



## Effect of conservation agriculture practices on productivity and sustainability of pigeonpea (*Cajanus cajan*)-wheat (*Triticum aestivum*) cropping system in Indo-Gangetic plains of India

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### ABSTRACT

A long term field experiment was conducted at Indian Agricultural Research Institute, New Delhi during 2008-09 to 2011-12 on a sandy loam soil to study the effect of tillage and crop establishment techniques, and residue management practices on pigeonpea (*Cajanus cajan* L.) - wheat (*Triticum aestivum* L.) cropping system. Results indicated that zero tillage-raised bed (ZT-B), zero tillage-flat bed (ZT-F) and conventional tillage-raised bed (CT-B) influenced pods/plant, spikes/m<sup>2</sup> and grains/spike in pigeonpea and wheat crop. Grain yield of pigeonpea and wheat in zero tillage was 5.4 and 2.47 % higher over conventional tillage, respectively. ZT-F had higher system productivity, net returns and benefit:cost ratio, but ZT-B had higher wheat equivalent yield (WEY). Among all the practices, system yield and net returns were lowest in conventional tillage-flat bed (CT-F). Application of residue gave 14.32 and 34.39 % higher pigeonpea and wheat grain yield, respectively, over the no residue. System productivity, WEY and sustainable yield index (SYI) also increased in combined use of pigeonpea+wheat residue @ 3 tonnes/ha over no residue application. Zero tillage with combined application of residue @ 3 tonnes/ha improved productivity and sustainability of the system. Similar net returns were gained with pigeonpea + wheat residue @ 3 tonnes/ha (₹ 84,500) and sole pigeonpea residue @ 3 tonnes/ha (₹ 84 200) application, but net B:C ratio was higher with pigeonpea residue @ 3 tonnes/ha (2.68) than pigeonpea + wheat residue @ 3 tonnes/ha (2.55) application.

**Key words:** Pigeonpea, Residue, System productivity, Sustainable yield index, Wheat equivalent yield, Zero-tillage

Conservation agriculture (CA) has drawn considerable attention of researchers as it has potential to improve resource use efficiency (Govaerts *et al.* 2006), productivity (Nyborg *et al.* 1995) and soil health (Limon-Ortega *et al.* 2000), besides many environmental benefits (Kassam *et al.* 2010). Globally, CA occupies 124.8 mha, but in India, area under zero tillage is approximately 2.2 mha and mostly confined to rice-wheat cropping system (RWCS) only (FAO 2013). Minimum mechanical soil disturbance, organic mulch cover and crop diversification constitute the major practices under CA. Ladha *et al.* (2000) reported that higher productivity of RWCS can be obtained with adoption of CA practices over the conventional ones. Further, many studies reported that zero tillage with residues retention on soil enhance the soil physical, chemical and biological properties (Jat *et al.* 2013). Gathala *et al.* (2011) opined that crop residue management with no-till has a potential to improve soil carbon pool.

Pigeonpea (*Cajanus cajan* L.) -wheat (*Triticum aestivum* L.) cropping system is one of the major cropping system in Indo-Gangetic plain (IGP) of India occupying 3.58 mha acreage. This system could be a potential alternative to replace cereal based cropping system particularly RWCS, which is threatening sustainability of natural resources (Singh and Dwivedi 2006). According to Saharawat *et al.* (2010), sustainability of RWCS can be enhanced by adopting conservation agricultural practices. But, the information on the effect of conservation agriculture practices on productivity and sustainability of pigeonpea-wheat cropping system is meager under north-western IGP of India. This system is likely to have a great potential to replace the fatigued rice-wheat cropping system. Keeping above facts in view, a four year field study was conducted to assess the effect of tillage and crop establishment techniques, and crop residue management practices on productivity, sustainability and economics of pigeonpea (*Cajanus cajan* L.)-wheat (*Triticum eastivum* L.) cropping system. Further aim of this study was to work out the relationship between residue application and sustainability of pigeonpea-wheat cropping system.

