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Tillage and residue management effect on soil properties, crop performance and energy relations in greengram (*Vigna radiata* L.) under maize-based cropping systems

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Abstract

Effect of tillage and crop residue management on soil properties, crop performance, energy relations and economics in greengram (*Vigna radiata* L.) was evaluated under four maize-based cropping systems in an Inceptisol of Delhi, India. Soil bulk density, hydraulic conductivity and aggregation at 0–15 cm layer were significantly affected both by tillage and cropping systems, while zero tillage significantly increased the soil organic carbon content. Yields of greengram were significantly higher in maize–chickpea and maize–mustard systems, more so with residue addition. When no residue was added, conventional tillage required 20% higher energy inputs than the zero tillage, while the residue addition increased the energy output in both tillage practices. Maize–wheat–greengram cropping system involved the maximum energy requirement and the cost of production. However, the largest net return was obtained from the maize–chickpea–greengram system under the conventional tillage with residue incorporation. Although zero tillage resulted in better aggregation, C content and N availability in soil, and reduced the energy inputs, cultivation of summer greengram appeared to be profitable under conventional tillage system with residue incorporation.

Keywords: Cropping systems; Energy; Tillage; Greengram; Yield

1. Introduction

In the Indo-Gangetic plains (IGP) of India, fields remain fallow for 70–80 days during summer after the harvest of winter crops. Short-duration crops like summer greengram (*Vigna radiata* L.) can be grown during this period with assured irrigation. This practice has received wide acceptance among the farmers and has occupied an area of about 1.0 Mha as it provides additional income, improves soil fertility and ensures efficient land utilization (Sharma, Prasad, Singh & Singh, 2000; Sharma & Sharma, 2004). Greengram, a native of the Indian subcontinent, is the third

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most important pulse crop after pigeonpea and chickpea. It is widely used in cuisines of India, China, Myanmar, Sri Lanka, Bangladesh and other south Asian countries. It is a short duration crop, tolerant to photoperiod and thermal variations, and thus has scope for expansion in time and area during spring and summer seasons.

Resource conserving technologies (RCTs) like zero tillage and residue retention have emerged over the past 2–3 decades as a means of achieving the sustainability of intensive cropping systems (Sharma, Jat, Saharawat, Singh and Singh, 2012). In addition to reduction in the cost of cultivation (Malik et al., 2005) and getting stable yields (Abrol & Sangar, 2006), RCTs also improve soil fertility through increased carbon accumulation and biological activity (Ghosh et al., 2010; Bhan & Behera, 2014), and reduce energy inputs (Behera & Sharma, 2011).

Although optimum sowing time for summer greengram in IGP is the 2nd fortnight of March, the sowing is often delayed to mid-April in cereal-based systems after harvest of winter crops. Conventional tillage practices, involving disc harrowing followed by a cultivator treatment for seed-bed preparation, further delay the sowing about 7–10 days. Zero tillage, on the other hand can advance the sowing time, as the crop can be sown without any field preparation through a single tractor operation using specially designed seed-cum-fertilizer drill. For sowing of summer greengram, a presowing irrigation is usually given and after 3–4 days of irrigation, when optimum soil moisture is reached, the crop is sown. Experiences from several locations in IGP showed that with zero-tillage technology, farmers were able to save on land preparation costs by nearly US$50 and diesel consumption by 50–60 l ha^{-1} (Chouhan, Sharma & Chhokar, 2003; Sangar, Abrol & Gupta, 2005).

In this study, the performance of greengram, as a component in maize-based rotations, was evaluated in terms of yield, energy requirement, and economy of cultivation, under conventional and zero tillage with or without residues. Some major soil properties were also studied including soil C and available N content, to identify the best tillage-crop rotation combinations.

2. Materials and methods

Field experiments involving maize (June–October) – mustard/chickpea/linseed/wheat (October–April) – greengram (April–June) were conducted during 2004–2007 on the research farm, Indian Agricultural Research Institute, New Delhi (28.4° N latitude and 77.18° E longitude; altitude of 228 mamsl). Four maize-based cropping systems (main plots) – maize–mustard–greengram (M–M–G), maize–chickpea–greengram (M–C–G), maize–linseed–greengram (M–L–G), and maize–wheat–greengram (M–W–G); and four tillage and residue management practices (subplots) – conventional tillage with residue removed (CT−R), conventional tillage with residue incorporation (CT+R), zero tillage with residue removed (ZT−R) and zero tillage with residue addition as mulch (ZT+R) were applied in split-plot design with 3 replications. Data were collected during the 4th and the last greengram crop (April–June, 2007). The soil (0–15 cm) at the experimental site was sandy loam (63, 12 and 25% sand, silt and clay respectively), pH 7.9, Walkley–Black organic C 3.2 g kg^{-1}, and total N 0.038%; available P and K 9.11 and 258 kg ha^{-1} respectively. Soil bulk density was 1.58 (0–15 cm) and 1.61 (15–30 cm) Mg m^{-3}; and available water capacity (0–100 cm) was 9.8 cm.

