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Research Paper

Influence of reduced nutrient levels on productivity, profitability and resource-use efficiency of rainfed pigeonpea (*Cajanus cajan*) under resource-conservation practices

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ABSTRACT

Rising cost of fuel and availability of effective package of practices for conservation tillage have now redefined the tillage practices in India in recent past. Hence an experiment was carried out with pigeonpea [*Cajanus cajan* (L.) Millsp.] with an objective of minimizing the inputs originating from non-renewable energy resources like fertilizer and diesel on a permanent site with 5 main-plot treatments, viz. zero-till (ZT) flat bed (FB) and zero-till (ZT) raised-bed (RB), in that with or without residue retention and conventional tillage (CT) practice, subplots with reduced recommended fertilizer dose (RDF). Resource-conservation practice of ZT-RB with crop-residue retention (CRR) along with 100% RDF recorded higher soil-moisture content at all the growth stages than the other practices, which helped plant to produce higher growth characters and SPAD readings and these in turn increased yield parameters like pods, seed weight/plant. Finally, seed yield (1.29 t/ha) and straw yield (4.61 t/ha) were significantly higher in ZT-RB with CRR than the other practices. Energy and economics showed that the ZT-RB with CRR along with RDF incured lower input energy and cost of cultivation. The gross (₹73,104/ha) and net returns (₹49,992/ha) and seed output energy (19,612 MJ/ha) were higher in ZT-RB with CRR along with 100% RDF, but remained at par with 75 and 50% RDF. Looking at sustainable yield index, energetic and economics in resource-conservation practice of ZT-RB with CRR, the nutrient requirement can be reduced up to 50% RDF.

Key words: Pigeonpea, Zero tillage, Nutrients, Sustainable yield index, Energy, Economics.

Conservation-agriculture (CA) practices serve as an alternative strategy to sustain agricultural production due to the growing resource degradation problems, particularly under rainfed conditions (Bana *et al*., 2016; Singh *et al*., 2021). Dryland agriculture is prominent in India, accounting for about 56% of the total cropped area and contributes ~87.5% pulses to the country's total production. The rainfed lands are also the areas that are prone to the ill-effects of climate change and experience hardships like drought and frequent crop failures. In South India, of late conservation agriculture is getting popular in the Deccan Plateau in rice–rice system with the second crop of rice getting replaced by maize. However, major bottlenecks in adopting conservation agriculture in semi-arid tropics under dryland conditions is due to insufficient amount of residues, water shortage, degraded nature of soil resource and resource-poor smallholder farmer. Conservation agriculture has potential for conserving the resources and enhancing productivity to achieve the goals of sustainable agriculture (Singh *et al*., 2016, 2020). Zero/minimum tillage practices can be an alternative over traditional tillage practices because of their potential to reduce production costs, less energy requirement, less weed problem, better crop residues management and higher or equal yield and benefit for the environment (Prasad *et al.,* 2016; Harish *et al*., 2021a). The retained surface crop residues increase the soil porosity and organic carbon. Residues mulch relieves water stress by reducing evaporation from the soil and keeping the surface soil moist during dry spells (Choudhary *et al*., 2020). Pigeonpea is a crop of rainfed and marginal environments, hence nutrient requirement and response are highly variable (Varatharajan *et al*., 2019a). Low efficiency in the uptake of fertilizer is another major factor that aggravates the negative environmental effects. The problems of

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rainfed areas of northern Karnataka are more diverse and intricate. Therefore, top priority is to be given for conservation of natural resources to sustain crop production. Hence, a field experiment was conducted with the objective of assessing the effect of long-term resource-conservation practices of zero tillage and residue management on productivity, profitability, resource-use efficiency and energetics of pigeonpea and their effect on reducing the fertilizer doses as well.

MATERIALS AND METHODS

A experiment was conducted in Diggi block at Agriculture Research Station, Bheemarayanagudi, (which comes in North Eastern Dry Zone (Zone-2) of Karnataka), University of Agricultural Sciences, Raichur (16° 72' N; 76° 79', 412 m altitude). No tillage operations were followed since 2009 in resource conservation plots. The soil was red sandy loam of the order Alfisols. The rainfall received during 2015 was 437.6 mm, being 17.1% lower average, and during 2016 was 398.2 mm, being 24% lower than average. The details of the experiment with regard to treatments are given in Table 1, where strip-plot design was used with 3 replications. One outside control plot was laid out wherein all operations were same as conventional tillage practice except for the addition of 6 t of FYM/ha which was incorporated before final harrowing. Pigeonpea genotype 'TS 3R' (12.5 kg/ha) was sown with help of tractor-drawn zero-till machine at 90-cm-row distance on all tillage plots and conventional tillage practice. Weeds were managed with pre-emergence herbicide pendimethalin 38.7 CS, and post-emergence herbicide Imazethapyr 10% SL in CA plots and inter-cultivation in conventional plots. The prophylactic measures were undertaken against pigeonpea pod-borer based on economic threshold level (ETL).

