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# Crop establishment, tillage and weed management techniques on weed dynamics and productivity of rice (*Oryza sativa*)˘chickpea (*Cicer arietinum*) cropping system

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ABSTRACT

A field study was conducted to study the effect of methods of rice establishment, tillage and weed management techniques in rice–chickpea cropping system. Treatments included four crop establishment techniques (transplanting, puddling and broadcasting sprouted rice seeds, i.e wet-seeding and dry seeding under conventional and zero tillage systems) in rice and two tillage (zero and conventional) and two weed control methods (weedy check and pendimethalin 1.0 kg/ha as pre-emergence + one hand weeding at 30 days after sowing) in succeeding chickpea. Rice field was infested with jungle rice [*Echinochloa colona* (L.) Link], *Caesulia* (*Caesulia axillaris* Roxb.), sessile joyweed [*Alternanthera sessilis* (L.) DC.], and rice flat sedge (*Cyperus iria* L.) and chickpea with wild oats (*Avena ludoviciana* Dur.) and toothed burclover (*Medicago hispida* Gaertn.). Results revealed that methods of rice establishment did influence the weed dynamics in rice–chickpea system. Mean yield of zero-till direct-seeded rice (3 262 kg/ha) was as good as that of puddle broadcast rice (3 343 kg/ha) and better than the transplanted rice (3 038 kg/ha). Effective weed control in preceding chickpea benefitted the succeeding rice crop. Methods of rice establishment and tillage did not influence the chickpea yield. Infestation of weeds caused 78.45% reduction in yield of chickpea. Maximum seed yield of chickpea (2 813 kg/ha) was noticed in pendimethalin followed by one HW under conventional tillage. Zero till direct-seeded rice followed by zero-till chickpea system was the best combination for maximizing system productivity, profitability and energy efficiency.

**Keywords**: Direct seeding, Rice-chickpea system, Transplanting, Weeds, Zero tillage

In northern part of India, rice (*Oryza sativa* L.)–chickpea (*Cicer arietinum* L.) is the predominant cropping system next to rice–wheat (*Triticum aestivum* L. emend. Fiori & Paol.) system (Arya *et al*. 2005). Chickpea, a drought-tolerant and high-value crop can be grown successfully when seeded after rice in late October to mid November (Gangwar and Singh, 2010). The inclusion of chickpea in sequence with rice economizes on nitrogen (20–30 kg/ha), improves the physical condition of the soil and helps in eradicating obnoxious weeds like wild oat (*Avena fatua*) and canary grass (*Phalaris minor*) (Ali and Basu 1992). Rice–chickpea system is generally practised on heavy soils where rice is mainly grown as transplanted (TPR) in puddle field. The sowing of chickpea in this system is often delayed until late November or early December either due to late rice harvest or excess moisture in the field and also due to longer turnaround time required for field preparation between rice and chickpea. Delay sowing of chickpea results to poor germination and seedling establishment due to less soil moisture and low temperature. The productivity could be increased by switching from transplanting to direct-seeding to allow more reliable establishment of succeeding crops on residual moisture immediately after the rice harvest (Mazid *et al*. 2003). Direct-seeded rice (DSR) matures 1–2 weeks before transplanted rice, thus reducing the risk of terminal drought and allowing earlier planting of a following non-rice crop (Saleh *et al*. 2000). Introducing zero tillage (ZT) may improve productivity as a result of timely sowing and may also reduce fuel, animal or human energy required for land preparation.

Weeds are major problem in rice-based cropping systems. Despite the maintenance of standing water in transplanted rice throughout the rice-growing season, the annual weeds subsequently infest the succeeding crops in higher intensity

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(Hassan *et al*. 2003). Chickpea being poor competitor to weeds, especially during initial growth period suffers 18–90% yield loss depending upon the nature and intensity of weed flora and management practices (Yaduraju and Mishra 2002). Soil tillage is one of the most important factors determining the abundance of weeds within given cropping systems (Hakansson 2003).

