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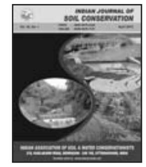

Effect of tillage and nutrient management on productivity, soil fertility and profitability of cotton+soybean rotated with soybean+pigeonpea intercropping system under semi-arid Vertisols in India

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ABSTRACT

Field experiments were conducted with cotton+soybean (1:1) in *kharif* seasons of 2005, 2007, 2009 rotated with soybean+pigeonpea (4:2) in 2006 and 2008 to identify an efficient tillage and nutrient management practice in a semi-arid Vertisol at Parbhani. The study was conducted in split-plot design with 3 tillage and 5 fertilizer N treatments. The cotton equivalent yield (CEY) ranged from 994 to 1419 kg ha^{-1} with mean of 1193 kg ha^{-1} and variation of 9.8%; while RWUE ranged from 1.21 to 1.69 kg ha^{-1} mm^{-1} with mean of 1.43 kg ha^{-1} mm^{-1} and variation of 9.2% over years. Conventional tillage (CT) and reduced tillage (RT$_1$) with 100% recommended RDF gave significantly higher CEY and RWUE compared to other treatments. CT + FYM @ 5 t ha^{-1}, CT + 50% RDF + Vermicompost @ 1.5 t ha^{-1} and RT$_1$+50% RDF+VC @ 1.5 t ha^{-1} gave lower bulk density; while CT+FYM @ 5 t ha^{-1} and CT+50% RDF+FYM @ 2.5 t ha^{-1} gave higher infiltration. Runoff and soil loss were significantly lower under CT+FYM @ 5 t ha^{-1} and CT+VC @ 3 t ha^{-1}. CT+50% N+FYM @ 2.5 t ha^{-1} and CT+100% N gave maximum gross returns, while CT+100% RDF and RT$_1$+100% N gave maximum net returns. RT$_1$+FYM @ 5 t ha^{-1}, RT$_1$+50% RDF+FYM @ 2.5 t ha^{-1} and RT$_1$+100% RDF were superior for maximum BC ratio. Based on a regression model of CEY through rainy days and crop seasonal rainfall, CT+100% RDF and RT$_1$+100% RDF were superior with maximum sustainability yield index over years.

Key words:
Crop rotation,
Energy use efficiency,
Fertilizer,
Intercropping,
Rainwater use efficiency,
Sustainability yield index,
Tillage

1. INTRODUCTION

Rainfed agriculture plays an important role in contributing to world food security. In India, area under rainfed agriculture is about 85 m ha representing 60% of net cultivated area and supports 40% population of the country. Apart from erratic rainfall, soils are highly degraded physically, chemically and biologically (Maruthi Sankar *et al.*, 2010; Sharma *et al.*, 2005; Vittal *et al.*, 2003). Intensive tillage practices using inversion implements such as mould board plough result in loss of surface crop residue and soil organic carbon from soil aggregates. This in combination with imbalanced fertilization and no recycling of crop residues has deteriorated soil quality leading to low yields in rainfed areas (Campbell *et al.*, 2001; Roldan *et al.*, 2003; Sharma *et al.*, 2008b). Lack of organic residue incorporation in the soil by mixture up on tillage has a major impact on behaviour and management of nutrients. Use of chemical fertilisers in an unbalanced manner resulted with multiple nutrient deficiencies, diminishing soil fertility and unsustainable yields.

Unger (1990) reported that zero or reduced tillage, green manuring and recycling of crop residues proved effective in improving soil fertility and quality in irrigated and temperate regions. No-tillage farming practiced in combination with growing a cover crop in rotation is widely recognized as a viable alternative to 'plough tillage' as a way to improve the environment and sustain natural resources. Lal (2007) reported that benefits of zero till farming in combination with residue retention are substantial in terms of erosion control, water conservation, soil fertility enhancement and carbon sequestration. Due to moisture scarcity, there is little scope to grow green manure and biomass without losing crop season. Except retention of root biomass below ground, low amount of residue is recycled back to agricultural fields. Sharma *et al.* (2005) reported that minimum tillage with 90 kg N ha^{-1} in castor–sorghum, maintained soil quality index of 1.10 in rainfed Alfisols. They reported that to maintain higher yield and soil quality, primary tillage along with organic residues and N application are crucial. Elimination of summer fallow in arid and semiarid regions and adopting no tillage with residue mulch improved soil structure, reduced bulk density and increased infiltration rate and yield (Lal, 2004; Shaver *et al.*, 2002). Sharma *et al.* (2011a, 2011b) observed that minimum tillage together with mulches had pronounced effect on soil physical properties, yield, energy and monetary returns of maize–wheat in sub-humid Inceptisols. Videnovic *et al.* (2011) attained significantly higher maize yield with conventional tillage compared to reduced tillage and no tillage, irrespective of fertilizer application in a Chernozem soil.

Effective use of implements helps to improve moisture retention capacity on deep black soils and enhance crop yield. Deep ploughing reduced bulk density in surface and sub-surface layers (Gurumurthy and Rao, 2006). Though efforts have gone into such studies in temperate regions, systematic long-term studies in rainfed semi-arid tropical regions, especially in developing countries are rare, because of difficulties in controlling weeds, less water infiltration in compacted soil and non-availability of appropriate seeding implements (Sharma *et al.*, 2008b). The Marathwada region has 80% area under assured and moderately high rainfall zone with more than 50% of medium to deep Vertisols. The region comprises of 8 districts with cultivable area of 56 lakh ha under semi-arid condition. The soils have considerable potential to supply nutrients and store sufficient soil moisture and support sustainable crop production. Cotton, sorghum, pigeonpea and soybean with cotton+soybean and soybean+pigeonpea are predominantly followed under dryland areas in the region. A single practice is insufficient to increase the productivity and strategy needs modification with integrated approach of soil and water conservation, crop, land, nutrient management and alternate land use for stabilising productivity. The challenge of improving productivity in rainfed areas can be addressed by a suitable tillage and nutrient management by efficiently utilizing natural resources. The present study was conducted to identify an efficient tillage and fertilizer management for attaining sustainable yield, net returns, rainwater and energy use efficiency from cotton + soybean and soybean + pigeonpea in rotation and improve soil fertility under semi-arid Vertisols.

2. MATERIALS AND METHODS

Experimental Details

Field experiments were conducted to study effects of tillage and fertilizer treatments on cotton + soybean (1:1) and soybean + pigeonpea (4:2) under rotation in a Vertisol at Parbhani in Maharastra during 2005 to 2009. Parbhani is located at latitude of $19^{0}16'$ N, longitude of $76^{0}47'$ E and altitude of 409 m above msl. The Vertisol has low to medium N and P_2O_5, high in K_2O and low in organic carbon. The region is classified into 3 rainfall zones *viz.,* scarcity zone (less than 700 mm), assured rainfall zone (700-900 mm) and moderately high rainfall zone (900-1100 mm). Major *kharif* crops of the region are cotton, soybean, sorghum, pearl millet, maize, pigeonpea, green gram and black gram, while sorghum, safflower and chickpea are grown in *rabi* season. The length of crop growing season is from 24^{th} to 40^{th} Standard Meteorological Week (SMW). The tillage treatments comprised of (i) conventional tillage (CT); (ii) reduced tillage + interculture (RT_1); and (iii) reduced tillage + herbicide (RT_2); while fertilizer treatments comprised of (i) FYM @ 5 t ha^{-1}; (ii) vermicompost (VC) @ 3 t ha^{-1}; (iii) 50% recommended dose of fertilizer (RDF) + FYM @ 2.5 t ha^{-1}; (iv) 50% RDF + VC @ 1.5 t ha^{-1}; and (v) 100% RDF. In the RT_1 treatment, one intercultural operation was done to control weeds. CT comprised of one ploughing + two harrowing; while RT_1 comprised of two harrowing + interculture (two hoeing + two weeding); and RT_2 comprised of two harrowing + herbicide (pre-emergence application of herbicide) + interculture (hoeing + weeding) after 45 days after sowing. In RT_2, pre-emergence herbicide *viz.*, Pendimethalin 30% EC @ 2.5 L 1000^{-1} litre water ha^{-1} in cotton + soybean and Oxyfluerofen 23.5% @ 425 ml 1000^{-1} litre water ha^{-1} in soybean + pigeonpea were used to control weeds.

