Indian Journal of Agricultural Sciences **89** (7): 1133–9, July 2019/Article
https://doi.org/10.56093/ijas.v89i7.91659

Effect of tillage and nutrient management on sorghum (*Sorghum bicolor*) productivity in Alfisols of semi-arid tropical India

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Received: 17 August 2018; Accepted: 25 January 2019

ABSTRACT

The combined effects of tillage intensity (conventional-CT, reduced-RT or no tillage-NT) and nutrient management (inorganic and/or organic) on sorghum [*Sorghum bicolor* (L.) Moench] production, soil properties, weed dynamics, energy use, and economics were studied on an Alfisols in Hyderabad, India for 3 years (2011-2013). Results revealed that conventional tillage significantly increased growth parameters, viz. leaf area index, SPAD, and plant height as compared to NT, and produced 14% higher grain yield (2.94 Mg/ha) when compared to RT (2.57 Mg/ha) and 58% to NT (1.86 Mg/ha) system. No tillage significantly increased the density of grassy weed *Brachiaria reptans* (34.50/m^2) as compared to RT (21.83/m^2) and CT (26.33/m^2). However, the density of *Cyperus iria* (78.67/m^2) and *Digera arvensis* (17.0/m^2) increased significantly in CT. Conventional tillage significantly increased soil moisture content and *Azotobacter* population at 0-15 cm soil depth compared to NT conditions. Conventional tillage and application of RDF (80:40:40 kg NPK/ha) recorded maximum yield, net returns, B:C ratio and energy productivity.

Key words: Alfisols, Energy use, Nutrient management, Sorghum, Tillage, Weeds

Sorghum [*Sorghum bicolor* (L.) Moench] is a drought resilient crop, grown extensively in arid and semi-arid regions of the world under sorghum–fallow (SF) system. Although India contributes 12.62% in world's sorghum area, it produces only 6.9% due to lower crop productivity (781 kg/ha). Crust prone soils, low organic matter and nitrogen, moisture stress, and infestation of grain mould disease are the most important factors affecting rainy season sorghum productivity. Tillage affects crop production, soil properties, and environments by influencing seedling emergence, root growth, nutrient and water use, weed dynamics, soil organic carbon dynamics etc. Conservation tillage system, especially no tillage (NT) is gaining importance in many crops as this technology has resulted in reduced soil erosion, improved soil health, crop productivity and profitability. Doran (1980) showed that NT management has resulted in the lowest loss of soil organic carbon (SOC) and nitrogen in the top soil over the time as compared to tilled soil. However, Patil and Sheelavantar (2006) observed that CT with integrated nutrient management conserved higher amount of soil water and resulted in increased sorghum yields. Conventional tillage facilitates plant availability of sub soil resources by alleviating high subsoil strength and facilitating deeper rooting (Schneider *et al.* 2017).

The application of organic resources plays a key role in semi-arid agricultural systems where soils are poor in organic matter content. Integrating organic resources and mineral fertilizers has been found to increase soil organic matter (Bationo and Burkert 2001). The addition of vermicompost stimulated mycorrhizal colonization of sorghum roots and increased shoot and root dry weights and N, P and K levels (Cavender *et al.* 2003). Use of vermicompost not only reduces the requirement of chemical fertilizers but also supplements all essential nutrients to increase crop yield besides improving the soil properties and processes (Sharma and Banik 2014). Intercropping of green manure crops may have dual advantage of adding biomass to soil and also by smothering the weeds as it is fast growing species (Dhyani *et al.* 2009). Use of *Sesbania aculeata* residues, as a green manure, can provide a substantial portion of total N in sorghum. Phosphate-solubilizing bacteria (PSB) play a crucial role in soil P solubilization (Add-Alla 1994), increasing the bioavailability of soil P for plants (Zhu *et al.* 2011). Similarly *Azospirillum* inoculation enhances mineral ion uptake and crop yields (Lin *et al.* 1983).