The present study was therefore, conducted to: (i) observe the effect of different methods of rice establishment, tillage and weed management techniques on weeds and productivity of rice–chickpea system, and (ii) compare economics and energy use of different rice–chickpea systems.

## MATERIALS AND METHODS

Field experiments were conducted for three years (2006–09) at Directorate of Weed Science Research, Jabalpur ($23^0$ 90' N, $79^0$ 58' E, 412 m above MSL), India. The soil was clay loam (Typic chromusterts) in texture, low in available nitrogen (245 kg/ha), medium in available phosphorus (18 kg P/ha), and high in available potassium (325 kg/ha), with organic carbon 0.54% and *p*H 7.5. The treatments included four rice establishment techniques in the main plot, and two tillage systems and two weed control methods for the following chickpea in the sub-plot, in a split-plot design with four replications. Each sub-plot measured 4.5 m × 10 m. The methods of rice (cv. Kranti) establishment were: (i) puddling and transplanting rice seedlings (TPR), puddling and broadcast sowing of sprouted rice seeds (PBR, also known as wet-seeded rice), conventionally tilled dry seeding of rice (DSR), and zero till direct-seeded rice (ZTDSR). After the harvesting the preceding crop, all the plots except ZTDSR were cultivated once with mould board plough. In TPR and PBR, puddling was done by flooding the plots and rotovating followed by leveling. Regarding the frequency of tillage in conventional DSR plots, two passes of cultivator and one planking (leveling with a wooden bar) operations were performed in addition to mould board ploughing. Treatments for chickpea involved two tillage (conventional and zero) and two weed control methods (pendimethalin 1.0 kg/ha as pre-emergence + one hand weeding at 30 days after sowing and weedy check). Conventional tillage consisted of tillage twice with a field cultivator, disked once with disc harrow and rototilled once after rice harvest. Zero till chickpea was planted by direct seeding into dead residue of rice without field preparation using zero till ferti-seed drill having inverted T-type furrow openers.

Sowing of PBR, DSR and ZTDSR and nursery for transplanting was done about a month in advance of date of transplanting. Direct seeding was thus done in the second week of June with 80 kg/ha seed while transplanting was done in the second week of July. In DSR, the soil was cultivated while it was dry. Sowing with zero till drill was done directly on the field without any tillage operation. Conventional and zero till drills were used for direct seeding of rice in conventional and zero tilled plots, respectively. Rice was harvested manually in the last week of October. Weeds were controlled with pre-emergence application of butachlor at 1.5 kg/ha, followed by one manual weeding at 30 days after sowing/transplanting.

The chickpea (cv. JG-315) was seeded at 75 kg/ha during first week of November each year. Glyphosate [N-(phosphonomethyl) glycine] at 1.0 kg/ha in 500 litre water/ha was applied one week before chickpea seeding in all the zero till plots to kill the existing vegetation. Pendimethalin 1.0 kg/ha was applied as pre-emergence (one day after sowing) with 500 litre water/ha using a knapsack sprayer, fitted with flat-fan nozzle. The crop received 2 sprinkler irrigations, first just after sowing and second at flower initiation stage. Weed density (no./$m^2$) was recorded at 60 days after sowing (DAS) in both rice and chickpea crops, whereas weed dry matter (g/$m^2$) in rice was collected at 60 DAS and in chickpea at 90 DAS from 1 m × 1 m by placing a quadrate of 50 cm × 50 cm randomly at four places in each plot. For nodulation studies, five chickpea plants were dug up at 60 DAS and roots were washed gently in running water to remove soil clods and trash. Root nodules from each plant were separated and counted. Dry weight of nodules was recorded after drying them at $60^0$C. Leaf area was measured at 60 DAS by removing all the leaves from each of five plants and passing them individually through a stationary leaf area meter (Model: LI-COR 3100 (Li-COR Inc., P.O. Box 4425, Lincoln, NE 68504).