Five plants were tagged at random from net plot area for recording growth observations and at maturity same plants were used for recording yield parameters. The chlorophyll content was measured with help of SPAD chlorophyll meter. The PVC pipes were cut at a length of 20 cm and 40 cm and were installed at mid of inter-row at 45 cm away from plants in net plot by digging hole with help of power augar and covered with cap. Soil-moisture content ($è_v$) was measured with help of time domain reflectometer (TDR), which was calibrated through gravimetric method. The TDR was installed at different depth like 0–20 cm and 20–40 cm depth at branch formation, flowering, mid-pod formation and maturity. One square meter area was marked and white plastic sheet was spread and on all sides weight was placed to safeguard it from wind. Leaf litter was collected from this 1 m^2 area was weighed and litter yield per ha (kg/ha) worked out. Seed and stalk yields in each net plot were weighed after threshing separately and converted to ha basis (Varatharajan *et al*., 2019a). Sustainable yield index (SYI) was computed as per Paul *et al.* (2016).

Economics was calculated using standard procedures (Kumar *et al*., 2019). Energy requirement for a particular field operation was calculated as the summation of human, bullock and mechanical and/or electric energy consumed. The calculation of energy requirement, the particulars which are taken for calculation of energy requirement were calculated as described by Devasenapathy *et al.* (2009). The data collected from the experiment were analysed statistically as per Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Growth and yield attributes

Conservation agricultur (CA) practices differed significantly with growth parameters at all the stages of crop in pooled data. Significantly higher plant height (137.1 cm), primary branches/plant (10.5), leaf area (23.08 dm^2/plant**)**, leaf-area index (1.71) were recorded in zero tillage-raised bed (ZT-RB) with crop-residues retention (CRR) at mid-flowering stage compared to the other CA practices and the lowest were recorded in conventional tillage (CT) practices (Table 2). The increased plant height and number of branches in ZT-RB with CRR was owing to higher soil-

Table 1. Description of experimental treatment

Main plots – tillage practices
M_1, Zero tillage - flatbed – No crop residue retention on the surface
M_2, Zero tillage - flatbed – Crop residue retention on the surface
M_3, Zero tillage - raised bed – No crop residue retention on the surface
M_4, Zero tillage - raised bed – Crop residue retention on the surface
M_5, Conventional tillage
Subplots – nutrient doses
S_1, 100% RDF (25 : 50 : 12.50 : 20 kg N, P_2O_5, K_2O, S/ha + 15 kg $ZnSO_4$/ha)
S_2, 75% RDF (18.75 : 37.5 : 9.37 : 15 kg N,P_2O_5, K_2O, S/ha + 11.25 kg $ZnSO_4$/ha)
S_3, 50% RDF (12.5 : 25 : 6.25 : 10 kg N, P_2O_5, K_2O, S/ha + 7.5 kg $ZnSO_4$/ha)
S_4, No fertilizers
Outside Control: 100% RDF (FYM + 25 : 50 : 12.5 : 20 kg N, P_2O_5, K_2O, S/ha + 15 kg $ZnSO_4$/ha)

moisture content which helped availability and nitrification of more nutrients, especially nitrogen. Higher nitrogen availability in soil led to increased absorption by the crop resulting cell multiplication and elongation that might have helped for increased plant height and number of branches/ plant (Harish *et al*., 2021a).

The increased leaf area/plant in ZT-RB with CRR in turn helped to increase the leaf-area index (LAI) at all the growth stages, reaching maximum at flowering stage in ZT-RB with CRR compared to CT practice. This might be owing leaf senescence and reduction in soil-moisture content from mid-pod formation stage to maturity stage. Reduction in soil-moisture content was at higher rate in CT practice compared to ZT-RB with CRR practices. These results are in conformity with the findings of Harish *et al*. (2021a), where ZT-RB with CRR recorded higher maize growth, yield attributes and yield.

Significantly higher plant height (133 cm), primary branches/plant (10.2), leaf area (21.29 dm^2/plant**)**, leaf-area index (1.58) were recorded when 100% recommended dose of inorganic fertilizer (RDF) applied at mid-flowering stage than the lower doses of nutrients. Interaction effect of ZT-RB with CRR along with 100% RDF recorded higher plant height (141.3 cm), primary branches/plant (11.5),

Table 2. Effect of conservation-agriculture practices and nutrient levels on growth at mid-flowering stage and yield parameters of rainfed pigeonpea at harvesting (pooled)