Adoption of the suitable tillage system and nutrient management contribute to mitigate the negative effects of moisture stress (Schlegel *et al.* 2017). In order to create a favourable zone for root penetration and rainfall infiltration, primary tillage coupled with proper nutrient management is

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crucial to improve the crop production in Alfisols of semi-arid tropic in India (Sharma *et al.* 2005).

With increasing cost of inputs such as fuel and fertilizers, it is logical to develop tillage and nutrient management practices. However, information on the effect of tillage and integrated nutrient management (INM) on sorghum grain yield, weeds, soil properties and energy-use for SF system for the semi-arid tropical region of India is limited. The objective of our study was to evaluate the effect of three tillage intensities and four INM systems on sorghum yield, weeds, and soil properties in a sorghum- fallow rotation.

MATERIALS AND METHODS

Field experiments were conducted at the research farm (17° 31' N, 78° 39' E, and an elevation of 545 m amsl) of the Indian Institute of Millets Research (IIMR), Hyderabad, India during rainy seasons of 2011, 2012 and 2013. The climate of the area is semi-arid and tropical, with an average annual rainfall of 857 mm (75-80% of which is received during June-September), minimum temperature of 8-10°C in December, and maximum temperature of 40-42°C in May. Mean monthly temperature, monthly rainfall, and pan evaporation during 2011-2013 are given in Fig. 1. The soil was an Alfisol, *Udic Rhodustalf*, sandy loam (65.6% sand, 12.8% silt and 21.6% clay), with 7.42 pH, 0.18 dS/m electrical conductivity, 0.35% organic carbon, 1.63 g/cc bulk density, 10.8% available soil moisture; low in available N (163 kg/ha), medium in available phosphorus (12.66 kg P/ha) and potassium (292 kg K_2O/ha) contents.

The experimental design was a split plot with three replications. Main plot treatments were three tillage intensities; conventional tillage (CT), reduced tillage (RT), and no-till (NT), and sub-plot treatments were four nutrient management systems (NM 1= recommended dose of fertilizer i.e. RDF–80:40:40 kg NPK/ha; NM 2, =75% RDF (60:30:30 kg NPK/ha, of which 75% N as inorganic and 25% N through vermicompost,+phosphate *solubilizing* bacteria (PSB)+*Azospirillum*; NM 3=75% RDF (60:30:30 kg NPK/ha, of which 75% N as inorganic +*Sesbania* live mulch at 30 days after sowing-DAS+PSB+*Azospirillum*; NM 4=75% RDF (60:30:30 kg NPK/ha, of which 75% N as inorganic + *Sesbania* brown manuring at 30 DAS) +PSB+*Azospirillum*). Each sub-plot was measured as 4.5 m × 12 m. The CT consisted of a deep ploughing at 35 cm depth using a tractor-mounted moldboard plough and an harrowing at 20 cm depth (two passes).The RT plots used harrowing at 20 cm depth (two passes). NT plots used herbicide; glyphosate [N-(Phosphonomethyl) glycine] at 1.0 kg/ha in 500 L water/ha one week before crop seeding for controlling existing weeds. Both PSB and *Azospirillum* were applied as seed treatment before sowing @ 2.5 g/kg seed. Seed treatment was done by mixing the sorghum seed with 10% jaggery-biofertilizers solution prior to sowing, and dried in shade. *Sesbania* brown manuring was done at 30 DAS by spraying 2,4-D ethyl easter at 0.50 kg a.i./ha. *Sesbania* live mulching-cum-partial incorporation was done by hand hoeing at 30 DAS.