The chemical analysis of soil samples was done after completion of first year (2005) and fifth year (2009) of experimentation to determine status of organic carbon (%) as described by Walkley and Black (1934); soil N based on Subbiah and Asija (1956) method; soil P based on Olsen *et al.* (1954) method; and soil K based on Jackson (1973) method. Daily type stage level recorders and 6" H flume were seasonally installed during crop growing season for each strip of organic, integrated and inorganic nutrient sources under each tillage method to measure runoff (mm) and soil loss (t ha^{-1}). Observations were recorded on bulk density (g/cm^3) and infiltration rate (cm hr^{-1}) after harvest of *kharif* crop. Soil bulk density and infiltration rates were measured with help of core cutter method and double infiltrometer rings (Blake and Hartage, 1986). Observations were recorded on yield of each crop and converted to cotton equivalent yield (kg ha^{-1}) from each system, rain water use efficiency (RWUE, kg ha^{-1} mm^{-1}), input energy (MJ ha^{-1}), output energy (MJ ha^{-1}), cost of cultivation (₹ ha^{-1}), gross returns (₹ ha^{-1}), net returns (₹ ha^{-1}) and benefit-cost ratio for comparing treatments. Weed count and its dry weight were recorded in RT_2 in first year of study (2005). The weed count included total number of monocot and dicot weeds. The study was conducted in a split-plot design with 3 replications and net plot size of 8.4 x 9.0 m. Tillage treatments were tried in main plots, while fertilizer treatments were tested in sub-plots.

The primary data on levels of input used (seed, fertilizer, herbicide, human and bullock labour, machinery hours); output attained (grain and straw yield); runoff; and soil loss were collected. Observations were recorded on labour (human and animal), diesel, seed, fertilizer, plant protection chemicals, biomass yield, power required under each treatment. The energy equivalents used are (i) 1.96 MJ $hour^{-1}$ for man; (ii) 1.57 MJ $hour^{-1}$ for woman; (iii) 10.1 MJ $hour^{-1}$ for pair of bullocks; (iv) 56.31 MJ $litre^{-1}$ of diesel; (v) 60.6 MJ kg^{-1} of N; (vi) 10.1 MJ kg^{-1} of P_2O_5; (vii) 120 MJ kg^{-1} of herbicide; (viii) 14.7 MJ kg^{-1} of seed; (ix) 18.0 MJ kg^{-1} of fodder yield; and (x) 62.7 MJ kg^{-1} of machinery. The energy requirement under tillage methods and nutrient sources was assessed based on input energy, output energy, energy use efficiency as a ratio of output and input energy and energy productivity (Mittal *et al.,* 1985).

Rainfall and its Distribution

The monthly rainfall ranged from 43.0 to 242.4 mm in June, 77.0 to 844.9 mm in July, 81.6 to 444.6 mm in August, 109.5 to 246.7 mm in September, 0 to 153.6 mm in October and 0 to 47.7 mm in November during 2005 to 2009. Maximum mean rainfall of 264.4 mm occurred in July, followed by 219.1 mm in August, 172.8 mm in September, 119.2 mm in June, 66.9 mm in October and 23.9 mm in November over years. However, September followed by August and June rainfall were more assured compared to other months as indicated by variation. The cumulative rainfall of June to November ranged from 620.9 mm (41 rainy days) in 2008 to 1309.1 mm (45 rainy days) in 2005 with mean of 866.4 mm (41 rainy days) and variation of 32.2%. The earliest date of sowing of the crops was on 13th June in 2008, while farthest was on 14th July in 2009. The earliest date of harvest was 10th February in 2010 for cotton, 3rd October in 2008 for soybean and 27th December in 2008 for pigeonpea; while farthest was 5th March in 2007 for cotton, 30th October in 2009 for soybean and 2nd January in 2006 for pigeonpea. The date of sowing and harvest of cotton, soybean and pigeonpea and monthly rainfall of June to November received in different years are given in Table 1.

Statistical Analysis

The analysis of variance (ANOVA) was performed to test tillage and fertilizer effects on cotton equivalent yield and RWUE in each year. The treatment differences could be compared based on least significant difference (*l.s.d.*) criteria (Gomez and Gomez, 1984). The criteria adopted to identify an efficient tillage and fertilizer treatment was sustainability yield index (SYI), which is derived as a 'ratio of the difference of mean yield and prediction error based on regression model and maximum yield attained by any treatment over years' (Behera *et al.*, 2007; Maruthi Sankar *et al.*, 2012a, 2012b and 2013; Vittal *et al.*, 2003). In order to assess the effect of rainy days (RD) and crop seasonal rainfall (CRF, mm) on cotton equivalent yield (CEY), we calibrate a linear regression model as

$$CEY = \pm \alpha \pm \beta_1 (RD) \pm \beta_2 (RD)^2 \pm \beta_3 (CRF) \pm \beta_4 (CRF)^2 \quad ....(1)$$

Where, α is intercept; β_1 *to* β_4 *are* slopes of rainy days and rainfall on yield attained by tillage and fertilizer treatments. The treatments which maintained positive β values under different rainfall conditions are superior from viewpoint of sustainability and efficient use of resources.

The sustainable yield index of treatment 'i' could be derived by using mean yield ($\bar{A}_i$) of the treatment over years; prediction error (Φ) based on regression model; and maximum yield (Y_{max}) attained by any treatment in the study period. The sustainable yield index " of treatment 'i' could be given as:

$$\eta_i = [(\bar{A}_i - \Phi) / (Y_{max})] * 100 \quad .... (2)$$

In equation (2), the mean yield of a treatment would get detrended by elimination of the unexplained variation in yield measured through variability in rainy days and crop seasonal rainfall over years based on model (1). The detrended yields are compared with the maximum yield attained by any treatment in the study period in order to

Table: 1
Descriptive statistics of rainfall, date of sowing and harvest of cotton, soybean and pigeonpea

Year	DoS	DoH			RD	June	July	Aug.	Sept.	Oct .	Nov .	June-Nov.	Total
		Cotton	Soybean	Pigeonpea									
2005	12-Jul	15-Feb	24-Oct		45	43.08	44.91	29.11	38.51	53.6	0.0	1309.1	1408.3
2006	27-Jun		5-Oct	2-Jan	43	130.4	106.4	444.6	153.8	50.2	38.0	923.4	992.6
2007	18-Jun	5-Mar	9-Oct		42	242.4	146.8	186.0	246.7	0.0	16.2	838.1	853.8
2008	13-Jun		3-Oct	27-Dec	41	128.2	147.0	81.6	215.6	30.7	17.8	620.9	648.1
2009	14-Jul	10-Feb	30-Oct		36	52.2	77.0	254.2	109.5	100.1	47.7	640.7	672.9
Mean					41	119.2	264.4	219.1	172.8	66.9	23.9	866.4	915.1
CV (%)					8.1	67.2	123.2	64.6	32.8	90.5	79.1	32.2	33.8

DoS = Date of sowing; DoH = Date of harvest; CGP = Crop growing period; RD = Rainy days assess the sustainability of a treatment for attaining maximum yield. A treatment with maximum η value could be identified and used for attaining sustainable yield of a crop under varying rainfall conditions.

The RWUE (kg ha^{-1} mm^{-1}) of treatments is expressed as a ratio of yield (kg ha^{-1}) and crop seasonal rainfall (CRF; mm) as described by Rockstrom *et al.* (2003) and is given as:

RWUE (kg ha^{-1} mm^{-1}) = [Grain yield (kg ha^{-1})] / [Crop seasonal rainfall (mm)] …...(3)

The energy use efficiency (EUE) is calculated as a ratio of total output and input energy and is given as:

EUE = [Total output energy (MJ ha^{-1})] / [Total input energy (MJ ha^{-1})] ..… (4)

The energy productivity (EP, kg MJ^{-1}) is calculated as a ratio of mean grain yield (kg ha^{-1}) and total input energy (MJ ha^{-1}) and is given as:

EP (kg MJ^{-1}) = [Grain yield (kg ha^{-1})] / [Total input energy (MJ ha^{-1})] …….. (5)

For computing economics of different treatments, all inputs and outputs were converted to monetary value to express them in a common unit. The cost of cultivation incurred, gross returns, net returns and benefit-cost ratio (BCR) attained by treatments were derived (Maruthi Sankar *et al.*, 2012a and Nema *et al.*, 2008). The gross returns (₹ ha^{-1}) were computed as a product of mean yield of each treatment over years and value of crop at each location. The net returns (₹ ha^{-1}) were computed as a difference of gross returns (₹ ha^{-1}) and cost of cultivation (₹ ha^{-1}). The BC ratio was derived as a ratio of gross returns and cost of cultivation.

3. RESULTS AND DISCUSSION

Based on observations recorded on monthly rainfall, crop seasonal rainfall of June to November significantly decreased over years. The annual rainfall had a R^2 of 0.86, while crop seasonal rainfall had R^2 of 0.85. The rate of decrease in annual rainfall from year to year was 181.53 mm $year^{-1}$ compared to decrease in crop seasonal rainfall of 161.11 mm yr^{-1}. The annual and crop seasonal rainfall are depicted in Fig. 1. The decreased rainfall had a significant influence on performance of tillage and fertilizer treatments on cotton equivalent yield, RWUE, monetary returns, energy use efficiency and changes in soil fertility of nutrients.