Treatment	Plant height (cm)	Primary branches/ plant	Leaf area (dm^2/plant)	Leaf area Index	SPAD values	Pods/ plant	Seed weight (g/plant)
Tillage practices (M)							
M1	124.0^{c}	9.09^{c}	19.29^{c}	1.43^{c}	38.55^{b}	64.7^{b}	25.1^{c}
M2	134.7^{ab}	9.78^{b}	21.20^{b}	1.57^{b}	40.03^{b}	82.6^{a}	29.0^{ab}
M3	129.3^{bc}	9.25^{bc}	20.25^{bc}	1.50^{bc}	39.07^{b}	69.1^{b}	26.8^{bc}
M4	137.1^{a}	10.5^{a}	23.08^{a}	1.71^{a}	41.98^{a}	88.5^{a}	30.8^{a}
M5	115.8^{d}	7.66^{d}	18.02^{d}	1.33^{d}	36.48^{c}	55.0^{c}	21.5^{d}
SEm±	2.21	0.17	0.32	0.03	0.59	1.9	0.7
Nutrient doses (S)							
S1	133.0^{a}	10.2^{a}	21.29^{a}	1.58^{a}	41.83^{a}	75.2^{a}	27.8^{a}
S2	129.7^{b}	9.50^{b}	20.68^{ab}	1.53^{ab}	39.57^{ab}	72.6^{b}	27.0^{ab}
S3	127.2^{c}	8.95^{bc}	20.04^{ab}	1.48^{bc}	38.69^{ab}	71.1^{bc}	26.2^{bc}
S4	122.8^{d}	8.43^{c}	19.44^{b}	1.44^{c}	36.80^{b}	69.0^{c}	25.7^{c}
SEm±	0.71	0.18	0.15	0.02^{b}	1.22	0.8	0.4
Interaction (M × S)							
M1S1	132.7^{a-c}	9.77^{b-f}	20.28^{f-i}	1.50^{f-i}	41.46^{a-c}	67.7^{f-h}	26.4^{f-h}
M1S2	125.1^{c-f}	9.23^{d-g}	19.58^{h-k}	1.45^{g-j}	38.80^{b-f}	65.0^{gh}	25.4^{hi}
M1S3	121.1^{d-g}	8.87^{e-h}	18.88^{jk}	1.40^{i-k}	38.09^{c-f}	63.8^{hi}	24.5^{i}
M1S4	117.2^{fg}	8.50^{gh}	18.41^{kl}	1.36^{jk}	35.84^{f}	62.4^{ij}	24.1^{ij}
M2S1	137.4^{ab}	10.9^{ab}	21.93^{c-e}	1.62^{c-e}	42.93^{ab}	85.2^{b-d}	29.9^{bc}
M2S2	137.1^{ab}	10.1^{b-e}	21.39^{d-f}	1.58^{d-f}	40.92^{a-e}	83.9^{cd}	29.2^{b-d}
M2S3	133.2^{a-c}	9.30^{d-g}	20.98^{d-g}	1.55^{d-g}	39.48^{b-f}	82.7^{d}	28.7^{cd}
M2S4	131.1^{a-d}	8.87^{e-h}	20.49^{f-i}	1.52^{e-h}	36.78^{ef}	78.6^{e}	28.2^{de}
M3S1	134.1^{a-c}	10.1^{b-d}	21.21^{d-g}	1.57^{d-f}	41.94^{a-c}	71.0^{f}	27.8^{d-f}
M3S2	131.1^{a-d}	9.39^{g-i}	20.63^{e-h}	1.53^{e-g}	38.96^{b-f}	69.7^{f}	26.9^{e-g}
M3S3	128.1^{b-e}	8.93^{d-h}	19.96^{g-j}	1.48^{f-i}	38.53^{b-f}	68.6^{fg}	26.4^{e-g}
M3S4	123.9^{c-f}	8.57^{f-h}	19.20^{i-k}	1.42^{h-j}	36.87^{d-f}	66.9^{f-h}	26.0^{gh}
M4S1	141.3^{a}	11.5^{a}	23.88^{a}	1.77^{a}	44.33^{a}	92.6^{a}	31.8^{a}
M4S2	138.6^{ab}	10.8^{ab}	23.36^{ab}	1.73^{ab}	42.24^{a-c}	89.1^{b}	31.6^{a}
M4S3	137.5^{ab}	10.5^{a-c}	22.83^{a-c}	1.69^{a-c}	41.31^{a-d}	87.4^{bc}	30.2^{b}
M4S4	131.1^{a-d}	9.26^{d-g}	22.24^{b-d}	1.65^{b-d}	40.03^{a-f}	84.5^{cd}	29.6^{b-k}
M5S1	119.6^{e-g}	8.53^{gh}	19.15^{i-k}	1.42^{h-j}	38.48^{b-f}	59.2^{j}	23.0^{kl}
M5S2	116.7^{fg}	8.00^{hi}	18.46^{kl}	1.37^{jk}	36.94^{d-f}	55.1^{k}	21.8^{lm}
M5S3	116.1^{fg}	7.13^{i}	17.57^{lm}	1.30^{kl}	36.03^{f}	53.1^{k}	21.0^{l-b}
M5S4	110.8^{g}	6.97^{i}	16.88^{m}	1.25^{l}	34.47^{g}	52.4^{k}	20.4^{m}
SEm±	3.51	0.35	0.47	0.04	1.27	2.2	0.8
Control	122.8	9.40	19.72	1.46	40.78	63.2	24.7
SEm±	3.27	0.36	0.45	0.04	1.55	2.1	0.8
CD(P=0.05)	9.35	1.03	1.28	0.11	4.44	6.0	2.2
Superscripts indicate	dmrt						

leaf area (23.88 dm^2/plant), leaf-area index (1.77) at mid-flowering, compared to all other combinations. Application of 100% RDF along with FYM in CT recorded higher growth parameters than the other nutrient doses in CT practices.