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## MATERIALS AND METHODS

The field experiment was conducted for four consecutive years during 2008-09 to 2011-12 at the research farm of Indian Agricultural Research Institute, New Delhi ((28°37'N, 77°09'E, 228.7 m above mean sea level). The climate is semi-arid and temperature is usually warm in most of the period in a year; summer is hot and long and winter is severe and short with average temperatures of 42°C and 15°C, respectively. The mean annual rainfall during the experiment was 309, 542, 986 and 671 mm during 2008-09, 2009-10, 2010-11 and 2011-12, respectively. The soil of the experimental site was sandy loam (15.6% clay, 18.2% silt and 66.2% sand) in texture with pH 7.9 (1:2.5 soil to water). The soil contained 0.36 % organic C, 164 kg/ha available N, 10.2 kg/ha 0.5 M NaHCO<sub>3</sub> extractable available P and 270 kg/ha NH<sub>4</sub>OAc extractable available K (Prasad *et al.* 2006). The treatments (16) comprised of combinations of 4 tillage and crop establishment techniques (conventional tillage – raised bed (CT-B); conventional tillage - flat bed (CT-F); zero tillage – raised bed (ZT-B) and zero tillage - flat bed (ZT-F)) in main plots and 4 residue management practices (no residue; sole wheat residue @ 3 tonnes/ha; sole pigeonpea residue @ 3 tonnes/ha and combined pigeonpea and wheat residue (50:50) @ 3 tonnes/ha) in subplots, allocated randomly in a split plot design and replicated thrice. Under conventional tillage, the plots were ploughed 4 – 5 times (2 disc harrowing + 2 cultivators + 1 planking), while in zero-tillage the crop was sown without any tillage operations. The raised bed (70 cm centre to centre width of beds) was formed with a tractor mounted bed planter and basal dose of NPK was applied at sowing of both the crops. Under conventional tillage, beds were dismantled after ploughing with cultivator (2 times) followed by planking during every growing season. In zero tillage conditions, beds were reshaped by bed planter with minimum soil disturbance. Pigeonpea residues @ 3 tonnes/ha were applied to the wheat crop, while wheat residues @ 3 tonnes/ha were applied to pigeonpea only. In combined (50:50) application of pigeonpea + wheat residue @ 3 tonnes/ha, wheat residue @ 1.5 tonnes/ha was applied during *kharif* season in pigeonpea crop and in same plot pigeonpea residue @ 1.5 tonnes/ha was added in wheat crop during *rabi* season. Pigeonpea (cv Pusa 991) was sown in rows at 70 cm apart so as to get one row in the centre of each bed (70 cm centre to centre spacing), while three rows of wheat (cv HD 2895) were accommodated on the respective beds. Fertilizer dose of 20:26:33 kg N, P and K/ha was applied as basal to pigeonpea, while a dose of 120:26:33 kg N, P and K/ha was applied to wheat (50% of N and full P and K as basal and rest 50% N at first irrigation). Pigeonpea was sown during first week of June and manually harvested about 10 cm above the ground level during third week of November. Wheat was sown in fourth week of November and harvested in third week of April across the years.

All the necessary observations including yield attributes and grain yield of pigeonpea and wheat were recorded. To

compute the productivity of the system wheat equivalent yield (WEY) was calculated by using the following formula.

$$WEY = \{ \text{yield of pigeonpea (tonnes/ha)} \times \text{price of pigeonpea (₹/tonnes)} \} / \text{price of wheat (₹/tonnes)}$$

Productivity of the system was worked out by adding wheat yield and wheat equivalent yield for respective years. Afterwards, system productivity was pooled across four years and analysis of variance was performed to draw some logical conclusions. Also, sustainable yield index (SYI) of the system was calculated by using following formula given by Singh *et al.* (1990).

$$SYI = (y - \sigma_{n-1}) / y_m$$

where  $y$  is mean yield of respective treatment,  $\sigma_{n-1}$  is the standard deviation (SD) and  $y_m$  is the maximum yield of the treatment during a year. A two-factor analysis of variance (ANOVA) was carried out to test the significance of treatments. Critical difference (CD at P=0.05) was used to determine whether means differed significantly or not. Microsoft excel (Microsoft corporation, USA) was used for statistical data analysis.