Effect of Tillage and Fertilizer Treatments on Yield and Rainwater Use Efficiency

The seed cotton equivalent yield ranged from 808 kg ha^{-1} attained by RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} (2008) to 1951 kg ha^{-1} attained by CT + 100% RDF (2007) with mean of 1193 kg ha^{-1} and variation of 9.8%. The RWUE ranged from

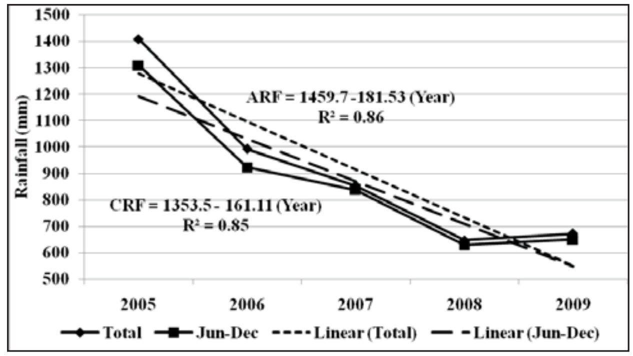

Fig. 1. Annual and crop seasonal rainfall during 2005 to 2009 at Parbhani

0.76 kg ha^{-1} mm^{-1} attained by RT_2 + FYM @ 5 t ha^{-1} (2005) to 2.28 kg ha^{-1} mm^{-1} attained by CT + 100% RDF (2007) with mean of 1.43 kg ha^{-1} mm^{-1} and variation of 9.2%. Based on ANOVA, effects of tillage and fertilizer on cotton equivalent yield and RWUE observed in different years along with *l.s.d.* values at $p < 0.05$ level are given in Table 2. The tillage treatments differed significantly in influencing yield and RWUE in all years, while fertilizer treatments differed significantly in 2007 and 2009 under cotton + soybean (1:1). There was a significant interaction effect of tillage and fertilizer on cotton equivalent yield and RWUE in 2006 and 2008 under soybean + pigeonpea (4:2). CT was superior to RT_1 in 2007 and RT_2 in 2005, 2006, 2007 and 2008. RT_1 was superior to RT_2 in 2006 and 2007, while both RT_1 and RT_2 were superior to CT in 2009. In 2007, 100% RDF was superior to FYM @ 5 t ha^{-1}, VC @ 3 t ha^{-1} and 50% RDF + VC @ 1.5 t ha^{-1}; while 50% RDF + FYM @ 2.5 t ha^{-1} was superior to FYM @ 5 t ha^{-1} and VC @ 3 t ha^{-1}; and 50% RDF + VC @ 1.5 t ha^{-1} was superior to VC @ 3 t ha^{-1}. In 2009, 100% RDF was superior to VC @ 3 t ha^{-1} and was at par with FYM @ 5 t ha^{-1}, 50% RDF + FYM @ 2.5 t ha^{-1} and 50% RDF + VC @ 1.5 t ha^{-1}; while FYM @ 5 t ha^{-1}, VC @ 3 t ha^{-1}, 50% RDF + FYM @ 2.5 t ha^{-1} and 50% RDF + VC @ 1.5 t ha^{-1} were at par with each other. A combination of organic and inorganic fertilizer was equally beneficial compared to 100% RDF under low crop seasonal rainfall received in 2009. Vittal *et al.* (1983) discussed on effects of deep tillage on productivity of different rainfed crops under semi-arid Alfisols. In a study by Kihara *et al.* (2012), the authors observed significant effects of tillage and fertilizer on yields of maize and soybean crops. Similarly, Nema *et al.* (2008) found significant differences in effects of tillage and fertilizer on pearl millet yield over years. Roul and Mahapatra (2006) observed that integrated use of organic and inorganic fertilizer would be more beneficial compared to inorganic fertilizers alone for rice and rice-based cropping systems.

Effect of Tillage and Fertilizer on Bulk Density, Infiltration Rate, Runoff and Soil Loss

The effects of tillage and fertilizer on bulk density,

Table: 2
Analysis of variance of cotton equivalent yield and rainwater use efficiency attained by tillage and fertilizer

Tillage	Cotton equivalent yield (kg ha^{-1})						Rainwater use efficiency (kg mm^{-1} ha^{-1})					
	FYM @ 5 t ha^{-1}	VC @ 3 t ha^{-1}	50% RDF+ FYM @ 2.5 t ha^{-1}	50% RDF+ VC @ 1.5 t ha^{-1}	100% RDF	Mean	FYM @ 5 t ha^{-1}	VC @ 3 t ha^{-1}	50% RDF+ FYM @ 2.5 t ha^{-1}	50% RDF+ VC @ 1.5 t ha^{-1}	100% RDF	Mean
2005 : Cotton + soybean (1:1)												
CT	1318	1374	1471	1536	1637	1467a	1.01	1.05	1.12	1.17	1.25	1.12a
RT 1	1138	1193	1290	1356	1457	1287ab	0.87	0.91	0.99	1.04	1.11	0.98ab
RT 2	993	1049	1146	1211	1312	1142b	0.76	0.80	0.88	0.93	1.00	0.87b
Mean	1150	1205	1302	1368	1469	1299	0.88	0.92	1.00	1.05	1.12	0.99
LSD (T)	324						0.25					
LSD (F)	NS						NS					
LSD(TxF)	NS						NS					
2006 : Soybean + pigeonpea (4:2)												
CT	1156	1117	1189	1077	1287	1165a	1.25	1.21	1.29	1.17	1.39	1.26a
RT 1	1146	1106	1178	1066	1277	1155a	1.24	1.20	1.27	1.15	1.38	1.25a
RT 2	1034	995	1067	955	1165	1043b	1.12	1.08	1.15	1.03	1.26	1.13b
Mean	1112	1073	1145	1033	1243	1121	1.20	1.16	1.24	1.12	1.34	1.21
LSD (T)	112						0.12					
LSD (F)	NS						NS					
LSD(TxF)	150						0.16					
2007 : Cotton + soybean (1:1)												
CT	1614	1483	1825	1743	1951	1723a	1.89	1.74	2.14	2.04	2.28	2.02a
RT 1	1439	1308	1650	1568	1776	1548b	1.69	1.53	1.93	1.84	2.08	1.81b
RT 2	1234	1103	1445	1363	1571	1343c	1.44	1.29	1.69	1.60	1.84	1.57c
Mean	1429cd	1298d	1640ab	1558bc	1766a	1538	1.67cd	1.52d	1.92ab	1.83bc	2.07a	1.80
LSD (T)	63						0.07					
LSD (F)	150						0.18					
LSD(TxF)	NS						NS					
2008 : Soybean + pigeonpea (4:2)												
CT	1147	1033	1102	973	1203	1092a	1.82	1.64	1.75	1.54	1.91	1.73a
RT 1	1134	1020	1089	960	1191	1079ab	1.80	1.62	1.73	1.52	1.89	1.71ab
RT 2	982	868	937	808	1038	927b	1.56	1.38	1.49	1.28	1.65	1.47b
Mean	1088	974	1043	914	1144	1032	1.73	1.55	1.66	1.45	1.82	1.64
LSD (T)	164						0.26					
LSD (F)	NS						NS					
LSD(TxF)	160						0.25					
2009 : Cotton + soybean (1:1)												
CT	874	844	890	873	1019	900b	1.36	1.32	1.39	1.36	1.59	1.40b
RT 1	992	962	1008	991	1137	1018a	1.55	1.50	1.57	1.55	1.77	1.59a
RT 2	988	958	1005	988	1133	1014a	1.54	1.49	1.57	1.54	1.77	1.58a
Mean	951ab	921 b	968ab	951ab	1096a	977	1.48ab	1.44b	1.51ab	1.48ab	1.71a	1.52
LSD (T)	107						0.17					
LSD (F)	160						0.25					
LSD(TxF)	NS						NS					

LSD = Least significant difference at $p < 0.05$ level; NS = Not significant
Treatments with same letter indicate at par values

infiltration rate, runoff and soil loss are given in Table 3. The bulk density ranged from 1.19 g cm^{-3} under CT + FYM @ 5 t ha^{-1} to 1.31 g cm^{-3} under RT_2 + VC @ 3 t ha^{-1} with mean of 1.26 g cm^{-3} and variation of 2.8%. The bulk density in the plots of CT + FYM @ 5 t ha^{-1}, CT + 50% RDF + VC @ 1.5 t ha^{-1} and RT_1 + 50% RDF + VC @ 1.5 t ha^{-1} was less than Mean–SD, while bulk density in the plot of RT_2 + VC @ 3 t ha^{-1} was more than Mean + SD. The remaining 11 treatments had bulk density within Mean–SD to Mean + SD.