The climate is semi-arid and sub-tropical, with extreme hot summers and cool winters. During the period of study, the total rainfall was 124.2 mm, of which 0.0, 40.4 and 83.8 mm was received during April, May and June, respectively. The daily evaporation (USWB class ‘A’ open evaporimeter) ranged from 6.2 to 11.9, 8.0 to 12.4 and

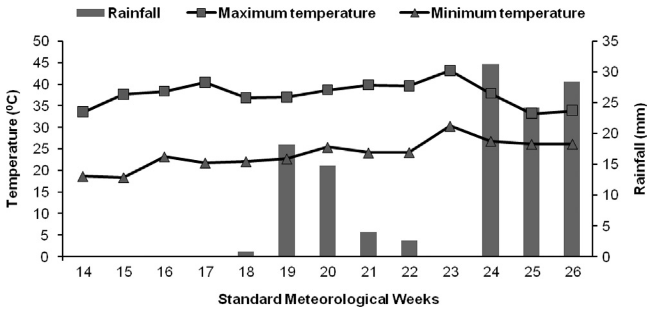

Fig. 1. Temperature and rainfall situations during the crop period (April–June, 2007).

Table 1
Schedule of field operations in greengram during the experiment.

Operation	Days before (DBS) or after (DAS) sowing
Before sowing	
Ploughing of field	10 DBS
Pre-sowing irrigation	5 DBS
Layout of the field	2 DBS
Fertilizer application	At the time of sowing
After sowing	
Bund making	2 DAS
Thinning/gap filling	10 DAS
Irrigation[a]	15 and 31 DAS
Residue incorporation	10 DBS, 2 DAS
Hand weeding	20 DAS and 35 DAS
Measurement of plant height	15, 30, 45 and 60 DAS
Plant dry matter accumulation and LAI	15, 30, 45 and 60 DAS
Picking of pods (1st picking)	58 DAS
Recording of yield attributes	60 DAS
Final harvesting	65 DAS
Threshing	70 DAS

[a] No supplementary irrigations at later stages of crop growth were required, due to rainfall of 0.8, 6.0, 1.6, 10.6, 14.8, 0.4, 3.6, 2.6, 26.0, 5.2, and 24.2 mm at 17, 21, 26, 31, 40, 41, 43, 61, 62, 63 and 71 DAS, respectively.

6.2 to 15.8 mm d^{-1} during these three months, respectively. Mean monthly maximum temperature in June was 46.0 °C; relative humidity ranged from 35.0% to 96% during the cropping season. The mean maximum and minimum temperature and rainfall received during crop period are shown in Fig. 1.

The schedule of field operations is summarized in Table 1. In conventional tillage, after the harvest of preceding crop, plots were ploughed with a disc harrow twice and cultivator twice followed by planking in preparation for sowing the next crop. In zero tillage and conventional tillage plots, summer greengram was sown with a specially designed zero-till seed-cum-fertilizer-planter without any prior tillage operation. The zero-till planter enabled sowing the crop even with crop residues of 5–10 t ha^{-1} on the surface.

Greengram var. “Pusa Vishal” was sown at 20 kg ha^{-1} on April 16, 2007 by the zero-till planter at a depth of 4–5 cm and 30 cm row-to-row spacing with 10 rows per plot. A thinning operation was made at 10 days after sowing to maintain plant to plant distance of 5 cm. In maize crop-residue of greengram was applied at 2.5 t ha^{-1} during the rainy season, while in the rotation involving mustard, linseed, chickpea and wheat, residue of maize was applied at 3.0 t ha^{-1}. In greengram, the crop residues of mustard, linseed and chickpea were applied at 2.5 t ha^{-1}, while wheat residue was applied at 3 t ha^{-1} in respective plots. Fertilizer rates of 20 kg N and 40 kg P_2O_5 ha^{-1} were applied to greengram using urea and single super phosphate at the time of sowing. The recommended dose of fertilizer for linseed, chickpea, mustard and wheat crop was 60:30:30, 20:60:40, 80:40:40 and 120:60:40 kg N, P_2O_5, K_2O ha^{-1}, respectively. Similarly, the maize crop was uniformly fertilized with 120:60:40 kg N, P_2O_5, K_2O ha^{-1} during the rainy season. The field was kept weed-free through hoeing at 20 and 35 days after sowing. All plant-protection measures were taken to maintain the crop healthy and disease-free.

Soil bulk density (ρ_b) was measured by using a core sampler. Three cores were collected from each plot, and ρ_b was determined (Mishra & Ahmad, 1987). The saturated hydraulic conductivity (K_s) at harvest was determined by the constant head method with a permeameter (Mishra & Ahmad, 1987). Aggregate stability was measured using a wet sieving technique (Haynes, 1993) and expressed as the mean weight diameter (MWD, mm) of wet-sieved aggregates. Briefly, 50 g air-dried 2–6 mm soil aggregates were transferred to the top of a set of sieves having 4, 2, 1.0, 0.5 0.25 and 0.1 mm openings, and were mechanically moved up and down at 25 cycles min^{-1} for 15 min. Soil organic C (Oxidizable; SOC) was estimated by the Walkley and Black (1934) method. Soil available and total N were determined using the procedures as given in Prasad, Shivay, Kumar and Sharma (2006).

Fresh green leaves were separated from the stem, cleaned, and leaf area was measured using a leaf area meter (Model LICOR 3000, USA). Leaf area index was calculated as the ratio of leaf area to the average ground area occupied. Plant samples (1 m row) were collected and dried at 70 °C till constant weights were obtained and the dry weights were expressed as g m^{-2}.