Sorghum cultivar 'CSH 16' was sown at a depth of 5 cm with seeds spaced at 15 cm in rows 45 cm apart in the third week of June, each year @ 10 kg/ha seed. In INM

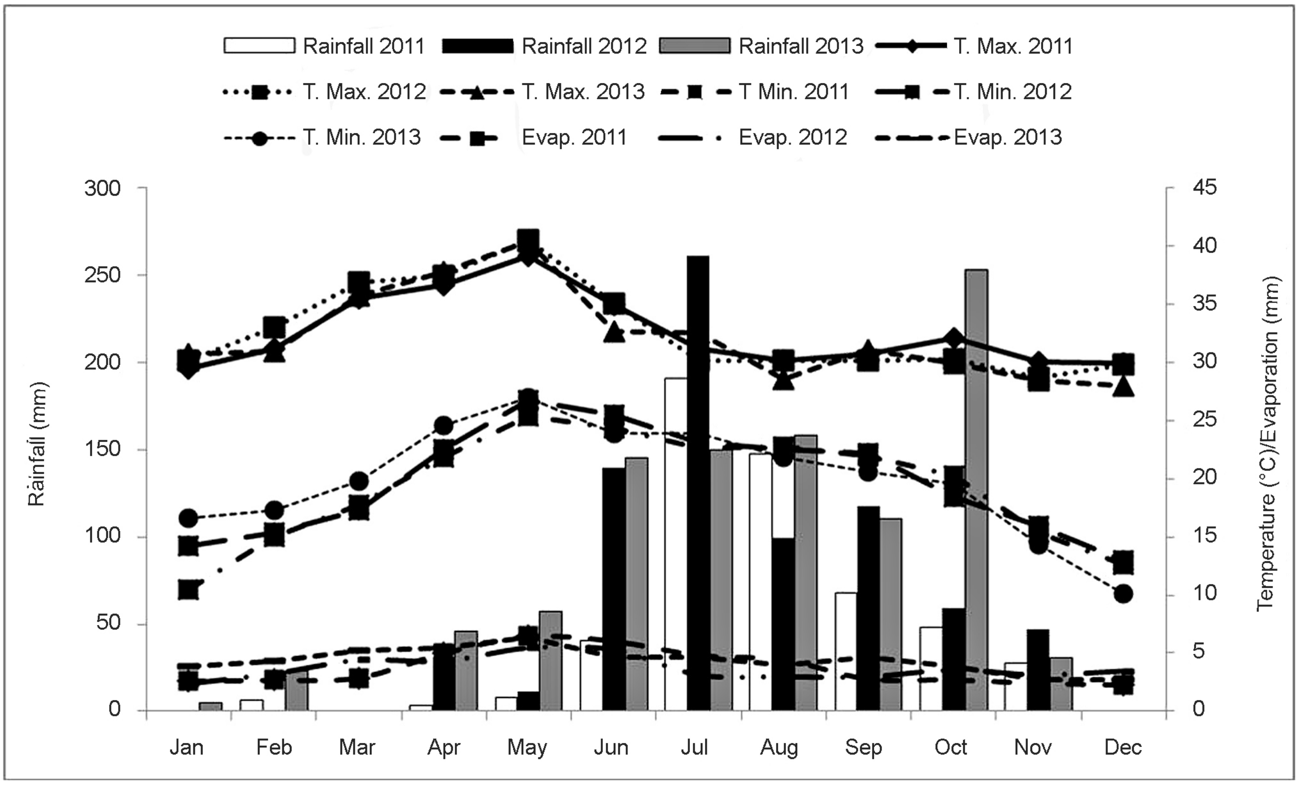

Fig 1. Mean monthly temperature, rainfall and pan evaporation from January 2011 to December 2013