Table: 3
Effect of tillage and fertilizer on bulk density, infiltration rate, runoff, soil loss and energy use

Treatments	Bulk density ($g\ cm^{-3}$)	Infiltration rate ($cm\ hr^{-1}$)	Runoff (mm)	Soil loss ($t\ ha^{-1}yr^{-1}$)	Input energy ($MJ\ ha^{-1}$)	Output energy ($MJ\ ha^{-1}$)	EP	ER
CT+FYM @ 5 t ha^{-1}	1.19 a	1.43 c	125.2 a	2.88 a	9094 b	22628 b	0.16 b	2.49 b
CT+VC @ 3 t ha^{-1}	1.26 b	1.32 b	125.2 a	2.88 a	9094 b	20976 b	0.15 b	2.31 b
CT+ 50% RDF + FYM @ 2.5 t ha^{-1}	1.26 b	1.39 c	126.9 b	2.95 b	10105 b	23020 b	0.15 b	2.28 b
CT+ 50% RDF+VC @ 1.5 t ha^{-1}	1.20 a	1.32 b	126.9 b	2.95 b	10105 b	21141 b	0.14 a	2.09 a
CT+ 100% RDF	1.24 b	1.27 b	128.0 b	3.03 b	11116 c	26071 c	0.15 b	2.35 b
RT_1+FYM @ 5 t ha^{-1}	1.28 b	1.36 b	128.7 b	3.04 b	8458 a	23815 b	0.18 c	2.82 c
RT_1+VC @ 3 t ha^{-1}	1.27 b	1.25 b	128.7 b	3.04 b	8458 a	22163 b	0.17 b	2.62 b
RT_1+ 50% RDF + FYM @ 2.5 t ha^{-1}	1.25 b	1.25 b	130.3 b	3.11 b	9469 b	24206 b	0.17 b	2.56 b
RT_1+ 50% RDF+ VC @ 1.5 t ha^{-1}	1.21 a	1.21 b	130.3 b	3.11 b	9469 b	22328 b	0.16 b	2.36 b
RT_1+ 100% RDF	1.27 b	1.21 b	131.4 b	3.19 b	10480 c	27258 c	0.17 b	2.60 b
RT_2+FYM@5 t ha^{-1}	1.30 b	1.11 b	132.2 b	3.35 b	8438 a	21867 b	0.17 b	2.59 b
RT_2+ VC@3 t ha^{-1}	1.31 c	1.03 a	132.2 b	3.35 b	8438 a	20216 a	0.16 b	2.40 b
RT_2+ 50% RDF + FYM @ 2.5 t ha^{-1}	1.26 b	1.07 a	133.9 c	3.42 c	9449 b	22259 b	0.15 b	2.36 b
RT_2+50% RDF+ VC @ 1.5 t ha^{-1}	1.30 b	1.04 a	133.9 c	3.42 c	9449 b	20380 a	0.14 a	2.16 a
RT_2+ 100% RDF	1.27 b	1.00 a	135.0 c	3.50 c	10460 c	25310 c	0.16 b	2.42 b
Mean	1.26	1.22	129.9	3.14	9472	22909	0.16	2.43
CV (%)	2.8	11.4	2.4	6.7	8.9	9.0	7.8	7.8
Mean – SD	1.22	1.08	126.8	2.93	8628	20836	0.15	2.24
Mean + SD	1.30	1.36	133.1	3.35	10316	24982	0.17	2.62

a = < Mean – SD; b = Mean – SD to Mean + SD; c = > Mean + SD; EP = Energy productivity ($kg\ MJ^{-1}$); ER = Energy ratio (OE/IE)

The infiltration rate ranged from 1.00 cm hr^{-1} in the plot under RT_2 + 100% RDF to 1.43 cm hr^{-1} in the plot under CT + FYM @ 5 t ha^{-1} with mean of 1.22 cm hr^{-1} and variation of 11.4%. RT_2 + VC @ 3 t ha^{-1}, RT_2 + 50% RDF + FYM @ 2.5 t ha^{-1}, RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 100% RDF had an infiltration rate of less than Mean–SD, while CT + FYM @ 5 t ha^{-1} and CT + 50% RDF + FYM @ 2.5 t ha^{-1} had an infiltration rate of more than Mean + SD. The remaining 9 treatments had infiltration rate within Mean–SD to Mean + SD.

The runoff ranged from 125.2 mm under CT + FYM @ 5 t ha^{-1} and CT + VC @ 3 t ha^{-1} to 135.0 mm under RT_2 + 100% RDF with mean of 129.9 mm and variation of 2.4%. The runoff in the plots of CT + FYM @ 5 t ha^{-1} and CT + VC @ 3 t ha^{-1} was less than Mean – SD, while the runoff in the plots of RT_2 + 50% RDF + FYM @ 2.5 t ha^{-1}, RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 100% RDF was more than Mean + SD. The remaining 10 treatments had runoff within Mean–SD to Mean + SD.

The soil loss ranged from 2.88 t ha^{-1} under CT + FYM @ 5 t ha^{-1} and CT + VC @ 3 t ha^{-1} to 3.50 t ha^{-1} under RT_2 + 100% RDF with mean of 3.15 t ha^{-1} and variation of 6.7%. The soil loss in the plots of CT + FYM @ 5 t ha^{-1} and CT + VC @ 3 t ha^{-1} was less than Mean – SD, while the soil loss in the plots of RT_2 + 50% RDF + FYM @ 2.5 t ha^{-1}, RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 100% RDF was more than Mean + SD. The remaining 10 treatments had soil loss within Mean–SD to Mean + SD.

Effect of Tillage and Fertilizer Treatments on Output Energy and Energy Productivity

The effects of tillage and fertilizer treatments on energy productivity and output/input energy ratio are given in Table 3. The input energy ranged from 8438 MJ ha^{-1} under RT_2 + FYM @ 5 t ha^{-1} and RT_2 + VC @ 3 t ha^{-1} to 11116 MJ ha^{-1}

under CT + 100% RDF with mean of 9472 MJ ha^{-1} and variation of 8.9%. The input energy in RT1 + FYM @ 5 t ha^{-1}, RT_1 + VC @ 3 t ha^{-1}, RT_2 + FYM @ 5 t ha^{-1} and RT_2 + VC @ 3 t ha^{-1} was less than Mean–SD, while the input energy in CT + 100% RDF, RT_1 + 100% RDF and RT_2 + 100% RDF was more than Mean + SD. All the remaining 8 treatments had input energy within Mean–SD to Mean + SD.

The output energy ranged from 20216 MJ ha^{-1} under RT2 + VC @ 3 t ha^{-1} to 27258 MJ ha^{-1} under RT_1 + 100% RDF with mean of 22909 MJ ha^{-1} and variation of 9.0%. RT2 + VC @ 3 t ha^{-1} and RT_2 + 50% RDF + VC @ 3 t ha^{-1} gave output energy of less than Mean–SD, while CT + 100% RDF, RT_1 + 100% RDF and RT_2 + 100% RDF gave output energy of more than Mean + SD. The output energy by the remaining 10 treatments was within Mean–SD to Mean + SD.

The energy productivity which indicates the crop productivity per unit of input energy ranged from 0.14 kg MJ^{-1} attained by CT + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} to 0.18 kg MJ^{-1} attained by RT_1 + FYM @ 5 t ha^{-1} with mean of 0.16 kg MJ^{-1} and variation of 7.8%. CT + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} gave energy productivity of less than Mean–SD, while RT_1 + FYM @ 5 t ha^{-1} gave energy productivity of more than Mean + SD. The remaining 12 treatments gave energy productivity within Mean–SD to Mean + SD.

The output/input energy ratio ranged from 2.09 under CT + 50% RDF + VC @ 1.5 t ha^{-1} to 2.82 under RT_1 + FYM @ 5 t ha^{-1} with mean of 2.43 and variation of 7.8%. CT + 50% RDF + VC @ 1.5 t ha^{-1} and RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} gave output/input energy ratio of less than Mean–SD compared to RT_1 + FYM @ 5 t ha^{-1} which gave ratio of more than Mean + SD. All the remaining 12 treatments gave output/input energy ratio within Mean–SD to Mean + SD limit. In a paper by Richey *et al.* (1977), the authors described on the crop productivity and energy requirement for corn and soybean with different tillage and planting systems. The authors observed that a tillage and planting system with lower input energy is desirable for attaining maximum output energy. Maruthi Sankar *et al*. (2013) described on the input and output energy, energy productivity and output: input energy ratio based on field experiments conducted on rice-lentil, rice-horse gram and rice-linseed crop sequences under different soil and agro-climatic conditions. With application of tillage and fertilizer treatments for 5 years, the authors observed that for higher energy use efficiency, crop productivity and output energy should be maximum with minimum use of input energy under rainfed conditions.