Crop growth rate (CGR; g m^{-2} d^{-1}) was calculated as: $CGR=(W_2-W_1)/(t_2-t_1)$, where, W_1 and W_2 are dry weights at t_1 and t_2 DAS, respectively. Similarly, the relative growth rate (RGR) was expressed as the dry weight increase between t_1 and t_2 in relation to the initial weight, W_1: $RGR=(\mathrm{Log_e}W_2-\mathrm{Log_e}W_1)/(t_2-t_1)$

Observations were recorded on root length, dry weight and volume at 40 DAS using standard procedures (Mishra & Ahmad, 1987). Blocks of soil up to 30 cm depth with plant roots were taken out from five random places. Roots were washed, detached from the main stem at the first node, and length (cm) was measured from crown part to root tip. Root volume was measured following the water displacement method. Ten representative roots were taken and dipped in a measuring cylinder filled with water. The quantity of water displaced was taken as root volume (cm^3). Roots were dried at 70 °C and dry weight (g) was calculated.

The number of pods was counted at harvesting and average value was expressed as pods $plant^{-1}$. Twenty pods were selected and the number of seeds was recorded and expressed seeds pod^{-1}. One thousand seeds were counted by a seed counter, weighed and expressed as 1000-seed weight. Bundle weight of the finally harvested plants was taken after sun-drying but before threshing. Stover yield was calculated after subtracting the seed yield, and expressed in kg ha^{-1}. The weight of fallen leaves was not accounted for in the total biomass production.

Representative seed samples were taken from each plot, oven-dried and ground in a mini-grinder. Similarly, the stover samples were ground into finer pieces. Nitrogen concentration was estimated by the modified Kjeldahl method. The uptake of N by seed and stover at maturity was computed by multiplying the biomass with the respective N concentration.

The energy requirement for cultivation was estimated in terms of renewable and non-renewable energy. Renewable energy components were manual, animal/bullock drafts, seeds, and manure, while chemical fertilizers

Table 2
Energy equivalents for different inputs and outputs.Source: Mittal and Dhawan (1988)

Particulars	Units	Equivalent energy (MJ)
A. Input		
1. Human labor		
(a) Adult man	Man-hour	1.96
(b) Woman	Woman-hour	1.57
3. Diesel	L	56.31
5. Electricity	KW h	11.93
6.Machinery		
(a) Electric motor	kg	64.8
(b) Farm Machinery including self propelled machines	kg	62.7
7. Chemical fertilizer		
(a) Nitrogen	kg	60.60
(b) Phosphate (P_2O_5)	kg	11.1
(c) Potash (K_2O)	kg	6.7
9. Chemicals		
(a) Superior chemicals	kg	120
10. Seed	As output of crop production system	
B. Output		
I. Main product		
(a) Greengram grain	kg	14.7
II. By product		
(a) Stover	kg	12.5

(NPK), tractor, diesel, electricity, lubricants, machinery, and agro-chemicals constituted the non-renewable energy inputs. The physical output was related to both grain and straw yields. The energy values for inputs (e.g. seeds, fertilizer and labor) and outputs (grain and stover) were estimated using energy equivalents as recommended by Singh, Pal, Thakur and Verma (1997) and Mittal and Dhawan (1998). The details on energy equivalents are given in the Table 2.

The following energy parameters were calculated as suggested by Singh et al. (1997).

(1) Energy efficiency = [Energy output (MJ ha^{-1})/Energy input (MJ ha^{-1})]
(2) Net energy (MJ ha^{-1}) = [Energy output (MJ ha^{-1}) − Energy input (MJ ha^{-1})]
(3) Energy productivity (kg MJ^{-1}) = [Output (grain + stover) (kg ha^{-1})/Energy input (MJ ha^{-1})]
(4) Energy intensity (in physical terms, MJ kg^{-1}) = [Energy output (MJ ha^{-1})/Output (grain + stover) (kg ha^{-1})]
(5) Energy intensity (in economic terms, MJ Rs^{-1}) = [Energy output (MJ ha^{-1})/Cost of cultivation (Rs ha^{-1})] [Rs is Indian Rupee]

The gross and net returns and benefit:cost ratio (gross returns per rupee invested) was calculated on the basis of existing rate of inputs and output. Total variable cost included the cost of inputs such as seeds, fertilizers, irrigation and cultural operations like ploughing, sowing, weeding, harvesting and threshing, and so on.

(1) Gross returns = Price of greengram seed + price of greengram stover;
(2) Net returns = Gross returns − total variable costs;
(3) Benefit:cost ratio = Gross returns/total variable cost.

The data were analyzed through standard analysis of variance (ANOVA) for split-plot design using MSTAT-C software. Results are presented at 5% level of significance (P = 0.05).

Table 3
Soil properties as influenced by cropping system and tillage and residue management practice.