The economic and energy requirements for all the treatments were measured for the growing period of the crops during 2008–09 (third year). Different economic indicators, viz net returns and benefit : cost ratio were calculated based on the existing price of the inputs and outputs. To calculate the input energy, all inputs in the form of labour, machinery, fuel, fertilizer, seed, pesticide and irrigation were taken into consideration with use of energy conversion factors (Devasenapathy *et al*. 2009). Weed density and weed dry matter values in chickpea were subjected to square root transformation [v(x + 0.5)] before statistical analysis to normalize data distribution. All the data were subjected to analysis of variance (ANOVA) by using a split-plot design and main effects and interactions were tested for significance. Treatment means obtained by ANOVA were compared using least significant difference (LSD) procedures at $P$=0.05 level of significance.

## RESULTS AND DISCUSSION

### *Effect in rice*

*Weed density and weed dry matter:* The dominant weeds in rice were jungle rice [*Echinochloa colona* (L.) Link], *Caesulia* (*Caesulia axillaris* Roxb.), sessile joyweed [*Alternanthera sessilis* (L.) DC.], and rice flat sedge (*Cyperus iria* L.). During 2008, due to prolonged initial submergence blistering ammania (*Ammania baccifera* L.) was observed as a new weed and *A. sessilis* was completely eliminated. Density and dry weight of weeds associated with rice was influenced by methods of rice establishment (Table 1). Transplanted rice being at par with direct-seeded rice significantly reduced the density of *E. colona* as compared to zero till direct-seeded rice and puddle broadcast rice. Significantly, higher density of *C. iria* was observed under transplanted rice as compared to puddle broadcast and direct-seeded rice. Density of *C. axillaris* decreased over years and the effect of rice establishment techniques was inconsistent. Different tillage practices adopted in chickpea crop did not influence the density of individual weeds in succeeding rice crop, except that of *A. sessilis*, which was significantly higher in ZT than CT. Application of pendimethalin at 1.0 kg/ha, followed by one hand weeding at 30 DAS in preceding chickpea crop reduced the density of weeds in subsequent rice crop except that of *E. colona* and *C. iria* which were not affected. Among rice establishment techniques, puddle broadcast rice recorded the lowest weed dry weight due to higher plant (rice) population and better weed suppression. Zero tillage in preceding chickpea crop resulted in significantly lower weed dry weight in rice than conventional tillage, however, different weed control treatments did not affect the weed dry weight.

*Grain yield and its attributes:* Rice establishment techniques had significant effect on its grain yield (Table 2). During 2006, significantly the lowest grain yield under transplanted rice (1 891 kg/ha) was due to moisture stress at panicle initiation stage and higher weed growth, particularly *A. sessilis*, leading to severe crop-weed competition and poor crop growth. However, in 2008, transplanted rice (4 816 kg/ha), being at par with ZTDSR (4 428 kg/ha) and PBR (4 411 kg/ha) produced significantly higher grain yield than DSR (3 533 kg/ha). Different tillage treatments applied to preceding chickpea crop did not lead to significant effect on grain yield of rice crop. Similar findings were reported in rice-wheat system where ZT in wheat did not have any significant effect on subsequent paddy crop management or yields (Erenstein *et al*., 2008a). Effective weed control in chickpea with pendimethalin + one hand weeding improved the grain yield of succeeding rice by 19.2% as compared to weedy check. This might be due to a lesser nutrients removal by weeds, which in turn, made more nutrients available to succeeding rice crop. Puddle broadcast rice being at par with DSR produced significantly higher number of panicles (275/m$^2$) than transplanted rice (205/m$^2$). Puddle broadcast rice also recorded significantly higher 1000-grain weight (25.25 g) than ZTDSR (23.28 g). Different tillage and weed control practices applied to preceding chickpea crop did not have significant effect on growth and yield attributes of succeeding rice crop.