Effect of Tillage and Fertilizer Treatments on Soil Parameters

Based on soil analysis done in each tillage and fertilizer treatment at start (2005) and end of the study (2009), observations recorded on soil pH, electrical conductivity, soil organic carbon, $CaCo_3$, soil available N, P and K and changes in different soil parameters are given in Table 4. The mean soil pH increased from 7.3 in 2005 to 8.0 (increase of 9.7%) in 2009, while EC decreased from 0.63 to 0.13 (decrease of 79.2%) in respective years. The organic carbon increased from 0.51 to 0.62% (increase of 22.1%), while $CaCo_3$ increased from 3.99 to 5.2% (increase of 29.4%) from 2005 to 2009. There was a decrease of soil available N from 153 to 131 kg ha^{-1} (decrease of 14.6%), soil available P from 5.7 to 4.8 kg ha^{-1} (decrease of 15.0%); while

Table: 4
Effect of tillage and fertilizer on soil parameters observed at the end of the study (2009)

Treatment	Soil parameters observed in 2005													
	pH = 7.3		EC = 0.63		OC = 0.51%		$CaCo_3$=3.99%		SN= 153 kg ha^{-1}		SP = 5.7 kg ha^{-1}		SK= 635 kg ha^{-1}	
	2009	λ	2009	λ	2009	λ	2009	λ	2009	λ	2009	λ	2009	λ
CT+FYM	8.1 b	11.0b	0.13b	-79.4b	0.60b	17.6a	5.7b	41.6b	129b	-15.7b	5.1b	-10.5c	899b	41.6b
CT+VC	8.0 b	9.6b	0.13b	-79.4b	0.62b	21.6b	6.0c	50.4c	129b	-15.7b	5.0b	-12.3b	893b	40.6b
CT+RDF+ FYM	8.0 b	9.6b	0.14b	-77.8c	0.61b	19.6b	6.3c	57.1c	124a	-19.0a	5.3c	-7.0c	875b	37.8b
CT+RDF+ VC	8.0 b	9.6b	0.14b	-77.8c	0.59a	15.7a	6.2c	55.4c	130b	-15.0b	4.8b	-15.8b	882b	38.9b
CT+RDF	8.0 b	9.6b	0.14b	-77.8c	0.64b	25.5b	6.3c	57.6c	124a	-19.0	4.8b	-15.8b	866b	36.4b
RT_1+ FYM	8.2 c	12.3c	0.12b	-81.0a	0.62b	21.6b	4.2a	4.8a	136c	-11.1c	5.0b	-12.3b	913c	43.8c
RT_1+ VC	8.1 b	11.0b	0.12b	-81.0a	0.64b	25.5b	4.5b	13.5b	136c	-11.1c	4.9b	-14.0b	907c	42.8c
RT_1+RDF +FYM	8.1 b	11.0b	0.13b	-79.4b	0.62b	21.6b	4.8b	20.3b	131b	-14.4b	5.2c	-8.8c	888b	39.8b
RT_1+ RDF+ VC	8.1 b	11.0b	0.13b	-79.4b	0.61b	19.6b	4.7b	18.5b	137c	-10.5c	4.7b	-17.5b	896b	41.1b
RT_1+ RDF	8.0 b	9.6b	0.13b	-79.4b	0.65c	27.5c	4.8b	20.8b	130b	-15.0b	4.7b	-17.5b	879b	38.4b
RT_2+ FYM	8.0 b	9.6b	0.13b	-79.4b	0.62b	21.6b	4.4b	9.3a	133b	-13.1b	4.7b	-17.5b	842b	32.6b
RT_2+ VC	7.9 b	8.2a	0.13b	-79.4b	0.64b	25.5b	4.7b	18.0b	132b	-13.7b	4.7b	-17.5b	836b	31.7b
RT_2+RDF+ FYM	7.9 b	8.2a	0.13b	-79.4b	0.62b	21.6b	5.0b	24.8b	128b	-16.3b	4.9b	-14.0b	817a	28.7a
RT_2+RDF+VC	7.9 b	8.2a	0.14b	-77.8c	0.61b	19.6b	4.9b	23.1b	134b	-12.4b	4.5a	-21.1a	825a	29.9a
RT_2+ RDF	7.8 a	6.8a	0.13b	-79.4b	0.65c	27.5c	5.0b	25.3b	127b	-17.0b	4.4a	-22.8a	808a	27.2a
Mean	8.0	9.7	0.13	-79.2	0.62	22.1	5.2	29.4	131	-14.6	4.8	-15.0	868	36.8
CV (%)	1.3	14.6	4.9	-1.3	2.9	15.9	14.0	61.6	3.1	-18.2	5.1	-29.0	3.9	14.7
Mean–SD	7.9	8.3	0.12	-80.2	0.60	18.6	4.4	11.3	127	-17.3	4.6	-19.3	834	31.4
Mean+SD	8.1	11.1	0.14	-78.1	0.64	25.6	5.9	47.5	135	-11.9	5.1	-10.6	903	42.2

λ = Change (%) over 2005

soil available K increased from 635 to 868 kg ha^{-1} (increase of 36.8%) during 2005 to 2009.

Based on effects of tillage and fertilizer observed on soil parameters at the end of study, RT_2 + 100% RDF had pH of 7.8 (6.8% increase) which was less than Mean–SD, while RT1 + FYM @ 5 t ha^{-1} had pH of 8.2 (12.3% increase) which was more than Mean + SD. The remaining treatments had pH in the range of Mean–SD and Mean + SD. The treatments provided EC in the range of Mean–SD to Mean + SD. RT_1 + FYM @ 5 t ha^{-1} and RT_1 + VC @ 3 t ha^{-1} gave minimum EC of 0.12 (decrease of 81.0%), while CT + 50% RDF + FYM @ 2.5 t ha^{-1} and CT + 50% RDF + VC @ 1.5 t ha^{-1} gave maximum EC of 0.14 (decrease of 77.8%) in 2009. CT + 50% RDF + VC @ 1.5 t ha^{-1} gave lowest OC of 0.59% (increase of 15.7%) which was below Mean–SD, while RT_1 + 100% RDF gave maximum OC of 0.65% (increase of 27.5%) in 2009 which was more than Mean + SD. RT_1 + FYM @ 5 t ha^{-1} gave minimum $CaCo_3$ of 4.2% (increase of 4.8%) which was less than Mean-SD, while CT + 100% RDF gave maximum $CaCo_3$ of 6.3% (increase of 57.6%) which was more than Mean + SD.

CT + 50% RDF + FYM @ 2.5 t ha^{-1} and CT + 100% RDF gave minimum soil N of 124 kg ha^{-1} (decrease of 19.0%) which was below Mean-SD, while RT_1 + 50% RDF + VC @ 1.5 t ha^{-1} gave maximum soil N of 137 kg ha^{-1} (decrease of 10.5%) which was more than Mean + SD over years. RT_2 + 100% RDF gave minimum soil P of 4.4 kg ha^{-1} (decrease of 22.8%) which was less than Mean-SD, while CT + 50% RDF + FYM @ 2.5 t ha^{-1} gave maximum soil P of 5.3 kg ha^{-1} (decrease of 7.0%) which was above Mean + SD in 2009. Similarly, RT_2 + 100% RDF gave minimum soil K of 808 kg ha^{-1} (increase of 27.2%) which was less than Mean-SD, while RT_1 + FYM @ 5 t ha^{-1} gave maximum soil K of 913 kg ha^{-1} (increase of 43.8%) which was above Mean + SD. Sharma *et al.* (2008a) found a significant effect of conjunctive use of organic and inorganic nutrient sources on soil fertility and quality apart from attaining significantly higher productivity of sunflower under semi-arid Alfisols.

Effect of Fertilizer on Weed Count and Dry Weight under Reduced Tillage+Herbicide Application

Observations were recorded on monocot and dicot weed number and dry weight as influenced by fertilizer treatments under RT_2 plot and mean and variation observed in each treatment are given in Table 5. 100% RDF increased monocot weeds of 2.50 m^{-2} to a maximum compared to VC @ 3 t ha^{-1} which gave minimum number of weeds of 2.16 m^{-2}. FYM @ 5 t ha^{-1} gave maximum number dicot weeds of 6.47 m^{-2}, while 100% RDF gave minimum number of 4.59 m^{-2} under reduced tillage condition. However, total number of weeds (sum of monocot and dicot weeds) ranged from 7.09 m^{-2} under 100% RDF to 8.73 m^{-2} under FYM @ 5 t ha^{-1}. Maximum monocot weed dry weight of 119.0 g m^{-2} was observed with application of VC @ 3 t ha^{-1}, while minimum of 55.6 g m^{-2} was observed with 50% RDF + VC @ 1.5 t ha^{-1}. FYM @ 5 t ha^{-1} gave maximum dicot weed dry weight of 70.1 g m^{-2}, while VC @ 3 t ha^{-1} gave minimum of 35.7 g m^{-2}. However, maximum total dry weight of 175.9 g m^{-2} was observed under FYM @ 5 t ha^{-1}, while minimum of 115.1 g m^{-2} was under 50% RDF + VC @ 1.5 t ha^{-1}. The treatments gave mean monocot weed number of 2.33 m^{-2} and dicot weed number of 5.65 m^{-2} with variation of 5.6 and 14.1% respectively compared to total weed number of 7.98 m^{-2} with variation of 8.5%. They gave mean monocot weed dry weight of 93.7 g m^{-2} and dicot dry weight of 58.2 g m^{-2} with variation of 26.0 and 23.7%, respectively compared to total mean dry weight of 151.9 g m^{-2} with variation of 16.0%.