Chlorophyll meter reading (SPAD)

The pooled data indicated that effect of different CA practices varied significantly with higher SPAD readings (41.98) recorded at mid-flowering stage in ZT-RB with CRR than the remaining treatments. Significantly higher SPAD readings (41.83) were recorded with 100% RDF, but were at par with 75 and 50% RDF during mid-flowering stage. This was due to balanced nutrient that resulted in more chlorophyll development in crop plant, which helped in production of higher plant dry matter (Kumar *et al.*, 2019). Higher quantity of fertilizer increased the plant chlorophyll content and plant biomass growth, thereby increasing SPAD values (Govaerts *et al.,* 2006). Interaction effect revealed that SPAD values were higher in ZT-RB with CRR along with 100% RDF at mid-flowering (44.3). Further, it was observed that application of 100% RDF (recommended dose of inorganic + FYM) in CT resulted in more SPAD values (40.8) at mid-flowering than all the doses of recommended inorganic fertilizer in CT practice. The SPAD values were higher in ZT-RB with CRR owing

Table 3. Effect of conservation agriculture practices and nutrient levels on yield, yield parameters and leaf litter yield of rainfed pigeonpea (pooled)

Treatment	Seed yield (t/ha)	Stalk yield (t/ha)	Harvest index (%)	100-seed weight (g)	Leaf litter yield (kg/ha)		
					Mid-flowering	Mid-pod formation	Maturity
Tillage practices (M)							
M1	1.07 ^{c}	4.07 ^{b}	20.8 ^{a}	9.68 ^{b}	90 ^{ab}	268 ^{ab}	372 ^{c}
M2	1.18 ^{b}	4.34 ^{b}	21.4 ^{a}	9.77 ^{ab}	81 ^{c}	251 ^{c}	389 ^{b}
M3	1.11 ^{c}	4.20 ^{b}	20.9 ^{a}	9.74 ^{b}	86 ^{bc}	261 ^{b}	378 ^{c}
M4	1.29 ^{a}	4.61 ^{a}	21.8 ^{a}	9.86 ^{a}	74 ^{d}	243 ^{c}	410 ^{a}
M5	0.96 ^{d}	3.66 ^{c}	20.6 ^{a}	9.58 ^{c}	92 ^{a}	272 ^{a}	355 ^{d}
SEm±	0.02	0.08	0.39	0.03	1.6	2.7	2.8
Nutrient doses (S)							
S1	1.18 ^{a}	4.31 ^{a}	21.4 ^{a}	9.84 ^{a}	92 ^{a}	270 ^{a}	394 ^{a}
S2	1.15 ^{a}	4.23 ^{ab}	21.3 ^{a}	9.76 ^{ab}	87 ^{ab}	263 ^{b}	385 ^{b}
S3	1.11 ^{b}	4.13 ^{b}	21.1 ^{a}	9.69 ^{ab}	82 ^{bc}	256 ^{c}	377 ^{c}
S4	1.05 ^{c}	4.03 ^{c}	20.6 ^{a}	9.60 ^{b}	77 ^{c}	246 ^{d}	367 ^{d}
SEm±	0.01	0.03	0.22	0.04	1.9	1.2	1.5
Interaction (M × S)							
M1S1	1.13 ^{fg}	4.22 $^{c-g}$	21.2 ^{a}	9.81 ^{a}	98 ^{ab}	275 ^{bc}	392 $^{c-f}$
M1S2	1.10 ^{fg}	4.14 $^{d-h}$	21.1 ^{a}	9.74 ^{a}	93 $^{b-d}$	269 $^{c-e}$	379 ^{gh}
M1S3	1.05 ^{h}	4.01 $^{e-h}$	20.6 ^{a}	9.68 ^{a}	88 $^{d-g}$	269 $^{c-e}$	364 ^{j}
M1S4	0.99 ^{i}	3.91 $^{f-i}$	20.2 ^{a}	9.49 ^{a}	83 $^{g-i}$	259 $^{f-h}$	352 ^{k}
M2S1	1.22 ^{c}	4.43 $^{a-e}$	21.6 ^{a}	9.87 ^{a}	88 $^{d-g}$	264 $^{e-g}$	400 ^{cd}
M2S2	1.20 ^{cd}	4.38 $^{a-e}$	21.5 ^{a}	9.78 ^{a}	83 $^{f-i}$	255 ^{h}	393 $^{d-f}$
M2S3	1.18 ^{de}	4.32 $^{a-f}$	21.4 ^{a}	9.72 ^{a}	79 $^{i-k}$	248 ^{ij}	386 $^{f-h}$
M2S4	1.12 ^{fg}	4.22 $^{c-g}$	21.0 ^{a}	9.70 ^{a}	74 ^{kl}	234 ^{l}	377 $^{g-i}$
M3S1	1.17 ^{de}	4.30 $^{b-f}$	21.4 ^{a}	9.86 ^{a}	94 $^{a-d}$	273 $^{b-d}$	388 $^{e-g}$
M3S2	1.14 ^{ef}	4.28 $^{b-g}$	21.2 ^{a}	9.76 ^{a}	89 $^{c-f}$	266 $^{d-f}$	381 ^{gh}
M3S3	1.10 ^{g}	4.17 $^{c-g}$	20.8 ^{a}	9.69 ^{a}	83 $^{f-i}$	258 ^{gh}	376 ^{hi}
M3S4	1.03 ^{h}	4.08 $^{d-h}$	20.2 ^{a}	9.63 ^{a}	79 $^{i-k}$	247 ^{jk}	366 ^{ij}
M4S1	1.33 ^{a}	4.73 ^{a}	22.1 ^{a}	9.94 ^{a}	81 $^{h-j}$	255 ^{hi}	423 ^{a}
M4S2	1.31 ^{ab}	4.65 ^{ab}	22.0 ^{a}	9.86 ^{a}	76 $^{j-l}$	246 ^{jk}	414 ^{ab}
M4S3	1.28 ^{b}	4.56 $^{a-c}$	21.9 ^{a}	9.85 ^{a}	72 ^{lm}	240 ^{kl}	405 ^{bc}
M4S4	1.24 ^{c}	4.51 $^{a-d}$	21.6 ^{a}	9.79 ^{a}	67 ^{m}	230 ^{m}	397 $^{c-e}$
M5S1	1.03 ^{h}	3.86 $^{g-i}$	20.9 ^{a}	9.70 ^{a}	99 ^{a}	287 ^{a}	367 ^{ij}
M5S2	0.99 ^{i}	3.75 $^{h-j}$	20.6 ^{a}	9.67 ^{a}	95 $^{a-c}$	278 ^{b}	359 ^{j}
M5S3	0.93 ^{j}	3.58 ^{ij}	20.6 ^{a}	9.55 ^{a}	90 $^{c-e}$	267 ^{de}	355 ^{k}
M5S4	0.87 ^{k}	3.44 ^{j}	20.1 ^{a}	9.39 ^{a}	85 $^{e-h}$	255 ^{hi}	341 ^{l}
SEm±	0.03	0.14	0.68	0.06	2.2	3.4	4.2
Control	1.08	4.01	21.2	9.74	86	261	377
SEm±	0.03	0.12	0.65	0.07	2.7	3.7	4.4
CD (P=0.05)	0.08	0.36	NS	0.20	7.7	10.5	12.5