Treatment	Depth (cm)						
	ρ_s (Mg m^{-3})		K_s (cm h^{-1})		MWD (mm)	SOC (g kg^{-1})	
	0–15	15–30	0–15	15–30	0–15	0–15	15–30
Cropping system							
M–M–G	1.50	1.59	1.55	1.38	0.68	3.38	2.25
M–C–G	1.53	1.62	1.70	1.40	0.70	4.03	2.65
M–L–G	1.63	1.65	1.50	1.50	0.64	3.30	2.23
M–W–G	1.62	1.68	1.49	1.50	0.68	3.33	2.48
SEm ±	0.01	0.03	0.10	0.04	0.05	0.31	0.22
CD (P = 0.05)	0.04	NS	0.36	0.14	NS	0.48	NS
Tillage and residue management							
CT − R	1.58	1.63	0.74	0.73	0.54	2.73	2.30
CT + R	1.50	1.68	1.36	0.40	0.66	3.58	2.48
ZT − R	1.65	1.62	0.89	0.81	0.72	3.38	2.65
ZT + R	1.59	1.61	1.26	1.13	0.74	4.35	2.15
SEm ±	0.02	0.03	0.07	0.04	0.03	0.29	0.16
CD (P = 0.05)	0.09	NS	0.20	0.13	0.05	0.62	NS

MWD, Mean Weight Diameter; SOC, Soil Organic Carbon.

3. Results and discussion

The short-term (3 years) changes may not actually stay over a long-period, but could be indicator of the direction of changes. Cropping systems and tillage had significant impact on soil bulk density at 0–15 cm only (Table 3). It was lower in M–M–G and M–C–G, and with the residue addition under zero tillage. This is similar to results from Mondal et al. (2013) where residue addition resulted in lowering the bulk density under similar type of soils. The saturated hydraulic conductivity was marginally higher in M–C–G in the 0–15 cm layer, but residue addition increased the conductivity under both conventional and zero tillage systems. Soil aggregation (0–15 cm) was not affected by cropping systems, but it was affected by tillage. The ZT+R and ZT−R had 12 and 33% larger MWD than CT+R and CT−R, respectively indicating tillage effect dominating over the residue addition.

Cropping systems influenced the soil organic C changes in the 0–15 cm layer. The M–C–G resulted in 19, 21 and 22% higher C than M–M–G, M–W–G and M–L–G systems, respectively. As a legume crop, chickpea was more efficient in raising the level of soil C. The highest C content was recorded in ZT+R, where residue addition had a clear advantage. Similarly, the tillage effect was significant at the 0–15 cm layer only, with highest increase in C under ZT+R. The residue addition resulted in improvement of soil C content in the plough layer, resulting in lowering the bulk density or increasing the conductivity. Residue addition improved soil aggregation more in conventional than zero tillage (Mondal et al., 2013). The organic C content increased soil aggregation, as has been reported extensively in Indian soils (Bandyopadhyay, Misra, Ghosh & Hati, 2010; Kumari et al., 2011; Mondal et al., 2013; Das et al., 2014). The effect of conservation tillage on enhancing SOC sequestration has been reported by several researchers (Lal, 1994; Potter, Jones, Tolbert & Onger, 1997; Lal, 1999; Post & Kwon, 2000).

In this study, zero tillage resulted in a net increase of 16–27% in soil C content over conventional tillage. Ploughing disturbs the soil and promotes oxidation of organic C in soils. Studies reported 30–60% of C depletion due to cultivation in the subtropical regions of India (e.g. Swarup, Maana & Singh, 2000; Lal, 2004). A net increase in SOC content was observed with crop residues under both zero and conventional tillage. This was obviously associated with a large amount of crop residues and root biomass C in residue-added plots, which significantly improved the yield of crops (Mandal et al., 2008).

The dry weight and volume of greengram roots were significantly higher in M–W–G (Table 4). Zero till resulted in better root biomass and volume, but it significantly reduced root length, possibly due to higher bulk density at 0–

Table 4
Root parameters in summer greengram crop as influenced by cropping system and tillage and residue management.

Treatment	Root parameter at 40 DAS		
	Length (cm)	Dry weight (g)	Volume (cm^3)
Cropping system			
M–M–G	13.92	0.351	1.775
M–C–G	14.06	0.356	1.858
M–L–G	13.75	0.305	1.425
M–W–G	13.62	0.445	2.133
SEm ±	0.225	0.006	0.027
CD (P=0.05)	0.78	0.019	0.093
Tillage and residue management			
CT−R	15.45	0.364	1.875
CT+R	14.87	0.320	1.467
ZT−R	13.30	0.382	1.958
ZT+R	12.72	0.391	1.892
SEm ±	0.405	0.001	0.046
CD (P=0.05)	1.182	0.033	0.135

Table 5
Dry matter accumulation (g m^{-2}), leaf area index, absolute and relative crop growth rate (CGR and RGR in g m^{-2} d^{-1}) in summer greengram under maize-based cropping systems and tillage and residue management practices.

