 ± 0.3^a	184.0 ± 0.6^{gh}	185.2 ± 0.7^h	186.0 ± 0.7^{hi}	187.0 ± 1.0^i
176.5 ± 1.4^a	177.7 ± 1.1^a	177.8 ± 1.0^a	180.2 ± 0.8^a	180.0 ± 1.6^{de}	181.2 ± 1.2^{de}	181.3 ± 1.2^{de}	183.7 ± 0.8^{fg}
	(2006: NS)				(2007: 2.5)		
WUE (kg CEY ha^{-1} mm^{-1})							
3.25 ± 0.24^{ef}	4.44 ± 0.28^h	5.25 ± 0.28^{ij}	5.59 ± 0.48^{jk}	1.78 ± 0.04^{abc}	1.76 ± 0.03^{abc}	1.91 ± 0.05^{bc}	2.07 ± 0.16^c
2.99 ± 0.18^{de}	3.33 ± 0.22^{efg}	3.72 ± 0.31^g	4.19 ± 0.30^h	1.56 ± 0.11^{ab}	1.72 ± 0.14^{abc}	1.87 ± 0.05^{abc}	2.10 ± 0.13^c
3.17 ± 0.24^{def}	4.10 ± 0.36^h	4.99 ± 0.25^i	5.77 ± 0.40^k	3.68 ± 0.47^{ef}	4.55 ± 0.28^g	5.62 ± 0.30^h	6.21 ± 0.39^i
1.13 ± 0.17^a	1.27 ± 0.16^a	1.53 ± 0.19^{ab}	1.89 ± 0.17^{bc}	1.40 ± 0.12^a	1.60 ± 0.04^{ab}	1.64 ± 0.07^{ab}	1.87 ± 0.12^{abc}
2.25 ± 0.30^c	2.79 ± 0.25^d	3.11 ± 0.20^{de}	3.49 ± 0.18^{fg}	2.77 ± 0.21^d	3.23 ± 0.15^{de}	3.52 ± 0.23^{ef}	3.82 ± 0.18^f
	(2006: 0.42)				(2007: 0.49)		
WUE (kg BY ha^{-1} mm^{-1})							
5.00 ± 0.46^a	6.68 ± 0.47^b	$7.95 \pm 0.62b^{cd}$	9.29 ± 1.20^{ef}	16.32 ± 0.40^{cde}	16.63 ± 0.28^{cde}	17.97 ± 0.35^{efg}	19.11 ± 0.70^{fg}
7.52 ± 0.55^{bc}	8.43 ± 0.57^{cde}	9.25 ± 0.64^{de}	10.47 ± 0.69^{fg}	13.96 ± 0.84^{ab}	15.83 ± 0.79^c	17.63 ± 0.62^{de}	19.67 ± 0.92^{fg}
5.13 ± 0.42^a	6.69 ± 0.33^b	8.02 ± 0.43^{cd}	8.98 ± 0.63^{de}	13.09 ± 1.29^a	16.50 ± 0.72^{cde}	19.83 ± 0.57^g	22.37 ± 1.03^h
8.46 ± 1.27^{cde}	10.52 ± 1.40^{fg}	12.47 ± 1.66^h	14.75 ± 1.53^i	13.81 ± 1.21^{ab}	15.19 ± 0.38^{bc}	15.87 ± 0.69^{cd}	17.85 ± 1.25^{ef}
8.09 ± 0.76^{cde}	11.15 ± 1.14^g	13.14 ± 0.83^h	14.66 ± 0.79^i	12.93 ± 0.49^a	14.77 ± 0.37^{abc}	15.72 ± 0.81^c	16.92 ± 0.61^{de}
	(2006: 1.31)				(2007: 1.88)		
Total nutrient (N, P, K) uptake (kg ha^{-1} y^{-1})							
27.1 ± 2.5^a	37.5 ± 2.5^a	44.2 ± 3.2^a	50.5 ± 6.3^a	49.6 ± 1.7^{ab}	56.2 ± 1.9^{bcd}	62.7 ± 1.6^{de}	72.1 ± 3.1^{fg}
41.3 ± 2.8^a	45.7 ± 3.3^a	53.6 ± 3.9^a	62.5 ± 4.3^a	51.3 ± 3.0^{ab}	61.7 ± 1.9^{de}	71.6 ± 2.0^{fg}	76.2 ± 3.7^{gh}
28.7 ± 2.4^a	36.7 ± 2.1^a	44.9 ± 3.1^a	50.9 ± 3.4^a	66.5 ± 8.2^{ef}	82.4 ± 5.5^h	107.2 ± 5.0^i	114.2 ± 5.2^i
29.3 ± 4.6^a	35.2 ± 3.9^a	45.9 ± 5.6^a	58.1 ± 4.5^a	48.3 ± 2.9^a	57.0 ± 1.5^{bcd}	60.8 ± 3.3^{de}	62.9 ± 2.9^{de}
26.7 ± 4.3^a	32.1 ± 3.6^a	37.1 ± 3.3^a	43.4 ± 3.5^a	45.5 ± 1.7^a	58.9 ± 2.4^{cde}	58.0 ± 2.1^{cd}	60.5 ± 3.9^{de}
	(2006: 5.4)				(2007: 8.1)		