to balanced supply of nutrients as per the requirement, in turn by soil-moisture content by the crop at all stages and during the study SPAD values gradually increased up to mid-pod formation stage and then decreased with time SPAD represents canopy expansion and senescence (Govaerts *et al.*, 2006, 2007).

Yield parameters

Yield parameters, viz. pod number (88.5), seed weight/plant (30.8 g) and 100-seed weight (9.86 g) were highest when pigeonpea was grown in ZT-RB with CRR, but were on par with ZT-FB without residues retention. This was mainly owing to higher dry-matter production, translocation and accumulation in reproductive parts. The results confirm with the findings of Khan and Parvej (2010). In general, higher yield was obtained during 2016 owing to well-distributed rainfall throughout growing period compared to 2015.

Application of 100% RDF resulted in significantly more pods/plant (75.2), seed weight/plant (27.8 g) and 100-seed weight (9.84 g). The highest pods (92.6) and seed weight/plant (31.8 g) were produced when crop was grown with 100% RDF in ZT-RB with CRR. Higher pods (63.2) and seed weight/plant (24.7 g) were registered in 100% RDF (+ FYM plots) than 75% RDF, 50% RDF and without fertilizers plots under CT practice.

Table 4. Effect of conservation agriculture practices and nutrient levels on soil-moisture content (%) at different stages (Pooled)