Treatment	DAS														
	Dry matter accumulation				Leaf area index			Crop growth rate				Relative growth rate			
	15	30	45	60	15	30	45	0–15	16–30	31–45	46–60	0–15	16–30	31–45	46–60
Cropping system															
M–M–G	7.688	56.11	361.1	407.8	0.149	1.326	3.805	0.513	3.200	12.68	9.746	0.036	0.318	0.270	0.108
M–C–G	8.805	58.16	269.0	457.3	0.144	1.220	3.691	0.587	3.200	13.52	13.08	0.048	0.318	0.420	0.960
M–L–G	8.210	54.61	190.1	385.2	0.130	1.089	3.587	0.547	3.113	9.025	14.40	0.036	0.312	0.246	0.132
M–W–G	9.605	57.88	254.6	400.8	0.140	1.121	3.638	0.640	3.253	14.15	7.766	0.060	0.324	0.270	0.060
SEm ±	0.583	1.836	7.665	7.664	0.006	0.058	0.042	0.033	0.133	0.660	0.786	0.006	0.012	0.066	0.018
CD (P=0.05)	NS	NS	26.52	26.52	NS	NS	NS	NS	NS	2.284	2.719	NS	NS	NS	NS
Tillage and residue management															
CT−R	7.671	62.88	241.9	367.6	0.137	1.140	3.688	0.507	3.713	11.92	8.292	0.024	0.354	0.384	0.078
CT+R	10.23	72.55	264.4	467.0	0.157	1.337	3.872	0.680	4.126	12.89	13.50	0.066	0.336	0.216	0.960
ZT−R	7.849	45.11	219.2	386.3	0.120	1.049	3.402	0.519	2.480	11.04	11.14	0.042	0.276	0.300	0.960
ZT+R	8.555	46.22	249.4	430.3	0.150	1.231	3.758	0.560	2.533	13.53	12.05	0.042	0.288	0.288	0.132
SEm ±	0.475	2.808	9.926	10.54	0.007	0.044	0.054	0.027	0.173	0.680	0.946	0.006	0.012	0.078	0.012
CD (P=0.05)	1.211	8.194	28.97	30.76	0.020	0.128	0.159	0.041	0.505	NS	2.761	0.024	0.036	NS	NS

15 cm layer, which prevented roots to extend down the profile. This also suggests that soil compaction results in less fine but more bulky roots, as evidenced by increased root weight and volume in zero tillage.

Performance of greengram was better in rotation with maize–chickpea or maize–mustard combinations (Table 5). Leaf area and dry matter were superior in M–C–G system. This could be due to improvement in soil fertility when chickpea was introduced in the nutrient exhaustive cereal systems, and the allelopathic effects in soil after cultivation of linseed. Dry matter accumulations were significantly lower in zero tillage, possibly because soils at plough layer depth become compact in the initial years of zero tillage, and this might have adverse effect on root and plant growth. Better crop growth and yield under conventional tillage as compared to zero tillage have been reported earlier (Sharma, De Datta & Redulla, 1999; Sangakkara, 2007). Residue incorporation under conventional tillage was the most effective in improving seed yield of greengram, while removal of the same in zero tillage had adverse impacts. It is apparent that benefits of zero tillage are accrued only when residues are retained as mulch over the soil. Moreover, chickpea residues with low C:N ratio improved soil properties, resulting in higher yields. The effect of mustard was manifested through its deep root system and therefore, yields of summer greengram were better. The yield improvement in conventional over zero tillage was 25–35%, depending upon the residue addition. However, germination of greengram was not significantly influenced due to tillage practices.

While N concentration in grain was impacted by the cropping system, tillage had impact only on stover N concentration (Table 6). The N concentration in grains was higher in M–C–G, and the lowest in the M–W–G system. The concentration was maximum in CT+R, and the lowest in the ZT−R treatment. Residue addition resulted in higher N concentration in stover and grains under both tillage practices.

The N-uptake by the crop followed a nearly similar pattern. The highest uptake of 35.91 kg ha^{-1} in grain and 77.76 kg ha^{-1} in stover were recorded in M–C–G. Although residue addition improved the N-uptake by the crop, tillage possibly helped in greater N-mineralization from the residues, resulting in higher grain and stover N in CT+R. Residue additions also improved the total N, C and other nutrients content in soil, which resulted in higher N uptake. The cereal–cereal rotation depleted soil N.In cereal–legume rotation like M–C–G, the biological N-fixation probably enhanced the availability of N (Halvorson, Wienhold & Black, 2002). Even in the sub-layer, the availability

Table 6
Yield attributes and yields, N concentration and uptake in summer greengram under different cropping systems, and tillage and residue management practices.

Treatment	Number of			1000-seed weight (g)	kg ha^{-1}				N concentration (%)		N uptake (kg ha^{-1})		
	Pods plant^{-1}	Grains pod^{-1}	Branches plant^{-1}		Yield of		Biological yield	Harvest index	Grain	Stover	Grain	Stover	Total
					Seed	Stover							
Cropping system													
M–M–G	15.20	8.10	3.100	42.17	844.3	2764	3608	0.230	3.511	1.247	30.08	35.04	65.12
M–C–G	15.23	8.13	2.900	44.61	899.2	3389	4116	0.218	4.022	1.239	35.91	41.85	77.76
M–L–G	12.53	8.03	3.025	46.48	694.7	2772	3467	0.201	3.463	1.202	24.26	32.63	56.89
M–W–G	14.65	7.95	3.750	44.17	769.2	2902	3671	0.208	2.945	1.264	22.92	36.73	59.65
SEm ±	0.598	0.04	0.062	1.457	32.15	92.05	68.98	0.0145	0.198	0.066	2.001	2.100	3.082
CD (P=0.05)	NS	0.14	0.217	NS	111	318.4	238.7	NS	0.686	NS	6.923	NS	10.63
Tillage and residue management													
CT−R	14.17	8.08	2.800	43.61	752.7	2733	3486	0.215	3.429	1.300	26.66	35.50	62.16
CT+R	16.00	8.19	3.300	44.77	1062.2	3136	4200	0.253	3.607	1.358	38.16	42.10	80.26
ZT−R	13.65	7.99	3.275	44.30	602.7	2874	3477	0.176	3.316	1.138	20.10	32.83	52.93
ZT+R	13.80	8.00	3.400	44.76	789.7	3083	3873	0.205	3.587	1.158	28.25	35.23	63.48
SEm ±	0.62	0.03	0.142	0.87	34.73	95.32	94.88	0.0115	0.189	0.049	2.291	1.522	2.728
CD (P=0.05)	1.80	0.09	0.414	NS	101.3	278.1	189.4	0.0335	NS	0.142	6.687	4.442	7.962

Table 7
Energy relations in greengram based cropping systems as affected by tillage and residue management.