Effect of Tillage and Fertilizer Treatments on RWUE and Sustainability Yield Index

In order to measure sustainability of tillage and fertilizer treatments, a regression model of cotton equivalent yield (CEY) was calibrated through number of rainy days and rainfall (mm) received during June to November in different years. The model gave R^2 of 0.66 for predicting yield with prediction error of 152 kg ha^{-1}. Both rainy days and rainfall significantly influenced the cotton equivalent yield attained by treatments at $p < 0.01$ level. The

Table: 5
Weed count and dry weight in reduced tillage + herbicide plot as affected by treatments in 2005

Fertilizer treatment	Weed (Number m^{-2})			Weed dry weight (g m^{-2})		
	Monocot.	Dicot.	Total	Monocot.	Dicot.	Total
FYM @ 5 t ha-1	2.26 b	6.47 c	8.73 c	105.8 b	70.1 b	175.9 b
VC @ 3 t ha-1	2.16 a	6.42 b	8.58 b	119.0 c	35.7 a	154.7 b
50% RDF + FYM @ 2.5 t ha-1	2.41 b	5.40 b	7.81 b	86.0 b	56.9 b	142.9 b
50% RDF + VC @ 1.5 t ha-1	2.33 b	5.36 b	7.69 b	55.6 a	59.5 b	115.1 a
100% RDF	2.50 c	4.59 a	7.09 a	101.9 b	68.8 b	170.7 b
Mean	2.33	5.65	7.98	93.7	58.2	151.9
CV (%)	5.64	14.10	8.47	26.0	23.7	16.0
Mean-SD	2.20	4.85	7.30	69.3	44.4	127.5
Mean+SD	2.46	6.44	8.66	117.9	72.0	176.2

a = < Mean–SDb : Mean–SD to Mean+SD; c = > Mean+SD model of CEY through rainy days and rainfall observed during crop growing period is

$$CEY = -152725^{**} + 2.31^{**} (CRF) + 0.002^{**} (CRF)^2 + 7885.3^{**} (CRD) - 102.1^{**} (CRD)^2 \quad \ldots (5)$$

Using mean yield of each tillage and fertilizer treatment over 5 years, prediction error of 152 kg ha^{-1} based on regression model and maximum yield of 1951 kg ha^{-1} attained by CT + 100% RDF in 2007, the SYI of each treatment was derived as described by Maruthi Sankar *et al*. (2012a, 2012b and 2013). The SYI would indicate how close is the mean yield of a treatment to maximum potential yield attained in the study period.

Effect of Tillage and Fertilizer on CEY and RWUE under Different Cropping Systems

The mean cotton equivalent yield and RWUE observed under each rotation are given in Table 6. The cotton equivalent yield ranged from 1037 kg ha^{-1} with RWUE of 1.20 kg ha^{-1} mm^{-1} attained by RT_2 + VC @ 3 t ha^{-1} to 1535 kg ha^{-1} with RWUE of 1.71 kg ha^{-1} mm^{-1} attained by CT + 100% RDF under cotton + soybean (1:1). The CEQ ranged from 881 kg ha^{-1} (RWUE of 1.16 kg ha^{-1} mm^{-1}) attained by RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} to 1245 kg ha^{-1} (RWUE of 1.65 kg ha^{-1} mm^{-1}) attained by CT + 100% RDF under soybean + pigeonpea (4:2). When both systems were combined, the CEQ ranged from 994 kg ha^{-1} with RWUE of 1.21 kg ha^{-1} mm^{-1} attained by RT_2 + VC @ 3 t ha^{-1} to 1419 kg ha^{-1} with RWUE of 1.69 kg ha^{-1} mm^{-1} attained by CT + 100% RDF. RT_2 + FYM @ 5 t ha^{-1} under cotton + soybean (1:1); RT_2 + VC @ 3 t ha^{-1} under both systems; RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} under soybean + pigeonpea (4:2) attained CEY of less than Mean–SD, while CT + 100% RDF and RT_1 + 100% RDF attained CEY of more than Mean+SD. The remaining 10 treatments attained CEY between Mean–SD and Mean+SD. The RWUE of treatments derived in our paper are based on methodology proposed by Rockstrom *et al*. (2003). The results indicated that significantly higher RWUE was attained in 2008 and 2009 under lower crop seasonal rainfall compared to lower RWUE under higher rainfall received in 2005, 2006 and 2007. They are in conformity with those reported by Nema *et al*. (2008) and Maruthi Sankar *et al*. (2012a and 2013) for crops under different agro-climatic environments.

Effects of Tillage and Fertilizer Treatments on Monetary Returns

The mean cost of cultivation incurred and gross and net returns attained by tillage and fertilizer treatments are given in Table 7. Under cotton + soybean (1:1), cost of cultivation ranged from ₹ 10,511 ha^{-1} incurred by RT_1+ FYM @ 5 t ha^{-1} to ₹ 13,686 ha^{-1} incurred by CT + 50% RDF + VC @ 1.5 t ha^{-1} with mean of ₹ 12,388 ha^{-1} and variation of 10.7%. Under soybean + pigeonpea (4:2), cost of cultivation ranged from ₹ 7,728 ha^{-1} incurred by RT_1+ 50% RDF + FYM @ 2.5 t ha^{-1} to ₹ 16,364 ha^{-1} incurred by CT + VC @ 3 t ha^{-1} with mean of ₹11,648 ha^{-1} and variation of 30.5%. However, it ranged from ₹ 9,452 ha^{-1} under RT_1+ FYM @ 5 t ha^{-1} to ₹ 14,724 ha^{-1} under CT + VC @ 3 t ha^{-1} with mean of ₹ 12,092 ha^{-1} and variation of 17.9% when both systems were considered. The cost of cultivation incurred by the 5 reduced tillage +

Table: 6
Cotton equivalent yield and RWUE attained by tillage and fertilizer under different systems

Treatments	Cotton equivalent yield (kg ha^{-1})			Rainwater use efficiency (kg ha^{-1}mm^{-1})		
	C+S (5,7,9)*	S+P (6,8)#	Pooled	C+S (5,7,9)*	S+P (6,8)#	Pooled
CT+FYM @ 5 t ha-1	1269b	1151b	1222 b	1.42b	1.54b	1.47 b
CT+VC @ 3 t ha-1	1233b	1075b	1170 b	1.37b	1.42b	1.39 b
CT+ 50% RDF + FYM @ 2.5 t ha-1	1395b	1145b	1295 b	1.55b	1.52b	1.54 b
CT+ 50% RDF+VC @ 1.5 t ha-1	1384b	1025b	1240 b	1.53b	1.35b	1.46 b
CT+ 100% RDF	1535c	1245c	1419 c	1.71c	1.65c	1.69 c
RT1+ FYM @ 5 t ha-1	1189b	1140b	1170 b	1.37b	1.52b	1.43 b
RT1+VC @ 3 t ha-1	1154b	1063b	1118 b	1.31b	1.41b	1.35 b
RT1+ 50% RDF + FYM @ 2.5 t ha-1	1316b	1134b	1243 b	1.50b	1.50b	1.50 b
RT1+ 50% RDF+ VC @ 1.5 t ha-1	1305b	1013b	1188 b	1.47b	1.34b	1.42 b
RT1+ 100% RDF	1456c	1234c	1367 c	1.66c	1.64c	1.65 c
RT2+ FYM @ 5 t ha-1	1072a	1008b	1046 a	1.25a	1.34b	1.28 a
RT2+ VC @ 3 t ha-1	1037a	931a	994 a	1.20a	1.23a	1.21 a
RT2+ 50% RDF + FYM @ 2.5 t ha-1	1198b	1002b	1120 b	1.38b	1.32b	1.36 b
RT2+ 50% RDF+ VC @ 1.5 t ha-1	1187b	881a	1065 a	1.35b	1.16a	1.28 a
RT2+ 100% RDF	1339b	1102b	1244 b	1.54b	1.45b	1.50 b
Mean	1271	1076	1193	1.44	1.43	1.43
CV (%)	10.9	9.5	9.8	9.9	9.8	9.2
Mean - SD	1133	974	1077	1.30	1.29	1.30
Mean + SD	1410	1179	1310	1.58	1.57	1.57