## RESULTS AND DISCUSSION

*Yield attributes of pigeonpea and wheat*

Zero tillage – raised bed (ZT-B), conventional tillage – raised bed (CT-B) and zero tillage – flat bed (ZT-F) were found statistically comparable to each other with respect to pods/plant in pigeonpea (Table 1). Plots under conventional

Table 1 Yield attributes of pigeonpea and wheat as influenced by tillage and crop establishment, and residue management practices (data pooled over four years)

Treatment	Pigeonpea			Wheat		
	Pods/ plant	Seeds/ pod	Seed index	Spikes/ m <sup>2</sup>	Grains/ spike	Test weight (g)
<i>Tillage and crop establishment</i>						
CT-B	154.7	3.4	73.9	408.0	42.8	39.3
CT-F	149.2	3.2	73.5	424.9	45.2	41.6
ZT-B	155.6	3.6	74.3	412.8	44.8	40.6
ZT-F	153.2	3.4	73.5	429.0	47.0	42.9
SEm±	1.3	0.1	2.1	1.1	0.6	0.7
CD (P=0.05)	4.4	NS	NS	3.8	1.7	NS
<i>Residue management (3 tonnes/ha)</i>						
No residue	137.2	2.5	70.2	323.8	38.1	34.3
Wheat residue	151.5	3.5	73.0	411.6	43.8	40.8
Pigeonpea residue	160.2	3.7	75.3	457.3	47.6	43.1
Pigeonpea + wheat residue	163.7	3.9	76.8	481.9	50.2	46.2
SEm±	0.9	0.1	0.9	1.0	0.3	0.5
CD (P=0.05)	2.7	0.3	2.5	3.0	0.9	1.7

\*CT-B: Conventional tillage-raised bed; CT-F: conventional tillage-flat bed; ZT-B: zero tillage-raised bed; ZT-F: zero tillage-flat bed; Seed index: 100-seed weight; Test weight: 1000-grain weight; NS: Not significant

till-flat bed (CT-F) resulted in lowest number of pods/plant, which was at par to ZT-F and significantly lower to ZT-B and CT-B in pigeonpea. However, seeds/pod and seed index of pigeonpea remained unaffected significantly due to imposition of different tillage and crop management techniques. Contrary to the results obtained in pigeonpea, plots under ZT-F proved significantly better option with respect to yield attributes of wheat. The highest number of spikes/m<sup>2</sup> and grains/spike in wheat was recorded with ZT-F plots, which was significantly higher than rest of the tillage and crop establishment techniques. The effects of tillage practices and crop establishment techniques on 1000-grain weight of wheat were observed non-significant. Hence, it is evident that ZT-B treatment in pigeonpea and ZT-F in wheat, in general, favored the yield attributing characters. Irrespective of crop and nature of residues, different yield attributing parameters were influenced significantly due to application of crop residues @ 3 tonnes/ha on soil surface. Application of pigeonpea residues @ 3 tonnes/ha alone or in combination with wheat residues @ 3 tonnes/ha was advantageous over wheat residue @ 3 tonnes/ha or no residue, especially with respect to pods/plant in pigeonpea, and spikes/m<sup>2</sup>, grains/spike and 1000-grain weight in wheat. The highest number of pods/plant in pigeonpea was recorded with pigeonpea + wheat residues @ 3 tonnes/ha application, which was significantly higher to all the other residue management practices. However, values of seeds/pod and seed index in pigeonpea were observed at par with addition of pigeonpea residues @ 3 tonnes/ha alone or combined use of pigeonpea + wheat residues (50:50 ratio) @ 3 tonnes/ha. In wheat, highest values of spikes/m<sup>2</sup>, grains/spike and 1000-grain weight were recorded with pigeonpea + wheat residues @ 3 tonnes/ha application, which were significantly higher than all the other residue management practices. Overall, application of pigeonpea residues @ 3 tonnes/ha alone or combined use of pigeonpea + wheat residues @ 3 tonnes/ha favored most of the yield attributes in pigeonpea, but in wheat the combined use of pigeonpea + wheat residues @ 3 tonnes/ha was most effective in enhancing the values of yield attributes. Pigeonpea residues are rich in nitrogen and therefore have lower C: N ratio, which causes their faster decomposition/mineralization compared with wheat residues. The wider C: N ratio of wheat residues causes immobilization of N, which resulted in its lesser impact on yield attributes (Shivran and Ahlawat 2005).