Treatment	Energy requirement (MJ)	Energy output (MJ ha^{-1})			Net energy (MJ ha^{-1})	Energy efficiency	Energy productivity (kg MJ^{-1})	Energy intensity	
		Grain	Stover	Total				Physical (MJ kg^{-1})	Economic (MJ Rs^{-1})
Cropping system									
M–M–G	23,676	12,410	34,547	46,957	23,281	3.335	0.257	13.01	3.899
M–C–G	23,676	13,218	42,363	55,581	31,905	4.123	0.319	12.96	4.464
M–L–G	23,676	10,212	34,654	44,866	21,190	3.120	0.241	12.94	3.810
M–W–G	26,913	11,307	36,273	47,580	20,666	3.281	0.254	12.96	3.598
SEm ±		472.7	1151	1337	1377	0.126	0.010	0.02	0.109
CD (P=0.05)		1636	3981	4628	4628	0.435	0.036	NS	0.379
Tillage and residue management									
CT−R	8756	11,064	34,163	45,227	36,471	5.165	0.398	12.97	3.859
CT+R	41,705	15,615	39,203	54,818	13,113	1.319	0.101	13.06	4.020
ZT−R	7322	8859	35,929	44,788	37,466	6.117	0.475	12.89	4.013
ZT+R	40,158	11,608	38,541	50,150	9991	1.257	0.097	12.95	3.878
SEm ±		510.6	1191	1209	1209	0.129	0.010	0.02	0.104
CD (P=0.05)		1490	3477	3529	3529	0.376	0.029	0.06	0.302

Table 8
Economics of summer greengram cultivation in different cropping systems and tillage practices and residue management (Rs 65 ≡ 1 USD).

Treatment	Gross returns (Rs ha^{-1})			Cost of production (Rs ha^{-1})	Net returns (Rs ha^{-1})	Benefit:cost ratio
	Grain Rs ha^{-1}	Stover	Total			
Cropping system						
M–M–G	25,327	691	26,018	12,020	13,998	2.138
M–C–G	26,975	847	27,822	12,520	15,302	2.219
M–L–G	20,840	693	21,533	11,757	9775	1.822
M–W–G	23,075	725	23,800	13,320	10,480	1.774
SEm ±	964.8	23.01	970.1		970.1	0.071
CD (P=0.05)	3338	79.62	3357		3357	0.245
Tillage and residue management						
CT−R	22,580	683	23,263	11,720	11,543	1.985
CT+R	31,867	784	32,651	13,686	18,965	2.411
ZT−R	18,080	718	18,798	11,160	7638	1.684
ZT+R	23,690	771	24,461	13,051	11,409	1.872
SEm ±	1042	23.83	1038		1038	0.082
CD (P=0.05)	3041	69.54	3029		3029	0.240

of N increased in M–C–G, in comparison to other cropping systems. Chickpea, being a deep-rooted (tap root) crop, possibly improved N availability even in the sub-surface layer.

The net energy and the use efficiency (output–input ratio) were significantly higher in M–C–G (31,905 MJ ha^{-1}) than the other cropping systems (Table 7). The lowest net energy was obtained in M–W–G, while the energy efficiency was the lowest in M–L–G cropping system. With no residues, net energy was higher in zero tillage (37,466 MJ), but with addition of residues, conventional tillage had higher net energy. However, the lowest energy efficiency was obtained where residue was retained in the soil, with marginally higher efficiency in CT+R.

The energy productivity was significantly different among cropping systems, and strongly influenced by tillage practices. The highest energy productivity (0.319 kg MJ^{-1}) was obtained in the M–C–G cropping system, while the rest were statistically similar. The highest energy productivity was recorded when residue was removed (0.475 and 0.398 kg MJ^{-1})in ZT and CT, respectively, but it declined sharply when it was retained in the system. Energy intensity in economic terms (energy consumed per rupee of investment) was significantly higher in M–C–G (4.464 MJ Rs^{-1}), but was similar in physical terms (energy per unit of grain yield). In physical terms, CT+R had significantly higher energy intensity, although in economic terms, it was similar among tillage and residue management practices.

Zero tillage offers farmers one of a great opportunity to reduce energy inputs in crop production. For example, tillage is eliminated ~~in zero tillage~~, and energy conserved as a consequence (Behera & Sharma, 2011), although some of the conserved energy is offset by the use of herbicides. In this study, conventional tillage plots were ploughed twice with a disc harrow followed twice by cultivator. In zero tillage, these practices were obviously avoided, which reduced the energy requirement by 19.5%. The energy requirement in M–W–G was 13.6% higher due to application of 0.5 t ha^{-1} of additional wheat residues in this treatment.