### *Effect in chickpea*

*Weed density and weed dry matter:* Wild oats (*Avena ludoviciana* Dur.) and toothed burclover (*Medicago hispida* Gaertn.) were the dominant weeds in chickpea. Rice establishment techniques did not influence the density of *A. ludoviciana*, however, transplanted rice as compared to ZTDSR, significantly reduced the density of *M. hispida* in

Table 1 Effect of rice establishment techniques, tillage and weed management on density and dry weight of weeds in rice at 60 days after sowing (pooled data of three years)

| Treatment | Weed density (No./m$^2$) | | | | | | Total weed dry weight (g/m$^2$) |
|---|---|---|---|---|---|---|---|
| | *Echinochloa colona* | *Cyperus iria* | *Caesulia axillaris* | *Alternanthera sessilis* | *Ammania baccifera** | Total | |
| *Rice establishment techniques* | | | | | | | |
| TPR | 3.45 | 22.25 | 9.8 | 17.7 | 11.4 | 53.5 | 64.87 |
| PBR | 5.50 | 8.40 | 10.2 | 23.0 | 10.7 | 43.1 | 51.63 |
| DSR | 3.60 | 11.85 | 11.45 | 12.6 | 10.1 | 43.1 | 73.11 |
| ZTDSR | 4.30 | 13.05 | 10.2 | 25.0 | 9.9 | 49.25 | 74.05 |
| LSD (*P*=0.05) | 0.75 | 3.55 | NS | 3.8 | NS | NS | 15.5 |
| *Tillage* | | | | | | | |
| Zero | 4.4 | 13.45 | 10.05 | 22.7 | 11.5 | 49.25 | 61.7 |
| Conventional | 3.9 | 13.25 | 10.75 | 16.1 | 9.7 | 45.10 | 70.2 |
| LSD (*P*=0.05) | NS | NS | NS | 3.0 | NS | NS | 5.6 |
| *Weed control* | | | | | | | |
| Weedy check | 3.8 | 15.45 | 11.95 | 23.2 | 10.6 | 52.4 | 67.6 |
| Pendimethalin 1.0 kg/ha+ one HW (30 DAS) | 4.5 | 13.30 | 8.90 | 15.7 | 10.5 | 43.75 | 64.2 |
| LSD (*P*=0.05) | NS | NS | 2.75 | 3.3 | NS | 7.25 | NS |

*Observed during 2008

Table 2 Plant height, yield-attributing characters and grain yield of rice as affected by different rice establishment, tillage and weed management techniques at harvest (pooled data of three years)

| Treatment | Plant height (cm) at harvest | No. of panicles/m² | Panicle length (cm) | Grains/ panicle | 1 000-grain weight (g) | Grain yield (kg/ha) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 2006 | 2007 | 2008 | Mean |
| *Rice establishment techniques* | | | | | | | | | |
| TPR | 65.93 | 205 | 19.88 | 109 | 23.43 | 1 891 | 2 407 | 4 816 | 3 038 |
| PBR | 67.57 | 275 | 19.76 | 99 | 25.25 | 2 875 | 2 743 | 4 411 | 3 343 |
| DSR | 64.82 | 244 | 20.15 | 104 | 23.53 | 2 657 | 2 433 | 3 533 | 2 874 |
| ZTDSR | 65.27 | 245 | 19.93 | 105 | 23.28 | 2 775 | 2 583 | 4 428 | 3 262 |
| LSD (*P*=0.05) | NS | 39 | NS | NS | 1.89 | 655 | NS | 794 | |
| *Tillage* | | | | | | | | | |
| Zero | 71.54 | 220 | 20.75 | 100 | 25.21 | | 2 479 | 4 404 | 3 442 |
| Conventional | 69.63 | 222 | 21.01 | 101 | 25.27 | | 2 603 | 4 191 | 3 397 |
| LSD (*P*=0.05) | 1.65 | NS | NS | NS | NS | | NS | NS | |
| *Weed control* | | | | | | | | | |
| Weedy check | 70.82 | 218 | 20.86 | 101 | 25.09 | | 2 230 | 4 009 | 3 120 |
| Pendimethalin 1.0 kg/ha + one HW (30 DAS) | 70.41 | 223 | 20.87 | 100 | 25.34 | | 2 852 | 4 585 | 3 719 |
| LSD (*P*=0.05) | NS | NS | NS | NS | NS | | 161 | NS | |

TPR,Transplanted rice; PBR,puddle broadcast rice; DSR,direct-seeded rice; ZT-DSR,zero-till direct seeded rice

chickpea (Table 3). This might be due to the effect of puddling on the vertical distribution of weed seeds in soil. Pre-emergence application of pendimethalin at 1.0 kg/ha, followed by one hand weeding at 30 DAS significantly reduced the density and dry weight of weeds as compared to weedy check. However, the effect was more pronounced on wild oats than that of toothed burclover due to emergence of later in different flushes.