### Yield

Tillage and crop establishment techniques influenced the grain yield of both pigeonpea and wheat significantly, except the grain yield of pigeonpea during first year (Table 2 and 3). Averaged across four years the grain yields of pigeonpea and wheat varied from 1.63 to 1.80 and 3.84 to 4.38 tonnes/ha, respectively. Under zero tillage, average grain yield of pigeonpea and wheat was 1.76 and 4.15 tonnes/ha, respectively. Likewise, corresponding grain yield for conventional tillage was 1.67 and 4.05 tonnes/ha, respectively. Hence, the grain yield of pigeonpea and wheat

Table 2 Yield of pigeonpea as influenced by tillage and crop establishment, and residue management practices

Treatment	Pigeonpea grain yield (tonnes/ha)					Pooled stalk yield (tonnes/ha)
	2008	2009	2010	2011	Pooled	
<i>Tillage and crop establishment</i>						
CT-B	1.69	1.73	1.70	1.75	1.72	5.78
CT-F	1.61	1.69	1.60	1.61	1.63	5.50
ZT-B	1.76	1.81	1.82	1.83	1.80	6.06
ZT-F	1.72	1.73	1.74	1.74	1.73	5.84
SEm±	0.03	0.02	0.03	0.02	0.03	0.07
CD	NS	0.07	0.08	0.07	0.05	0.26
(P=0.05)						
<i>Residue management 3 tonnes/ha</i>						
No residue	1.60	1.59	1.53	1.50	1.55	5.16
Wheat residue	1.71	1.78	1.75	1.69	1.73	5.83
Pigeonpea residue	1.73	1.79	1.79	1.90	1.80	6.14
Pigeonpea + wheat residue	1.73	1.80	1.79	1.84	1.79	6.05
SEm±	0.03	0.02	0.02	0.02	0.02	0.08
CD (P=0.05)	0.09	0.06	0.07	0.06	0.04	0.24

\*CT-B: Conventional tillage-raised bed; CT-F: conventional tillage-flat bed; ZT-B: zero tillage-raised bed; ZT-F: zero tillage-flat bed; NS: not significant

Table 3 Yield of wheat as influenced by tillage and crop establishment, and residue management practices

Treatment	Wheat grain yield (tonnes/ha)					Pooled straw yield (tonnes/ha)
	2008	2009	2010	2011	Pooled	
<i>Tillage and crop establishment</i>						
CT-B	3.81	3.86	3.90	3.79	3.84	5.24
CT-F	4.24	4.28	4.27	4.24	4.26	6.00
ZT-B	3.92	3.98	3.85	3.92	3.92	5.59
ZT-F	4.41	4.50	4.15	4.45	4.38	6.40
SEm±	0.04	0.06	0.04	0.03	0.01	0.05
CD (P=0.05)	0.15	0.20	0.15	0.10	0.03	0.19
<i>Residue management 3 tonnes/ha</i>						
No residue	3.15	3.56	3.57	3.26	3.39	4.56
Wheat residue	4.21	4.11	4.02	4.14	4.12	5.83
Pigeonpea residue	4.42	4.36	4.20	4.41	4.35	6.32
Pigeonpea + wheat residue	4.59	4.58	4.37	4.59	4.54	6.52
SEm±	0.04	0.05	0.03	0.03	0.01	0.05
CD (P=0.05)	0.13	0.14	0.09	0.09	0.02	0.13

\*CT-B: Conventional tillage-raised bed; CT-F: conventional tillage-flat bed; ZT-B: zero tillage-raised bed; ZT-F: zero tillage-flat bed

in zero tillage was 5.4 and 2.47 % higher over conventional tillage, respectively. Yield enhancement in zero tillage may be linked to subsequent lesser oxidation of organic C (OC)