Difference in grain and stover yields contributed to the variation in energy output. It was 23.9% higher in the M–C–G compared to the M–L–G cropping system. The net energy and the energy productivity were also higher in M–C–G. The M–W–G involved the highest energy input and output, resulting in low energy efficiency and productivity, as also reported by Mandal, Saha, Ghosh, Hati and Bandyopadhyay (2002). The energy output was highest with residue addition in both tillage systems, but the effect was higher under conventional tillage. The net energy, yield, and energy efficiency were lower where residues were applied. Since crop residues also have energy values, their addition in large quantities makes the system energy-inefficient. The energy productivity also followed a similar pattern. Energy consumed per rupee of investment was also highest in M–C–G and lowest in M–W–G, although the energy intensity values in this study is higher compared to those reported by Mandal et al. (2002). Residues at 2.5–3.0 t ha^{-1} were added in our experiments, which was not the case with Mandal et al. (2002). The energy intensity in economic terms was the highest in CT+R and the lowest in CT−R. The ZT+R and CT+R practices were more energy intensive and less energy efficient and energy productive, due to higher rates of residue application in the cropping systems.

Summer greengram is a short duration crop, grown between the winter and rainy seasons; it matures in 60–70 days. Another advantage is that inclusion of greengram in the rotation involves low investment. The cost of cultivation varied between Rs. 11,757 and 13,320 among cropping systems and Rs. 11,160 and 13,686 among tillage practices (Table 8). Residue application increased the cost of production by 16.8% in conventional tillage and 13.7% in zero tillage conditions. The variation is attributed by the cost of residues, e.g. wheat residue cost was the highest (Rs. 1200 t^{-1}), while the cost of linseed was minimum (Rs. 250 t^{-1}).

Economic returns from grains and straw differed substantially among the cropping and tillage systems. The highest gross and net returns from grains and straw were recorded in M–C–G, while the lowest returns came from M–L–G. Looking only at the cultivation treatments, the highest returns were obtained from CT+R, while ZT−R returned the lowest. Contribution of straw to gross income was negligible (3.1%). Residue application generated significantly higher income due to better soil fertility which augmented the yields and returns, although the part of returns was reduced by the cost of crop residues. In a study at New Delhi, Dodwadiya and Sharma (2012) reported a similar cost of production, net returns and benefit:cost ratio from summer greengram under different tillage practices. In conventional tillage system, residue retention could significantly increase the benefit:cost ratio. However, it had no effect in zero tillage.

4. Conclusions

Inclusion of summer greengram in a maize–chickpea system could be a viable option for obtaining higher crop productivity, improving soil fertility, and increasing energy efficiency. This is closely followed by maize–mustard–greengram system. Cultivation of summer greengram was most profitable under conventional tillage with crop residue addition. Zero tillage, however, provides other advantages. Cropping systems under zero tillage are more environment-friendly (contributing better soil aggregation, C accumulation and N availability) and economically sustainable (energy saving), although the productivity and economic return may be less.

The impact of tillage in this study is short-term, and the systems are yet to reach equilibrium. Although results may vary in the long-run, the short-term changes provide an indication of the direction of changes, and a useful notion on the advantages and limitations in adopting specific agronomic management practices.

References

Abrol, I. P., & Sangar, S. (2006). Sustaining Indian agriculture-conservation agriculture the way forward. *Current Science*, *91*(8), 1020–2015.

Bandyopadhyay, K. K., Misra, A. K., Ghosh, P. K., & Hati, K. M. (2010). Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soilless and Tillage Research*, *110*, 115–125.

Behera, U. K., & Sharma, A. R. (2011). Effect of conservation tillage on performance of greengram–mustard–cowpea cropping system. *Journal of Soilless and Water Conservation*, *10*(3), 233–236.

Bhan, Suraj, & Behera, U. K. (2014). Conservation agriculture in India – problems, prospects and policy issues. *International Soilless and Water Conservation Research*, *2*(4), 1–12.

Chouhan, D. S., Sharma, R. K., & Chhokar, R. S. (2003). New paradigms in tillage technology for wheat production. *Indian Journal of Agricultural Sciences*, *73*, 402–406.

Das, B., Chakraborty, D., Singh, V. K., Aggarwal, P., Singh, R., Dwivedi, B. S., & Mishra, R. P. (2014). Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate-associated carbon content in an intensive rice–wheat system. *Soilless and Tillage Research*, *136*, 9–18.

Dodwadiya, K. S., & Sharma, A. R. (2012). Effect of tillage and method of sowing on performance of greengram (*Vigna radiata*) varieties during summer and rainy seasons. *Indian Journal of Agricultural Sciences*, *82*(5), 462–465.

Ghosh, P. K., Das, A., Saha, R., Kharkrang, E., Tripathy, A. K., Munda, G. C., & Ngachan, S. V. (2010). Conservation agriculture towards achieving food security in north east India. *Current Science*, *99*(7), 915–921.

Halvorson, Ardell D., Wienhold, Brian J., & Black, Alfred L. (2002). Tillage, nitrogen and cropping system effects on soil carbon sequestration. *Soilless Science Society of America Journal*, *66*, 906–912.