study, deep tillage gave a greater advantage to legume growth compared to millet. Vittal et al. (1983) reported that the advantage of deep tillage to crop yields was found to be dependent on rainfall pattern and plant type.

The ability of roots to grow and explore soil for water and nutrients is a key determinant of plant growth rates (Clark et al., 2003) and root growth restrictions limit utilization of the water available in the soil profile in many rainfed areas (López-Bellido et al., 2007). Sandy soils developed under a hyper thermic regime have been shown to increase in strength as they dry (Gajri et al., 1994). High soil strength and pore rigidity restrict root growth and decrease the capacity of plants to efficiently utilize water and nutrients (Taylor, 1983). Deep tillage reduces soil strength and thus enhances root proliferation (Gajri et al., 1994), which helps to improve water availability and the utilization of nutrients by crops (Arora et al., 1991). In the present study, the average root length densities of pearl millet, moth bean and cluster bean were 40.3, 44.1 and 38.2% higher (data not presented), respectively, under deep compared to conventional tillage. Better storage of rainwater in the soil profile (Gupta et al., 2000) and improved root growth (Gajri et al., 1994) due to deep tillage may be responsible for the higher crop yields recorded in the present study.

In addition to moisture deficiency, widespread nutrient deficiencies and low nutrient applications are the major constraints to crop production in a hot, arid region. In the present study, nutrient application significantly improved productivity and WUE of all cropping systems (Tables 2 and 6). Along with proper mineral nutrition, adequate nutrient availability had a marked effect on water utilization by crops. Nutrient (particularly N and P) application has been shown to lead to early canopy growth, increased water uptake and reduced evaporation of water from the soil. Nutrient application increases the share of transpiration in total ET and thus improves yield and WUE without affecting total ET to any great extent (Gregory et al., 1984).

The combined application of organic residues and fertilizers is increasingly gaining recognition as one of the most appropriate ways of addressing soil fertility depletion, especially in low-external input systems, and forms an integral part of integrated soil fertility management (Vanlauwe et al., 2010). The greatest improvement in crop yields was achieved by the combined application of FYM and chemical fertilizer (Table 6). The results showed that greater yield benefits can be achieved with a combined application of organic residues and fertilizers compared to either resource applied alone (Gupta et al., 1983, 2000). Besides improving the supply of the nutrients, FYM combined with chemical fertilizer increases the moisture-retention characteristics and decreases the bulk density and saturated hydraulic conductivity of the soil (Gupta et al., 1983) in arid regions. The results of this study suggested that the combined application of FYM and chemical fertilizer was an appropriate option to supply plant nutrients to crops in arid regions.

The results demonstrated that legume based cropping systems were suitable for this region where the growing season is short and rainfall is low and often delayed. These systems helped to minimize production risks when the monsoon was delayed, which is the most common weather aberration in the region. Along with providing better seed yields and returns, these systems used resources (water and nutrients) more efficiently compared to millet based systems. The cultivation of legumes has been suggested in order to improve and maintain soil health under arid conditions (Tarafdar, 2009). Improvements in organic carbon [legume improves organic carbon by 7 and 18% compared to cereals and bulk soil, respectively (Tarafdar, 2009)], N content and the biological activity (Rao et al., 1995) of soils in arid regions due to legume cultivation has been recorded. This suggests that legume based cropping systems are better than millet-based systems at achieving higher returns, input (water and nutrient) utilization and maintaining soil quality and have been shown to improve crop

production sustainability in hot, arid regions. These results suggested that deep tillage and integrated nutrient management led to better crop yields in this hot, arid region.

Acknowledgments

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