Table 3 Effect of rice establishment techniques, tillage and weed management on density and dry weight of weeds in chickpea (pooled data of three years)

| Treatment | Weed density (No./m²) at 60 DAS | | | Weed dry weight (g/m²) at 90 DAS | | |
|---|---|---|---|---|---|---|
| | *Avena ludoviciana* | *Medicago hispida* | Total | *Avena ludoviciana* | *Medicago hispida* | Total |
| *Rice establishment techniques* | | | | | | |
| TPR | 6.91 (48) | 8.74 (76) | 11.41 (130) | 7.62 (58) | 6.84 (46) | 11.67 (136) |
| PBR | 7.34 (53) | 9.10 (82) | 11.99 (143) | 7.34 (53) | 7.39 (54) | 11.61 (134) |
| DSR | 6.99 (48) | 9.15 (83) | 11.81 (139) | 6.82 (46) | 7.51 (56) | 11.81 (139) |
| ZTDSR | 7.16 (51) | 9.68 (93) | 12.42 (154) | 6.91 (47) | 7.16 (51) | 11.37 (129) |
| LSD (*P*=0.05) | NS | 0.49 | NS | NS | NS | NS |
| *Tillage* | | | | | | |
| Zero | 6.97 (48) | 9.86 (97) | 12.43 (154) | 6.45 (41) | 7.4 (54) | 11.07 (122) |
| Conventional | 7.22 (52.1) | 8.47 (71) | 11.42 (130) | 7.77 (60) | 7.06 (49) | 11.76 (138) |
| LSD (*P*=0.05) | NS | NS | NS | 0.70 | NS | NS |
| *Weed control* | | | | | | |
| Weedy check | 9.68 (93) | 10.25 (105) | 14.42 (207) | 11.38 (129) | 10.14 (102) | 16.69 (278) |
| Pendimethalin 1.0 kg/ha + one HW (30 DAS) | 4.54 (20) | 8.07 (65) | 9.43 (88) | 2.83 (8) | 4.31 (18) | 6.57 (43) |
| LSD (*P*=0.05) | 0.71 | 0.68 | 1.11 | 0.71 | 0.68 | 1.14 |

TPR,Transplanted rice; PBR,puddle broadcast rice; DSR,direct-seeded rice; ZT-DSR,zero-till direct seeded rice
Data subjected to square root (x + 0.5) transformation; Values in parentheses are original.

*Plant population, growth and yield attributes:* Plant population, growth and yield attributes of chickpea were influenced significantly due to methods of rice establishment (Table 4). Initially (at 30 DAS), maximum plant population (69.13/m$^2$) was recorded in ZTDSR which was at par with DSR (65.44/m$^2$) but significantly superior to PBR (55.69/m$^2$) and TPR (53.50/m$^2$). However at harvest, the highest plant population (37.06/m$^2$) was recorded in PBR. Nodule dry weight and 100-seed weight were significantly higher in chickpea grown after TPR than the other methods. Zero tillage in chickpea had significantly higher plant population than CT. This may have been due to improved moisture conditions near the soil surface or greater seed-soil contact in ZT systems (Miller *et al*. 2002). However, the nodulation and yield parameters were significantly lower in ZT than CT. Weed infestation through out the crop growth period reduced final chickpea plant population (by 58.71%.), leaf area, nodulation, and yield attributes due to severe competition for solar radiation, nutrients and moisture. Controlling weeds with pendimethalin, followed by one HW improved the plant population, growth and yield attributes.