Treatment	Soil moisture (0–20 cm depth)				Soil moisture (20–40 cm depth)			
	Branching	Mid-flowering	Mid-pod formation	Maturity	Branching	Mid-flowering	Mid-pod formation	Maturity
Tillage practices (M)								
M1	13.06^{c}	13.80^{c}	9.60^{b}	3.70^{b}	14.57^{c}	16.02^{c}	10.70^{b}	3.94^{b}
M2	13.51^{ab}	14.46^{ab}	10.89^{a}	4.23^{ab}	16.00^{ab}	16.98^{ab}	12.23^{a}	4.58^{ab}
M3	12.92^{bc}	14.10^{bc}	9.79^{b}	3.83^{ab}	15.15^{bc}	16.57^{bc}	10.81^{b}	4.09^{ab}
M4	13.80^{a}	14.83^{a}	11.21^{a}	4.49^{a}	16.60^{a}	17.40^{a}	12.60^{a}	4.83^{a}
M5	9.94^{d}	10.73^{d}	7.08^{c}	2.82^{c}	11.46^{d}	12.38^{d}	7.83^{c}	2.95^{c}
SEm±	0.21	0.12	0.10	0.20	0.32	0.17	0.13	0.22
Nutrient doses (S)								
S1	13.06^{a}	14.11^{a}	10.30^{a}	4.17^{a}	15.40^{a}	16.47^{a}	11.49^{a}	4.47^{a}
S2	12.67^{a}	13.74^{a}	9.80^{a}	3.99^{a}	14.93^{a}	16.05^{a}	10.98^{a}	4.27^{a}
S3	12.35^{a}	13.46^{a}	9.55^{a}	3.67^{a}	14.54^{a}	15.73^{a}	10.64^{a}	3.91^{a}
S4	12.02^{a}	13.02^{a}	9.19^{a}	3.41^{a}	14.14^{a}	15.21^{a}	10.22^{a}	3.65^{a}
SEm±	0.27	0.33	0.29	0.18	0.54	0.53	0.46	0.40
Interaction (M × S)								
M1S1	12.98^{a-f}	14.45^{a-c}	9.92^{e-g}	4.15^{a-d}	15.20^{bc}	16.80^{b-d}	11.13^{e-h}	4.40^{b-d}
M1S2	12.67^{d-f}	14.15^{b-d}	9.67^{gh}	4.05^{b-e}	14.80^{cd}	16.42^{b-d}	10.77^{f-h}	4.35^{b-d}
M1S3	12.42^{ef}	13.52^{cd}	9.60^{gh}	3.43^{e-h}	14.47^{cd}	15.72^{de}	10.63^{gh}	3.67^{e-h}
M1S4	11.82^{fg}	13.08^{d}	9.22^{gh}	3.15^{g-i}	13.80^{d}	15.15^{e}	10.28^{h}	3.35^{f-h}
M2S1	14.15^{a}	14.90^{ab}	11.47^{ab}	4.70^{ab}	16.77^{a}	17.48^{ab}	12.92^{ab}	5.05^{a-b}
M2S2	13.87^{a-c}	14.60^{a-c}	10.95^{a-d}	4.32^{a-d}	16.42^{ab}	17.15^{a-c}	12.32^{a-d}	4.68^{a-c}
M2S3	13.17^{a-e}	14.30^{a-c}	10.63^{c-e}	4.10^{b-d}	15.57^{a-c}	16.78^{b-d}	11.97^{b-e}	4.45^{b-d}
M2S4	12.85^{c-f}	14.03^{b-d}	10.50^{d-f}	3.82^{c-f}	15.23^{bc}	16.48^{b-d}	11.70^{d-g}	4.15^{c-e}
M3S1	13.27^{a-e}	14.52^{a-c}	10.63^{c-e}	4.20^{a-d}	15.55^{a-c}	16.97^{a-c}	11.77^{c-f}	4.48^{b-d}
M3S2	13.00^{a-e}	14.25^{a-c}	9.78^{f-h}	4.08^{b-d}	15.25^{bc}	16.63^{b-d}	10.77^{f-h}	4.37^{b-d}
M3S3	12.92^{b-f}	14.02^{b-d}	9.68^{gh}	3.67^{d-g}	15.13^{b-d}	16.53^{b-d}	10.68^{f-h}	3.90^{d-f}
M3S4	12.50^{ef}	13.60^{cd}	9.07^{h}	3.38^{f-h}	14.65^{cd}	16.15^{c-e}	10.03^{h}	3.60^{e-g}
M4S1	14.07^{ab}	15.33^{a}	11.73^{a}	4.78^{a}	16.95^{a}	18.00^{a}	13.15^{a}	5.18^{a}
M4S2	13.88^{a-c}	14.82^{ab}	11.37^{a-c}	4.60^{ab}	16.65^{a}	17.43^{ab}	12.85^{a-c}	4.90^{ab}
M4S3	13.70^{a-d}	14.72^{ab}	10.88^{b-d}	4.40^{a-c}	16.47^{ab}	17.27^{a-c}	12.25^{a-d}	4.73^{a-c}
M4S4	13.55^{a-e}	14.47^{a-c}	10.85^{b-d}	4.17^{a-d}	16.35^{ab}	16.88^{bc}	12.15^{a-e}	4.50^{a-d}
M5S1	10.83^{gh}	11.37^{e}	7.75^{i}	3.05^{g-i}	12.55^{e}	13.13^{f}	8.50^{i}	3.23^{f-h}
M5S2	9.95^{hi}	10.88^{ef}	7.25^{ij}	2.93^{hi}	11.53^{ef}	12.62^{f}	8.22^{i}	3.05^{gh}
M5S3	9.57^{i}	10.75^{ef}	6.97^{j}	2.73^{i}	11.08^{f}	12.38^{f}	7.67^{ij}	2.82^{h}
M5S4	9.42^{i}	9.93^{f}	6.33^{j}	2.55^{i}	10.68^{f}	11.38^{g}	6.93^{j}	2.68^{h}
SEm±	0.37	0.31	0.24	0.27	0.48	0.33	0.32	0.28
Control	11.72	12.75	9.03	3.40	14.70	13.63	9.55	3.62
SEm±	0.35	0.35	0.25	0.26	0.43	0.39	0.32	0.28
CD (P=0.05)	1.02	1.00	0.74	0.76	1.25	1.11	0.92	0.81

Seed and straw yield

Among the CA practices, ZT-RB with CRR consistently resulted in higher seed yield (1.29 t/ha) and straw yield (4.61 t/ha) than the other tillage practices, whereas significantly lower seed and straw yields were recorded in CT practice. The yield increased in ZT-RB plots with CRR owing to the improvement in soil physical environment and soil organic carbon content, which helped in better root growth (Harish *et al*., 2021a).