treatment, the required rate (as per the treatment) of N as urea and di-ammonium phosphate (DAP), P_2O_5 as DAP, and K_2O as muriate of potash per hectare was applied. Full doses of phosphorus and potash and 1/2 of nitrogen were placed 2-3 cm below the seed as basal using ferti-seed drill (zero/conventional) at the seeding. Remaining 1/2 nitrogen was applied at 35 days after sowing (DAS). Furadan 3G (@20 kg/ha) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). The crop was raised under rainfed condition, except in 2011 where two irrigations were given due to less rainfall. Thinning was done manually at 20 and 30 DAS by removing excess plants. Growth parameters, i.e. leaf area index and SPAD value was recorded at 60 DAS, whereas plant height was taken at the harvest. Leaf area of the fourth leaf from the top was measured following the formula: leaf area = length × maximum width × 0.75 (Stickler *et al.* 1961) and the leaf area index (LAI) was calculated by dividing leaf area per plant with ground area per plant. Leaf chlorophyll concentration of the second leaf from the top was assessed at 50% flowering on 10 plants, with a portable Chlorophyll meter (SPAD-502 Minolta, Tokyo, Japan) and was expressed in arbitrary absorbance (or SPAD) values. Weed count, for estimating weed density at 25 DAS was recorded with the help of a quadrate (0.5 × 0.5 m) placed randomly at four spots in each plot. To record weed dry weight at crop harvest, weeds were cut at ground level, washed with tap water, sun dried, hot-air oven-dried at 70°C for 48 h, and then weighed.

At the conclusion of the experiment (after 3rd year) soil samples were collected for estimation of total soil bacteria, free living aerobic nitrogen fixing bacteria (*Azotobacter* spp.), and total fungi as per the standard procedures.

The economic requirements for all the treatments were measured for the growing period of the crop during 2013 (completion of the experiment). Different economic indicators were calculated based on the existing market price of the input and output. Energy equivalent of each parameter was calculated by using the energy conversion factors suggested by Singh *et al.* (2008) and Devasenapathy *et al.* (2009).

All the data were analyzed with Statistix 8.1 for analysis of variance (ANOVA) by using a split-plot design and main effects and interactions were tested for significance. Treatments were compared by computing the F-test. The significant differences between treatments were compared pare wise by critical difference at 5% level of probability.

RESULTS AND DISCUSSION

Effect on growth and yield: Averaged across 3 years, significantly higher growth parameters, viz. leaf area index, SPAD, and plant height were produced with CT compared to NT but yield components (panicle length and 100-seed weight) were on at par (Table 1). Leaf area index, SPAD value and plant height increased in CT by 10.6%, 10.3% and 7.1%, respectively compared to NT in pooled data. Reduced tillage was statistically similar to CT for all these components. Nutrient management practices significantly influenced the growth and yield attributes, except 100-seed weight of sorghum. Application of RDF (80:40:40 kg NPK/ha) (NM1) resulted in significant increase LAI, SPAD value, plant height and panicle length as compared to NM4. Harvest index was significantly lower in NM2 (23.65) as compared to NM1 (28.25).

Tillage had significant effect on grain yield of sorghum. Average over three years, the mean grain yield (2.94 Mg/ha) produced by conventional tillage was significantly 14% higher when compared to reduced tillage (2.57 Mg/ha) and 58% to no tillage (1.86 Mg/ha) (Table 1). This was due to mechanical modifications of soil profiles in CT system which could alleviate high subsoil strength, facilitating deeper rooting and, thus, the plant-availability of subsoil resources (Schneider *et al.* 2017). Higher soil water availability in CT compared to RT and NT from sowing to harvest might be responsible for higher leaf area index, better crop growth, and dry matter accumulation and translocation to head at reproductive stage of crop growth producing higher sorghum grain yield (Patil 2013). Deep tillage has been reported to enhance earthworm activities (Fenner *et al.* 1993) and increase the abundance of plant growth-promoting rhizobacteria and mycorrhizae in the subsoil (Steinbrenner and Naglitsch 1965).

The CT compared to RT and NT produced higher stover yield in pooled data. Stover yield in CT increased by 17.6% over RT and 24.4% over NT. Taller plants and higher leaf area index produced with CT compared with NT was responsible for higher stover yield. Our results did not confirm the findings of concluding better sorghum yields under NT compared with yields from CT and RT tillage systems (Unger 1984, Schlegel *et al.* 1999, Torbert *et al.* 2009, Schlegel, 2017). However, results confirmed the reports that concluded better sorghum yields from CT than RT and NT (Patil 2013, Mishra *et al.* 2014, Patil *et al.* 2016). Nutrient management practices significantly influenced the grain and stover yields of sorghum. Application of RDF (80:40:40 kg NPK/ha) (NM1) resulted in significant increase in grain yield as compared to other nutrient management systems. The yield benefits due to nutrient management was in the order NM1 > NM2 >NM3 >NM4. Averaged over all years, there was a 54.7%, 41.36% and 26.4% grain yield advantage in NM1 over NM4, NM3 and NM2, respectively. Similar trend was observed in stover yield as well.