* C+S = Cotton + soybean (1:1) in 2005, 2007 and 2009; #S+P = Soybean + pigeonpea (4:2) in 2006 and 2008

Table: 7
Cost of cultivation, gross and net returns attained by tillage and fertilizer in different systems

Treatments	Cost of cultivation (₹ ha^{-1})			Gross returns (₹ ha^{-1})			Net returns (₹ ha^{-1})		
	C+S (5,7,9)*	S+P (6,8)#	Pooled	C+S (5,7,9)*	S+P (6,8)#	Pooled	C+S (5,7,9)*	S+P (6,8)#	Pooled
CT+FYM @ 5 t ha^{-1}	13522b	16164c	14579 c	26887b	25787c	26447 b	13366b	9623b	11869 b
CT+VC @ 3 t ha^{-1}	13631b	16364c	14724 c	26103b	23857b	25205 b	12473b	7493a	10481 a
CT+ 50% RDF + FYM @ 2.5 t ha^{-1}	13659b	16028c	14607 c	29327c	25437c	27771 c	15668b	9410b	13165 b
CT+ 50% RDF+VC @ 1.5 t ha^{-1}	13686b	16153c	14673 c	29060b	22687b	26511 b	15374b	6535a	11838 b
CT+ 100% RDF	13648b	16156c	14651 c	32397c	27954c	30620 c	18749c	11798b	15968 c
RT1+FYM@5 t ha^{-1}	10511a	7864a	9452 a	23507a	22450b	23084 b	12997b	14586b	13633 b
RT1+VC @ 3 t ha^{-1}	10620a	8064a	9597 a	22724a	20520b	21842 a	12104b	12456b	12245 b
RT1+ 50% RDF + FYM @ 2.5 t ha^{-1}	10648a	7728a	9480 a	25948b	22100b	24408 b	15299b	14372c	14928 b
RT1+ 50% RDF+ VC @ 1.5 t ha^{-1}	10675a	7853a	9546 a	25680b	19350a	23148 b	15006b	11497b	13602 b
RT1+ 100% RDF	10637a	7856a	9525 a	29017b	24616b	27257 b	18380c	16761c	17732 c
RT2+FYM@5 t ha^{-1}	12809b	10889b	12041 b	23507a	22450b	23084 b	10699a	11561b	11044 b
RT2+ VC@3 t ha^{-1}	12918b	11089b	12186 b	22724a	20520b	21842 a	9806a	9431b	9656 a
RT2+ 50% RDF + FYM @ 2.5 t ha^{-1}	12946b	10752b	12069 b	25948b	22100b	24408 b	13001b	11348b	12340 b
RT2+50% RDF+ VC @ 1.5 t ha^{-1}	12973b	10877b	12135 b	25680b	19350a	23148 b	12708b	8473b	11014 b
RT2+ 100%RDF	12935b	10881b	12113 b	29017b	24616b	27257 b	16082b	13736b	15144 b
Mean	12388	11648	12092	26502	22920	25069	14114	11272	12977
CV (%)	10.7	30.5	17.9	10.6	10.8	10.0	18.1	25.2	17.1
Mean - SD	11057	8096	9925	23690	20450	22553	11554	8434	10753
Mean + SD	13719	15200	14259	29314	25389	27585	16674	14110	15201

a = < Mean – SD; b = Mean–SD to Mean+SD; c = > Mean+SD; *C+S= Cotton+soybean (1:1) in 2005, 2007 and 2009; #S+P= Soybean+pigeonpea (4:2) in 2006 and 2008

interculture treatments (RT_1) was less than Mean–SD under both systems and pooled over systems; while it was more than Mean+SD under 5 CT treatments in case of soybean + pigeonpea (4:2) and pooled over systems. The remaining 5 treatments of RT_2 with different combinations of fertilizer incurred cost of cultivation between Mean–SD and Mean+SD.

The gross returns ranged from ₹ 22,724 ha^{-1} under RT_1+ VC @ 3 t ha^{-1} and RT_2+ VC @ 3 t ha^{-1} to ₹ 32,397 ha^{-1} under CT+ 100% RDF with mean of ₹ 26,502 ha^{-1} and variation of 10.6% under cotton + soybean (1:1). It ranged from ₹ 19,350 ha^{-1} under RT_1+ 50% RDF+ VC @ 1.5 t ha^{-1} to ₹ 27,954 ha^{-1} under CT+ 100% RDF with mean of ₹ 22,920 ha^{-1} and variation of 10.8% under soybean + pigeonpea (4:2). The gross returns over systems ranged from ₹ 21,842 ha^{-1} under RT_1 + VC @ 3 t ha^{-1} and RT_2 + VC @ 3 t ha^{-1} to ₹ 30,620 ha^{-1} under CT + 100% RDF with mean of ₹ 25,069 ha^{-1} and variation of 10.0%. CT + 100% RDF and CT+ 50% RDF+ FYM @ 2.5 t ha^{-1} gave gross returns of more than Mean+SD under each system and pooled over systems; while RT_1+ FYM @ 5 t ha^{-1}, RT_1+ VC @ 3 t ha^{-1}, RT_2+ FYM @ 5 t ha^{-1}and RT_2+ VC @ 3 t ha^{-1} under cotton + soybean (1:1) and RT_1+ 50% RDF+ VC @ 1.5 t ha^{-1} and RT_2+50% RDF+ VC @ 1.5 t ha^{-1} under soybean + pigeonpea (4:2) gave gross returns of less than Mean–SD. CT+ FYM @ 5 t ha^{-1} gave gross returns of more than Mean+SD under soybean + pigeonpea (4:2). The remaining treatments attained net returns between Mean–SD and Mean+SD.

Under cotton + soybean (1:1), net returns ranged from ₹ 9806 ha^{-1} under RT_2 + VC @ 3 t ha^{-1} to ₹ 18,749 ha^{-1} under CT + 100% RDF with mean of ₹ 14,114 ha^{-1} and variation of 18.1%. Under soybean + pigeonpea (4:2), net returns ranged from ₹ 6,535 ha^{-1} under CT+ 50% RDF+VC @ 1.5 t ha^{-1} to ₹ 16,761 ha^{-1} under RT1 + 100% RDF with mean of ₹ 11,272 ha^{-1} and variation of 25.2%. When pooled over systems, net returns ranged from ₹ 9,656 ha^{-1} under RT_2 + VC @ 3 t ha^{-1} to ₹ 17,732 ha^{-1} under RT_1 + 100% RDF with mean of ₹ 12,977 ha^{-1} and variation of 17.1%. RT_2 + VC @ 3 t ha^{-1} and RT_2 + FYM @ 5 t ha^{-1} under cotton + soybean (1:1) and CT+VC @ 3 t ha^{-1} and CT+50% RDF+VC @ 1.5 t ha^{-1} under soybean + pigeonpea (4:1) gave net returns below Mean–SD compared to CT+VC @ 3 t ha^{-1} and RT_2+ VC @ 3 t ha^{-1} when pooled over systems. CT+100% RDF and RT_1+100% RDF under cotton+soybean (1:1) and RT_1+50% RDF+FYM @ 2.5 t ha^{-1} and RT_1+100% RDF under soybean + pigeonpea (4:2) gave net returns of more than Mean+SD, compared to CT+100% RDF and RT_1+100% RDF with above Mean+SD, while remaining treatments attained between Mean–SD and Mean+SD.

Effect of Tillage and Fertilizer Treatments on SYI and BCR under Different Crop Rotations

The mean SYI and BCR are given in Table 8. The SYI attained by tillage and fertilizer treatments ranged from 45.4% attained by RT_2 + VC @ 3 t ha^{-1} to 70.9% attained by CT + 100% RDF with mean of 57.4% and variation of 12.4% under cotton + soybean (1:1). The SYI ranged from

37.4% attained by RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} to 56.0% attained by CT + 100% RDF with mean of 47.4% and variation of 11.1% under soybean + pigeonpea (4:2). When pooled over years, SYI ranged from 43.2% attained by RT_2 + VC @ 3 t ha^{-1} to 64.9% attained by CT + 100% RDF with mean of 53.4% and variation of 11.2%. RT_2 + FYM @ 5 t ha^{-1} and RT_2 + VC @ 3 t ha^{-1} attained SYI of less than Mean–SD, while CT + 100% RDF and RT_1 + 100% RDF attained SYI of more than Mean+SD under cotton + soybean (1:1). Similarly, RT_2 + VC @ 3 t ha^{-1} and RT_2 + 50% RDF + VC @ 1.5 t ha^{-1} attained SYI of less than Mean–SD, while CT + 100% RDF and RT_1 + 100% RDF attained SYI of more than Mean+SD under soybean + pigeonpea (4:2). The remaining treatments attained SYI in the range of Mean–SD to Mean+SD.