*Chickpea yield:* Irrespective of the treatments, yield of chickpea increased over the years (Table 4). This might be due to the cumulative legume effect of chickpea on soil fertility. Methods of rice establishment did not influence the yield of chickpea except during 2007–08 when ZTDSR produced significantly higher seed yield (1 145 kg/ha) than PBR (948 kg/ha). On mean basis, weed competition in chickpea caused 78.45% reduction in seed yield due to drastic reduction in plant population and yield attributes. Tillage × weed management interaction for seed yield was significant during 2008–09. Maximum seed yield (2 813 kg/ha) was noticed in pendimethalin, followed by one hand weeding under conventional tillage. This clearly indicated that weed management in chickpea was more beneficial in conventional tillage.

*Economic analysis and energy efficiency*

The total cost of cultivation in TPR-CT chickpea system (₹ 31 410/ha) was higher than other systems due to higher costs involved in field preparation and transplanting operations in rice (Table 5). The highest net returns (₹ 33,600/ha) and benefit: cost ratio (2.33) was accrued with ZTDSR-ZT chickpea cropping system and the lowest with DSR-CT chickpea system (₹ 20 222/ha and 1.67). The PBR-CT chickpea system required maximum energy (20 867 MJ/ha) closely followed by TPR-CT chickpea (20,594 MJ/ha) due to higher energy required for puddling in rice and tillage operations in chickpea. The energy productivity (yield per unit energy consumed) was maximum (0.401 kg/MJ) in ZTDSR-ZT chickpea, followed by TPR-CT chickpea (0.327 kg/MJ). The output energy was maximum in TPR-CT chickpea (99 049 MJ/ha), followed by ZT DSR-ZT chickpea (96 344 MJ/ha) due to higher system productivity. The energy

Table 4 Plant population, nodulation, growth and yield attributing characters of chickpea as affected by different rice establishment techniques, tillage and weed management practices at harvest (pooled data of 3 years)

| Treatments | Plant population (No./m$^2$) at 30 DAS | Plant population (No./m$^2$) at Harvest | Leaf area (cm$^2$)/ plant at 60 DAS | Nodule dry weight at 60 DAS (g/plant) | Number of pods/ plant at 60 DAS | Number of seeds/ plant | 100-seed weight (g) | Seed yield (kg/ha) 2006–07 | 2007–08 | 2008–09 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Rice establishment techniques* | | | | | | | | | | | |
| TPR | 53.50 | 32.19 | 186 | 71.8 | 28.00 | 27.93 | 17.83 | 584 | 1 064 | 1 550 | 1 066 |
| PBR | 55.69 | 37.06 | 182 | 61.3 | 25.90 | 24.81 | 16.94 | 459 | 948 | 1 546 | 984 |
| DSR | 65.44 | 30.44 | 188 | 59.2 | 24.52 | 24.9 | 15.32 | 635 | 1 069 | 1 598 | 1 101 |
| ZTDSR | 69.13 | 32.25 | 186 | 55.2 | 27.57 | 26.00 | 15.64 | 532 | 1 145 | 1 629 | 1 102 |
| LSD ($P$ = 0.05) | 8.58 | 2.58 | NS | 9.2 | NS | NS | 1.82 | NS | 146 | NS | |
| *Tillage* | | | | | | | | | | | |
| Zero | 73.50 | 41.06 | 171 | 51.5 | 22.84 | 23.18 | 15.82 | 620 | 1 031 | 1 495 | 1 048 |
| Conventional | 48.38 | 24.91 | 200 | 72.1 | 30.13 | 28.86 | 17.02 | 485 | 1 082 | 1 666 | 1 078 |
| LSD ($P$ = 0.05) | 4.06 | 1.78 | 10 | 5.4 | 3.67 | 2.44 | 0.93 | 72 | NS | NS | |
| *Weed control* | | | | | | | | | | | |
| Weedy check | 59.91 | 19.28 | 138 | 57.6 | 15.67 | 15.61 | 15.26 | 229 | 324 | 566 | 373 |
| Pendimethalin 1.0 kg/ha + one HW (30 DAS) | 61.97 | 46.69 | 233 | 66.0 | 42.03 | 36.76 | 17.34 | 876 | 1 788 | 2 594 | 1 731 |
| LSD ($P$ = 0.05) | NS | 1.78 | 17 | 6.3 | 2.62 | 2.09 | 1.34 | 70 | 62 | 305 | |