Effect on weeds: The field was infested mainly with sedges (45.73%) and broad-leaved weeds (35.26%). *Brachiaria reptans* (18.56%) was the major grassy weed. Among broad-leaved weeds, *Trichodesma indicum* (2.40%) and *Digera arvensis* (6.89%) were prominent. *Cyperus iria* (45.73%) was the dominant sedge. Other broad-leaved weeds contributed 25.97% to the total weed flora. Tillage practices significantly influenced the population of weeds (Table 2). No tillage significantly increased the density of grassy weed *B. reptans* (34.50/m^2) as compared to RT (21.83/m^2) and CT (26.33/m^2). Higher population density of grassy weeds in NT as compared to CT system was also observed by Teasdale

Table 1 Tillage and nutrient management effects on growth, yield and yield components of grain sorghum over 3 years

Treatment	Leaf area index at 60 DAS	SPAD at 60 DAS*	Plant height (cm)	Panicle length (cm)	100-seed weight (g)	Grain yield (Mg/ ha)	Stover yield (t/ ha)	Harvest index (%)
Year								
2011	6.75	-	182	29.50	2.63	2.65	7.23	27.37
2012	6.49	-	176	28.01	2.69	2.44	6.68	25.99
2013	6.21	-	171	26.51	2.75	2.27	6.11	24.33
LSD (P=0.05)	0.26		7	1.53	NS	0.36	1.02	3.01
Tillage								
Conventional tillage	6.77	48.18	183	27.99	2.77	2.94	7.54	28.37
Reduced tillage	6.56	48.88	179[a]	28.80	2.68	2.57	6.41	28.72
No tillage	6.12	43.68	168	27.23	2.63	1.86	6.06	20.46
LSD (P=0.05)	0.41	3.65	5	NS	NS	0.36	1.12	6.49
Nutrient management								
NM 1	6.95	48.98	185	28.76	2.68	3.11	7.20	28.25
NM 2	6.35	47.92	173	27.60	2.62	2.46	6.91	23.65
NM 3	6.25	46.28	177	28.48	2.71	2.20	6.70	25.26
NM 4	6.39	44.99	171	27.18	2.76	2.01	5.91	26.42
LSD (P=0.05)	0.47	3.73	6	0.90	NS	0.42	1.25	3.80

*2013 only. Details at treatment are given under materials and methods.

et al. (1991). However, the density of *C. iria* (78.67/m^2) and *D. arvensis* (17.0/m^2) increased significantly in CT as compared to NT (58.17/m^2 and 3.50/m^2, respectively) system. Mishra and Singh (2012) also observed that choice of tillage system influence weed density and distribution. Soil tilling creates favourable conditions for some of the weed species resulting in higher population of *C. iria* and *D. arvensis* in CT and RT over NT. Although the total weed density was higher in CT, a significantly higher the total weed dry weight was observed in NT plots. This is in agreement with the results of Bilalis *et al.* (2001). Vigorous growth of *B. reptans* in NT contributed maximum towards total weed dry weight.