Among the nutrient doses, 100% RDF recorded significantly higher seed yield (1.18 t/ha) and straw yield (4.31 t/ha), but it was on a par with 75% RDF. The highest seed yield (1.33 t/ha) was recorded when 100% RDF was applied in ZT-RB plots with CRR.

Leaf-litter yield

Leaf-litter yield recorded at flowering and pod-formation stage was higher in CT and the lowest in ZT-RB plots with CRR compared to the other CA practices. This was owing to residue retention on surface conserves the soil moisture, which helps in retaining the leaves on plant (Varatharajan *et al*., 2019a). Among the nutrient doses at flowering and pod formation stage, 100% RDF recorded higher leaf-litter yield. The 100% RDF in CT practice recorded higher leaf-litter yield (99 and 287 kg/ha respectively) compared to all the other combinations.

Table 5. Effect of conservation agriculture practices and nutrient levels on sustainable yield index, economics and energetic (pooled)

Treatment	Sustainable yield index	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	Seed output energy (MJ/ha)	Input energy (MJ/ha)	Net energy (MJ/ha)
Tillage Practices (M)							
M1	0.59 ^{d}	58,616 ^{c}	20,418	38,198 ^{d}	15,667 ^{d}	4,164	11,503 ^{b}
M2	0.67 ^{b}	64,960 ^{b}	20,884	44,076 ^{b}	17,362 ^{b}	4,164	13,198 ^{a}
M3	0.64 ^{c}	61,045 ^{bc}	20,984	40,062 ^{c}	16,316 ^{c}	4,666	11,650 ^{b}
M4	0.72 ^{a}	70,879 ^{a}	21,484	49,395 ^{a}	18,962 ^{a}	4,666	14,297 ^{a}
M5	0.51 ^{e}	52,491 ^{d}	25,175	27,316 ^{e}	14,029 ^{e}	5,226	8,803 ^{c}
SEm±	0.003	1,324	-	1,324	354	-	354
Nutrient doses (S)							
S1	0.64 ^{a}	64,733 ^{a}	23,438	41,295 ^{a}	17,316 ^{a}	5,610	11,706 ^{a}
S2	0.63 ^{b}	63,103 ^{a}	22,538	40,565 ^{a}	16,866 ^{a}	5,023	11,843 ^{a}
S3	0.62 ^{c}	60,815 ^{b}	21,664	39,152 ^{ab}	16,254 ^{b}	4,437	11,817 ^{a}
S4	0.61 ^{d}	57,741 ^{c}	19,516	38,225 ^{b}	15,433 ^{c}	3,238	12,194 ^{a}
SEm±	0.002	609	-	609	162	-	162
Interaction (M × S)							
M1S1	0.60 ^{j}	62,196 ^{ef}	22,150	40,046 $^{d-f}$	16,623 ^{ef}	5,197	11,426 ^{e}
M1S2	0.59 ^{k}	60,748 ^{f}	21,140	39,608 $^{d-f}$	16,236 ^{f}	4,610	11,626 ^{e}
M1S3	0.59 ^{k}	57,475 ^{gh}	20,266	37,210 ^{fg}	15,362 ^{gh}	4,024	11,338 ^{e}
M1S4	0.57 ^{l}	54,047 ^{ij}	18,118	35,929 ^{g}	14,445 ^{ij}	2,825	11,620 ^{e}
M2S1	0.68 ^{d}	67,302 ^{cd}	22,513	44,789 ^{b}	17,988 ^{cd}	5,197	12,791 ^{d}
M2S2	0.67 ^{e}	65,991 ^{cd}	21,640	44,351 ^{b}	17,638 ^{cd}	4,610	13,028 ^{cd}
M2S3	0.67 ^{e}	64,708 $^{b-e}$	20,766	43,942 ^{bc}	17,295 ^{de}	4,024	13,271 ^{cd}
M2S4	0.65 ^{f}	61,838 ^{ef}	18,618	43,221 ^{bc}	16,528 ^{ef}	2,825	13,703 ^{bc}
M3S1	0.65 ^{f}	64,451 ^{de}	22,613	41,838 $^{b-d}$	17,226 ^{de}	5,699	11,527 ^{e}
M3S2	0.64 ^{g}	62,645 ^{ef}	21,740	40,906 $^{c-e}$	16,743 ^{ef}	5,112	11,631 ^{e}
M3S3	0.63 ^{h}	60,216 ^{fg}	20,866	39,350 $^{d-f}$	16,094 ^{fg}	4,526	11,569 ^{e}
M3S4	0.62 ^{i}	56,870 ^{hi}	18,718	38,153 $^{e-g}$	15,200 ^{hi}	3,327	11,873 ^{e}
M4S1	0.73 ^{a}	73,104 ^{a}	23,113	49,992 ^{a}	19,612 ^{a}	5,699	13,914 ^{bc}
M4S2	0.72 ^{b}	72,059 ^{a}	22,240	49,820 ^{a}	19,259 ^{a}	5,112	14,147 ^{ab}
M4S3	0.72 ^{b}	70,345 ^{ab}	21,366	48,980 ^{a}	18,801 ^{ab}	4,526	14,276 ^{ab}
M4S4	0.71 ^{c}	68,008 ^{bc}	19,218	48,790 ^{a}	18,177 ^{bc}	3,327	14,850 ^{a}
M5S1	0.52 ^{m}	56,613 ^{hi}	26,803	29,811 ^{h}	15,131 ^{hi}	6,259	8,872 ^{f}
M5S2	0.51 ^{n}	54,074 ^{ij}	25,933	28,142 ^{hi}	14,453 ^{ij}	5,673	8,780 ^{f}
M5S3	0.50 ^{o}	51,333 ^{j}	25,056	26,278 ^{ij}	13,720 ^{j}	5,086	8,635 ^{f}
M5S4	0.49 ^{p}	47,942 ^{k}	22,908	25,034 ^{j}	12,814 ^{k}	3,887	8,927 ^{f}
SEm±	0.004	1,565	-	1,565	418	-	418
Control	0.53	59,464	33,302	26,161	15,893	8,096	7,796
SEm±	0.004	1,518	-	1,518	405	-	405
CD (P=0.05)	0.012	4,339	-	4,339	1,159	-	1,159