Haynes, R. J. (1993). Effects of sample pre-treatment on aggregate stability measured by wet sieving of turbidimetry on soils of different cropping history. *Journal of Soilless Science*, *44*, 261–270.

Lal, R. (1994). Soil carbon sequestration to mitigate climate change. *Geoderma*, *123*, 1–22.

Lal, R. (1999). World crop land soils as a source and sink for atmospheric carbon. *Advances in Agronomy*, *71*, 145–175.

Lal, R. (2004). Soil carbon sequestration in India. *Climate Change*, *65*, 277–296.

Malik, R. K., Gupta, R. K., Singh, C. M., Yadav, A., Brar, S. S., Thakur, T. C....Sinha, R. K. (2005). Accelerating the adoption of resource conservation technologies in rice wheat system of the indo-gangetic plains. In *Proceedings of the project workshop, directorate of extension education*, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), June 1–2, 2005. Hisar, India: CCSHAU.

Kumari, Mamata, Chakraborty, D., Gathala, M. K., Pathak, H., Dwivedi, B. S., Tomar, R. K., … Ladha, J. K. (2011). Soil aggregation and associated organic C fractions as affected by tillage in a rice–wheat rotation in north India. *Soilless Science Society of America Journal*, *75*(2), 560–567.

Mandal, B., Majumdar, B., Adhya, T. K., Bandyopadhyay, P. K., Bandyopadhyay, A., Sarkar, D., … Mishra, A. K. (2008). Potential of double cropped rice ecology to conserve organic carbon under sub-tropical climate. *Global Change Biology*, *14*, 1–13.

Mandal, K. G., Saha, K. P., Ghosh, P. K., Hati, K. M., & Bandyopadhyay, P. K. (2002). Bioenergy and economic analysis of soybean-based crop production system in central India. *Biomass and Bioenergy*, *23*, 337–345.

Mishra, R. D., & Ahmad, M. (1987). *Manual on irrigation agronomy*. New Delhi, India: Oxford and IBH Publishing Co. Pvt. Ltd.

Mittal, J. P., & Dhawan, K. C. (1988). *Research manual on energy requirements in agricultural sector* (pp. 20–23)New Delhi: ICAR20–23.

Mondal, S., Chakraborty, D., Tomar, R. K., Singh, R., Garg, R. N., Aggarwal, P., … Behra, U. K. (2013). Tillage and residue management effect on soil hydro-physical environment under pigeonpea (*Cajanus cajan*)–wheat (*Triticum aestivum*) rotation. *Indian Journal of Agricultural Sciences*, *83*, 502–507.

Post, W. M., & Kwon, K. C. (2000). Soil carbon sequestration and land use change: processes and potential. *Global Change Biology*, *6*, 317–327.

Potter, K. N., Jones, O. R., Tolbert, H. A., & Onger, P. W. (1997). Crop rotation and tillage effects on organic carbon sequestration in the semi-arid southern great plains. *Soilless Science*, *162*, 140–147.

Prasad, R., Shivay, Y. S., Kumar, D., & Sharma, S. N. (2006). Learning by doing exercises in soil fertility (a practical manual for soil fertility) 2006. In *Proceedings of the division of agronomy*. New Delhi: Indian Agricultural Research Institute, p. 68.

Sangakkara, U. K. (2007). Effect of tillage and moisture levels on growth, yield and nodulation of common bean (*Phaseolus vulgaris*) and mungbean (*Phaseolus radiata*) in the dry season. *Indian Journal of Agronomy*, *49*, 60–63.

Sangar, S., Abrol, I. P., & Gupta, K. K. (2005). Conservation agriculture: conserving resource enhancing productivity. In *Proceedings of the centre for advancement of sustainable agriculture*. New Delhi: NAAS complex.

Sharma, A. R., Jat, M. L., Saharawat, Y. S., Singh, V. P., & Singh, R. (2012). Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. *Indian Journal of Agronomy*, *57*, 131–140. IAC Special Issue.

Sharma, P. P., De Datta, S. K., & Redulla, C. A. (1999). Response of maize (*Zea mays* L.) and mungbean (*Vigna radiata* L.) to tillage in relation to water table depth in tropical lowland rice soils. *Soilless and Tillage Research*, *12*, 65–79.

Sharma, S. K., & Sharma, S. N. (2004). Effect of cropping and nutrients applied to preceding crops on yield, nutrient uptake and economics of mungbean. *Indian Journal of Pulses Research*, *17*(2), 138–142.

Sharma, S. N., Prasad, R., Singh, S., & Singh, R. K. (2000). Influence of summer legumes in rice–wheat cropping system on soil fertility. *Indian Journal of Agricultural Sciences*, *70*, 300–306.

Singh, M. K., Pal, S. K., Thakur, R., & Verma, V. N. (1997). Energy input–output relationship of cropping systems. *Indian Journal of Agricultural Sciences*, *67*, 262–264.

Swarup, A., Maana, M. C., & Singh, G. B. (2000). Impact of land use and management practices on organic carbon dynamics in soil of India. In: R. Lal, J. M. Kimble, & B. A. Stewart (Eds.), *Global climate change and tropical ecosystems, advances in soil science* (pp. 261–281). Boca Raton, FL: CRC Press.

Walkley, A., & Black, C. A. (1934). An examination of Degtjareff methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soilless Science*, *37*, 29–38.