Nutrient management practices significantly influenced the population density of weeds. Application of RDF (80:40:40 kg NPK/ha) resulted in significant increase in *B. reptans* and *D. arvensis* population as compared to other treatments. The lowest density of these weeds was

Table 2 Weed density and dry weed biomass during 3rd year (2013)

Treatment	Weed density (no./m^2) at 25 DAS						Weed dry weight (g/m^2)
	Brachiaria reptans	*Cyperus iria*	*Trichodesma indicum*	*Digera arvensis*	Other broad-leaved weeds	Total weeds	
Tillage							
Conventional tillage	26.33	78.67	2.67	17.00	33.33	160.00	74.50
Reduced tillage	21.83	66.83	2.17	10.17	33.00	134.00	46.00
No tillage	34.50	58.17	5.83	3.50	49.33	151.33	92.33
LSD (P=0.05)	9.45	9.13	3.14	5.11	8.21	15.62	12.32
Nutrient management							
NM 1	32.44	66.44	3.11	13.78	44.22	156.44	58.00
NM 2	28.89	76.67	3.11	9.56	36.44	158.22	75.56
NM 3	22.67	64.00	4.00	7.78	38.89	137.33	73.83
NM 4	26.22	64.44	4.00	9.78	37.33	141.78	76.89
LSD (P=0.05)	7.56	NS	NS	3.22	NS	NS	10.66

Details of treatments are given under materials and methods.

recorded with application of 75% RDF (60:30:30 kg NPK/ha, of which 75% N as inorganic+*Sesbania* live mulch at 30 DAS+PSB+*Azospirillum*. The density of other weed species and total weeds did not vary significantly. The total weed dry weight was significantly lower in RDF as compared to other nutrient management treatments. Vigorous crop growth (higher plant height and LAI) due to adequate supply of nutrients in RDF resulted in better weed suppression and lower weed biomass accumulation.

Effect on soil properties and soil microbial population: After the harvest of 3rd year sorghum crop, soil moisture content at 0-15 cm soil depth was 24.07% higher in CT (13.71%) than NT (11.05%). Greater conservation of soil moisture in profile with CT was also reported by Patil (2013). Micro-basins created by tillage help in reducing runoff and soil erosion, and increasing soil infiltration and thereby water availability for crop production (Brhane *et al.* 2006). Other soil parameters, viz. soil pH, EC, organic carbon and NPK contents did not vary significantly due to different tillage systems (Table 3). Results of microbial population study are presented in Table 4. Free living nitrogen fixing bacteria *Azotobacter* spp. significantly differed among the treatments. Conventional tillage significantly increased *Azotobacter* population compared to NT conditions. This increase was irrespective of sub-treatments within the treatment, suggesting that it was the tillage conditions (CT or NT) rather than sub-treatment effect that caused this difference. *Azotobacter* spp. is an aerobic bacterium that needs free air for growth and multiplication. Conventional or reduced tillage provided better aeration than no tillage and the practice resulted in higher population of *Azotocater* in CT (3.34 $\log_{10}$cfu) and RT (3.07 $\log_{10}$cfu) than the NT (2.65 $\log_{10}$cfu). Total bacterial and fungal population did not differ significantly among the treatments. As treatments favoured conditions both for aerobic (CT and RT) and anaerobic (NT) situation, total bacterial population will not fluctuate much as soil harbours both aerobic and anaerobic bacteria. Similarly in the case of total fungal population, different nutrient management systems did not influence the microbial population.

Economic analysis and energy efficiency: The economics and energy parameters were calculated and given in Table 5. The total cost of cultivation (₹30945/ha) was 22.5% more in CT system than NT (₹25264/ha) system due to higher costs involved in field preparation. The highest net returns (₹23178/ha) and benefit: cost ratio (1.75) was accrued with CT system followed by RT (₹17868/ha and 1.62) and NT (₹9626/ha and 1.38) systems. The CT system required maximum energy (23,526 MJ/ha) due to higher energy required for field preparation, followed by RT (22,525 MJ/ha) and NT (20511 MJ/ha) systems. The output

Table 4 Effect of tillage and nutrient management on microbial population at the conclusion of the experiment

Treatment	Microbial population (CFU $\log_{10}$) for different microorganism		
	Azotobacter spp. (Jensen's agar)	Total bacteria (nutrient agar)	Total fungi (potato dextrose agar)
Tillage			
Conventional tillage	3.34	7.12	4.18
Reduced tillage	3.07	7.66	4.24
No tillage	2.65	7.40	3.98
LSD (P=0.05)	0.44	NS	NS
Nutrient management			
NM 1	3.08	7.53	4.12
NM 2	3.03	7.48	4.15
NM 3	2.92	7.24	4.02
NM 4	3.05	7.32	4.25
LSD (P=0.05)	NS	NS	NS

Details at treatments are given under materials and methods.