At maturity, ZT-RB with CRR (410 kg/ha) recorded significantly higher leaf-litter yield than all the other practices. Among the nutrient doses, significantly higher leaf-litter yield (394 kg/ha) was recorded in 100% RDF than the remaining doses. The ZT-RB with CRR coupled with 100% RDF recorded higher leaf-litter yield (423 kg/ha) than the other combinations. Application of 100% RDF along with FYM in CT resulted in higher leaf-litter yield than the other nutrient doses in CT practices.

Soil-moisture content

The pooled data indicated that at maturity, tillage practice of ZT-RB with CRR (4.49 %) recorded significantly higher soil moisture than the other practices. Zero-tillage with residues had higher soil moisture, both at surface (26%) 0–20 and 20–40 cm deeper layer (31%) than when residues were removed (19 and 21% respectively). Higher soil-moisture content was observed in 100% RDF at branching, mid-flowering, mid-pod formation and maturity stages (13.06, 14.11, 10.30 and 4.17% respectively). In interaction at maturity, higher soil moisture was recorded in zero-till-raised bed with residues retention with application of 100% RDF fertilizer (4.78%). At maturity 100% RDF (+ FYM) in CT recorded significantly higher soil-moisture content than no-fertilizer application. Higher moisture retention in soil in ZT-RB was owing to increased aggregation, reduced evaporation and improved infiltration (Fuentes *et al.,* 2009).

Sustainable yield index

The ZT-RB with CRR resulted in significantly highest sustainable yield index (0.72) than the other practices. Among the nutrients, 100% RDF resulted in significantly highest sustainable yield index compared to lower levels. With respect to interactions, ZT-RB with CRR along with 100% RDF recorded significantly highest sustainable yield index (0.73) than the other combinations.

Economics

Among the CA practices, ZT-RB with CRR gave significantly highest gross (₹70,879/ha) and net returns (₹49,395/ha) compared to all the other CA practices. The results are in line with Zeliha *et al.* (2011) and Singh *et al.* (2013), who also reported higher cost of production in CT compared to minimum tillage and ZT. Sepat *et al.* (2015) opined that addition of pigeonpea residues resulted in the highest net returns over no residues addition. Significantly highest gross (₹64,733/ha) and net returns (₹41,295/ha) were also recorded with the application of 100% RDF.

Energetics

Significantly highest seed output energy (18,962 MJ/ha) and net energy (14,297 MJ/ha) were observed in ZT-RB with CRR compared to all the other CA practices. Higher seed output energy was recorded in 100% RDF (17,316 MJ/ha). Effect of inorganic fertilizers on net energy was non-significant. Higher net energy was recorded in treatment where no fertilizer was applied (12,194 MJ/ha). More renewable energy was used in no-till systems than the other systems. The 100% RDF when applied in ZT-RB with CRR exhibited higher seed output energy than all the other combinations. Significantly higher net energy was observed in treatment where no fertilizer was applied in ZT-RB with CRR (14,850 MJ/ha). Pratibha *et al.* (2015) and Singh *et al.* (2013) reported higher input energy under CT than ZT sowing methods and they also reported the saving of energy consumption up to 10.76% less in ZT in comparison with CT practice sowing. The RDF (inorganic + FYM) produced lower net energy (7,796 MJ/ha) compared to all the combinations. This was due to additional input energy of FYM which was very high.

It was concluded that CA practice of ZT-RB with CRR along with 100% RDF (25 : 50 : 12.5 : 20 kg N, P_2O_5, K_2O, S/ha + 15 kg $ZnSO_4$/ha) resulted in higher seed and stalk yield over the other CA and CT practices. The moisture content was significantly higher in ZT-RB with CRR than the other practices. Net returns and benefit: cost ratio indicated that ZT-RB with CRR was proved optimum with 50% reduction in RDF. Energy especially diesel like non-renewable energy input in agriculture can also be saved in CA practices which helps in energy conservation and cost savings.

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