TPR,Transplanted rice; PBR,puddle broadcast rice; DSR,direct-seeded rice; ZT-DSR,zero-till direct seeded rice

Table 5 Comparison of yield, economics and energy use in rice-chickpea cropping system (based on third year 2008-09 data)

| Treatment | Yield (kg/ha) | | | Cost of cultivation (₹/ha) | Gross returns (₹/ha) | Net returns (₹/ha) | B:C ratio | Total energy requirement (MJ/ha) | Energy productivity (kg/MJ) | Output energy (MJ/ha) | Energy output: input ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice | Chickpea | Total | | | | | | | | |
| TPRice-ZT chickpea | 4 494 | 1 513 | 6 007 | 29 659 | 55 386 | 25 727 | 1.87 | 18 636 | 0.322 | 88 303 | 4.74 |
| TPRice-CT chickpea | 5 138 | 1 600 | 6 738 | 33 161 | 61 077 | 27 916 | 1.84 | 20 594 | 0.327 | 99 049 | 4.81 |
| Mean | 4 816 | 1 557 | 6 373 | 31 410 | 58 231 | 26 821 | 1.85 | 19 615 | 0.325 | 93 676 | 4.77 |
| PB Rice-ZT chickpea | 4 259 | 1 482 | 5 741 | 27 919 | 53 322 | 25 403 | 1.91 | 18 909 | 0.304 | 84 393 | 4.46 |
| PB Rice-CT chickpea | 4 576 | 1 618 | 6 194 | 31 421 | 57 735 | 26 314 | 1.84 | 20 867 | 0.297 | 91 052 | 4.36 |
| Mean | 4 418 | 1 550 | 5 968 | 29 670 | 55 529 | 25 859 | 1.87 | 19 888 | 0.300 | 87 722 | 4.41 |
| CTDSR-ZT chickpea | 3 817 | 1 497 | 5 314 | 26 809 | 50 709 | 23 900 | 1.89 | 17 629 | 0.301 | 78 116 | 4.43 |
| CTDSR-CT chickpea | 3 250 | 1 700 | 4 950 | 30 311 | 50 535 | 20 224 | 1.67 | 19 588 | 0.253 | 72 765 | 3.71 |
| Mean | 3 534 | 1 599 | 5 132 | 28 560 | 50 622 | 22 062 | 1.78 | 18 609 | 0.277 | 75 440 | 4.07 |
| ZTDSR-ZT chickpea | 5 044 | 1 510 | 6 554 | 25 309 | 58 909 | 33 600 | 2.33 | 16 334 | 0.401 | 96 344 | 5.90 |
| ZTDSR-CT chickpea | 3 813 | 1 748 | 5 561 | 28 811 | 55 025 | 26 214 | 1.91 | 18 293 | 0.304 | 81 747 | 4.47 |
| Mean | 4 429 | 1 629 | 6 058 | 27 060 | 56 967 | 29 907 | 2.12 | 17 313 | 0.353 | 89 045 | 5.18 |

TP,Transplanted; PB,puddle broadcast; DSR,direct-seeded rice; ZT,zero tillage; CT,conventional tillage

output:input ratio (5.90) was the highest in ZTDSR-ZT chickpea, followed by TPR-CT chickpea (4.81). The lowest energy productivity (0.253 kg/MJ), output energy (72 765 MJ/ha) and output: input ratio (3.71) was observed from DSR-CT chickpea system.

The study demonstrated that zero till direct-seeded rice, followed by zero-till chickpea was the best combination for maximizing system productivity, profitability and energy efficiency in Vertisols of Central India.

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