Table 3 Physico-chemical properties of soil after crop harvest (2013)

Treatment	Soil moisture content (%)	pH (1:2.5)	EC (1:2.5) (dS/m)	Organic carbon (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Tillage							
Conventional tillage	13.71	6.58	0.065	0.49	159.93	5.94	270.11
Reduced tillage	12.10	6.65	0.055	0.44	158.90	6.18	248.73
No tillage	11.05	6.60	0.044	0.45	149.48	5.98	242.02
LSD (P=0.05)	0.62	NS	NS	NS	NS	NS	NS
Nutrient management							
NM 1	12.54	6.62	0.046	0.46	175.62	7.00	234.97
NM 2	11.92	6.68	0.050	0.43	137.98	5.75	243.42
NM 3	12.32	6.65	0.051	0.44	143.56	5.20	276.38
NM 4	12.36	6.51	0.071	0.51	167.27	6.18	259.71
LSD (P=0.05)	NS	0.16	NS	NS	25.86	1.53	NS

Details at treatments are given under materials and methods.

Table 5 Effect of tillage and nutrient management on economic returns and energy efficiency at the conclusion of the experiment

Treatment	Economic returns			Energy parameters			Energy productivity (kg/MJ)
	Total variable cost (₹/ha)	Net returns (₹/ha)	B:C ratio	Input energy (MJ/ha)	Output energy (MJ/ha)	Output-input energy ratio	
Tillage							
Conventional tillage	30945	23178	1.75	23526	134149	5.67	0.431
Reduced tillage	28916	17868	1.62	22525	110127	4.86	0.369
No tillage	25264	9626	1.38	20511	93165	4.49	0.344
LSD (P=0.05)	-	3235	0.12	932	7275	0.27	0.037
Nutrient management							
NM 1	29343	26814	1.93	23320	126579	5.43	0.411
NM 2	30419	15606	1.51	21507	116029	5.36	0.408
NM 3	27630	13914	1.5	22426	112722	5.00	0.383
NM 4	26107	11238	1.43	22104	94576	4.24	0.324
LSD (P=0.05)	-	2135	0.11	759	6507	0.22	0.031

Details at treatments are given under materials and methods.

energy (134149 MJ/ha) and energy output: input ratio (5.67) were maximum in CT system due to higher productivity. The lowest output energy (93165 MJ/ha) and output: input ratio (4.49) was observed from NT system due to the lowest crop yields. The highest energy productivity (0.431 kg/MJ) was obtained in CT followed by RT (0.369 kg/MJ) and NT (0.344 kg/MJ) system. Among nutrient management treatments, application of RDF (80:40:40 kg NPK/ha) resulted in significant increase in net returns (₹26814/ha), B:C ratio (1.93), output-input energy ratio (5.53) and energy productivity (0.411kg/MJ).The higher returns and energy productivity with RDF was due to higher crop productivity as compared to other nutrient management systems. Mishra *et al.* (2014) also reported higher sorghum yield, net returns and energy-use efficiency with conventional tillage system and use of RDF through inorganic fertilizers.

Thus, it could be concluded that conservation tillage system may be an ideal for the rice-wheat cropping system of Indo-Gangetic Plains. The results of the present studies conducted in semi-arid regions of India appear to support the use of conventional tillage system because of the physical properties of the soils in semi-arid tropical India, particularly in Alfisols. Significantly higher yields and economic benefit were recorded in the decreasing order CT > RT >NT. Conventional tillage and application of RDF (80:40:40 kg NPK/ha) recorded maximum grain yield, net returns and energy productivity in rainy season grain sorghum.

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