The BC ratio ranged from 1.75 attained by RT_2+VC @ 3 t ha^{-1} to 2.82 attained by RT_1+100% RDF with mean of 2.18 and variation of 13.2% under cotton+soybean (1:1). It ranged from 1.43 attained by CT+50% RDF+VC @ 1.5 t ha^{-1} to 3.27 attained by RT_1+100% RDF with mean of 2.17 and variation of 28.4% under soybean+pigeonpea (4:2). When pooled over years, BCR ranged from 1.74 under CT+VC @ 3 t ha^{-1} to 3.00 under RT_1+ 100% RDF with mean of 2.18 and variation of 17.9%. RT_2+FYM @ 5 t ha^{-1} and RT_2 + VC @ 3 t ha^{-1} gave BCR within Mean–SD, while CT + VC @ 3 t ha^{-1} attained BCR of less than Mean–SD, while RT_1+50% RDF + FYM @ 2.5 t ha^{-1}, RT_1+50% RDF+ VC @ 1.5t ha^{-1} and RT_1+100% RDF attained BCR of above Mean+SD under cotton + soybean (1:1). CT+VC @ 3t ha^{-1}, CT+50% RDF+VC @ 1.5 t ha^{-1} attained BCR of less than Mean–SD, while RT_1+FYM @ 5 t ha^{-1}, RT_1+50% RDF+ FYM @ 2.5 t ha^{-1} and RT_1+100% RDF attained BCR of more than Mean+SD under soybean + pigeonpea (4:2). CT+VC @ 3 t ha^{-1} gave BCR of less than Mean–SD, while RT_1+FYM @ 5 t ha^{-1}, RT_1+50% RDF+ FYM @ 2.5 t ha^{-1} and RT_1+100% RDF attained more than Mean+SD when pooled over systems and remaining treatments gave between Mean–SD and Mean+SD.

Although CT+ 100% RDF gave maximum cotton equivalent yield, RWUE, SYI and gross returns, RT_1+ 100% RDF was efficient with maximum net returns of ₹ 17732 ha^{-1} and BC ratio of 3.00. It gave 2nd best and at par yield of 1367 kg ha^{-1} with SYI of 62.3% and RWUE of 1.65 kg $ha^{-1}mm^{-1}$ compared to CT+ 100% RDF. This was because of a significantly lower cost of cultivation of ₹ 9525 ha^{-1} incurred by RT_1 + 100% RDF compared to ₹ 14651 ha^{-1} by CT+ 100% RDF. Sarma *et al.* (2011) studied tillage effect on profitability of maize and soil fertility in Inceptisols and found that reduced tillage was beneficial for attaining high yield and profit compared to conventional tillage. Sarkar and Singh (1997) found that integrated nutrient management with organic and inorganic fertilizers was more profitable and improve soil fertility compared to inorganic fertilizers under dryland condition. Patil (2013) found that higher winter sorghum grain yield of 2020 kg ha^{-1} was attained by RT_1 (2 harrowing + 1 hoeing + hand weeding) compared to minimum yield of 1905 kg

Table: 8
Sustainability yield index and BC ratio attained by tillage and fertilizer treatments

Treatments	Sustainability yield index (%)			Benefit-cost ratio		
	C+S (5, 7, 9)*	S+P (6, 8)#	Pooled	C+S (5, 7, 9)*	S+P (6,8)#	Pooled
CT+FYM @ 5 t ha^{-1}	57.3b	51.2b	54.8 b	1.99b	1.60b	1.84 b
CT+VC @ 3 t ha^{-1}	55.4b	47.3b	52.2 b	1.92b	1.48a	1.74 a
CT+ 50% RDF + FYM @ 2.5 t ha^{-1}	63.7b	50.9b	58.6 b	2.15b	1.61b	1.94 b
CT+ 50% RDF+VC @ 1.5 t ha^{-1}	63.1b	44.7b	55.8 b	2.13b	1.43a	1.85 b
CT+ 100% RDF	70.9c	56.0c	64.9 c	2.38b	1.76b	2.13 b
RT1+FYM@5 t ha^{-1}	53.2b	50.6b	52.2 b	2.30b	3.06c	2.60 c
RT1+VC @ 3 t ha^{-1}	51.4b	46.7b	49.5 b	2.18b	2.69b	2.39 b
RT1+ 50% RDF + FYM @ 2.5 t ha^{-1}	59.7b	50.3b	55.9 b	2.53c	3.04c	2.73 c
RT1+ 50% RDF+ VC @ 1.5 t ha^{-1}	59.1b	44.1b	53.1 b	2.49c	2.61b	2.54 b
RT1+ 100% RDF	66.8c	55.5c	62.3 c	2.82c	3.27c	3.00 c
RT2+FYM@5 t ha^{-1}	47.2a	43.9b	45.8 a	1.83a	2.07b	1.93 b
RT2+ VC@3 t ha^{-1}	45.4a	39.9a	43.2 a	1.75a	1.85b	1.79 b
RT2+ 50% RDF + FYM @ 2.5 t ha^{-1}	53.6b	43.6b	49.6 b	2.01b	2.06b	2.03 b
RT2+50% RDF+ VC @ 1.5 t ha^{-1}	53.0b	37.4a	46.8 a	1.98b	1.78b	1.90 b
RT2+ 100% RDF	60.8b	48.7b	56.0 b	2.25b	2.25b	2.25 b
Mean	57.4	47.4	53.4	2.18	2.17	2.18
CV (%)	12.4	11.1	11.2	13.2	28.4	17.9
Mean - SD	50.3	42.1	47.4	1.89	1.56	1.79
Mean + SD	64.5	52.7	59.3	2.47	2.79	2.57

*C+S = Cotton+soybean (1:1) in 2005, 2007 and 2009; S+P = Soybean+pigeonpea (4:2) in 2006 and 2008

ha^{-1} attained by RT_2 (1 harrowing + 1 hoeing+ herbicide). Among N practices, yield of 2063 kg ha^{-1} was attained by 50% N (organic) + 50% N (urea) compared to 1892 kg ha^{-1} attained by N through organic materials under Vertisols.

4. CONCLUSIONS

Based on a study of tillage and fertilizer management for cotton+soybean (1:1) rotated with soybean+pigeonpea (4:2) in Vertisols at Parbhani, tillage effects were significantly different in all years, while fertilizer effects differed only in 2007 and 2009. The tillage x fertilizer interaction was significant in 2006 and 2008. The model of yield through rainy days and rainfall indicated that CT+100% RDF and RT_1+100% RDF were superior with maximum SYI. Although CT+100% RDF gave maximum yield (1419 kg ha^{-1}), RWUE (1.69 kg ha^{-1} mm^{-1}), SYI (64.9%) and gross returns (₹ 30620 ha^{-1}), RT_1+100% RDF was efficient with low cultivation cost (₹ 9525 ha^{-1}), maximum net returns (₹ 17732 ha^{-1}) and BC ratio (3.0) with at par yield (1367 kg ha^{-1}), SYI (62.3%), RWUE (1.65 kg ha^{-1} mm^{-1}) and output energy (27258 MJ ha^{-1}). RT_1 was superior with maximum increase of pH (10.3%), organic carbon (43.2%), soil N (7.6%) and soil K (565.7%) in 2009 compared to 2005. CT+FYM @ 5 t ha^{-1}, CT+50% RDF+VC @ 1.5 t ha^{-1} and RT_1+50% RDF+VC @ 1.5 t ha^{-1} gave low bulk density; while CT+FYM @ 5 t ha^{-1} and CT+50% RDF+FYM @ 2.5 t ha^{-1} gave high infiltration. CT+FYM @ 5 t ha^{-1} and CT+VC @ 3 t ha^{-1} were superior for minimizing runoff and soil loss. RT_1+FYM @ 5 t ha^{-1}, RT_1+VC @ 3 t ha^{-1}, RT_2+FYM @ 5 t ha^{-1} and RT_2+VC @ 3 t ha^{-1} involved low input energy; while CT+100% RDF, RT_1+100% RDF and RT_2 + 100% RDF gave high output energy; and RT_1 + FYM @ 5t ha^{-1} gave high energy productivity and output: input energy ratio. RT_1 + 100% RDF could be adopted for cotton + soybean (1:1) rotated with soybean + pigeonpea (4:2) to attain maximum CEY, SYI, RWUE, EUE and BC ratio and improve soil fertility in similar conditions.

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