over the years. Increase in OC over the years improves the structure of soil, especially micro-aggregates, which is active site of holding the labile C for longer periods. Higher yield of pigeonpea on beds may be ascribed to less competition with weed with respect to water, nutrients and space (Chauhan *et al.* 2004). Zero tillage with bed had lower traffic compaction especially at lower soil depth. The deep prolific roots of pigeonpea explored deeper soil layer, so efficient nutrient recycling occurred which was reflected in yield (Gangaiah *et al.* 2012). As soil of the experimental site was sandy loam in texture (loose soil), it was quite difficult to retain the beds in proper shape, which resulted in uneven distribution of plant population and hence reduced wheat yield. Application of residue significantly influenced the grain yields of both the crops over control (no residue) during all the years (Table 2 and 3). In pigeonpea, all residues applied @ 3 tonnes/ha were found comparable to each other. Average across the years, application of residues @ 3 tonnes/ha gave 14.3% higher grain yield over no residue application. Although in wheat, wheat residue @ 3 tonnes/ha gave lowest grain yield among the residues, furthermore combined application of pigeonpea and wheat residue @ 3 tonnes/ha was found superior over pigeonpea residue applied @ 3 tonnes/ha. During all the years, application of pigeonpea+wheat residue @ 3 tonnes/ha gave 34.4 % higher grain yield over no residue application. So, overall, combined application of pigeonpea + wheat residue @ 3 tonnes/ha was found suitable for enhancing the yields of both crops. Application of pigeonpea residues which had lower C: N ratio, mineralized N in shorter period and hence enhanced the growth and yields of both crops. Improvement in soil structure reduces losses of nitrogen and side by side improves plant N uptake. Increased N uptake in plant reflected in terms of higher biomass and grain yields. Carbon as a substratum is required for prolific growth of bacteria which is met out by higher C: N ratio of wheat residue. Mixed application of residue may be linked to biodiversity of micro-organisms (Singh *et al.* 2005).

#### System productivity and net returns

Among the tillage and crop establishment techniques, ZT-F plots had an upper edge over the others, especially with respect to system productivity, sustainable yield index (SYI), net returns and net benefit : cost (B:C) ratio (Table 4). The system productivity under ZT-F was obtained 6.52, 4.60 and 2.76% higher over CT-B, CT-F and ZT-B, respectively. However, highest wheat equivalent yield (WEY) was obtained with ZT-B, which was significantly higher over all the other tillage and crop establishment techniques. The highest value of SYI was recorded in ZT-F, which was significantly higher than CT-B, CT-F and ZT-B. Furthermore, net returns were also obtained highest with ZT-F, being 16.6, 9.9 and 6.9 % higher over CT-B, CT-F and ZT-B, respectively. At par WEY was obtained under pigeonpea residue alone @ 3 tonnes/ha and combined use of pigeonpea + wheat residue @ 3 tonnes/ha, both (Residues of pigeonpea and pigeonpea + wheat) yielded significantly

Table 4 System productivity (in wheat equivalent yield) and net returns of pigeonpea-wheat system as influenced by tillage and crop establishment, and residue management practices

Treatment	Wheat equivalent yield (tonnes/ha)	System productivity (tonnes/ha)	SYI of the system	Net returns of the system (× 10 <sup>3</sup> Rs)	Net B:C
<i>Tillage and crop establishment</i>					
CT-B	4.18	8.02	0.80	71.8	2.19
CT-F	3.95	8.20	0.84	76.1	2.37
ZT-B	4.39	8.31	0.82	78.3	2.60
ZT-F	4.21	8.58	0.87	83.7	2.80
SEm±	0.04	0.04	0.003		
CD (P=0.05)	0.13	0.14	0.01		
<i>Residue management(3 tonnes/ha)</i>					
No residue	3.76	7.14	0.71	65.6	2.49
Wheat residue	4.20	8.32	0.84	75.5	2.24
Pigeonpea residue	4.40	8.75	0.88	84.2	2.68
Pigeonpea + wheat residue	4.36	8.89	0.90	84.5	2.55
SEm±	0.04	0.04	0.004		
CD (P=0.05)	0.11	0.12	0.01		

\*CT-B: Conventional tillage-raised bed; CT-F: Conventional tillage-flat bed; ZT-B: Zero tillage-raised bed; ZT-F: Zero tillage-flat bed; System productivity: wheat equivalent yield of pigeonpea + wheat yield; SYI: Sustainability yield index; B:C: Benefit:cost ratio; MSP of pigeonpea for 2008-09, 2009-10, 2010-11 and 2011-12 was 2000, 2300, 3000 and 3200 Rs/q, respectively. MSP of wheat for 2008-09, 2009-10, 2010-11 and 2011-12 was 1 000, 1 080, 1 100 and 1 120 Rs/q, respectively.

higher WEY over no residue or wheat residue application @ 3 tonnes/ha. Combined application of pigeonpea + wheat residue @ 3 tonnes/ha gave significantly higher system productivity and SYI than all other residue management practices. Correlation analysis showed a positive and significant (Pd<sup>0.01</sup>) linear relationship ( $R^2 = 0.999$ ) between system productivity and sustainable yield index as influenced by crop residues (Fig. 1). The combined use of pigeonpea

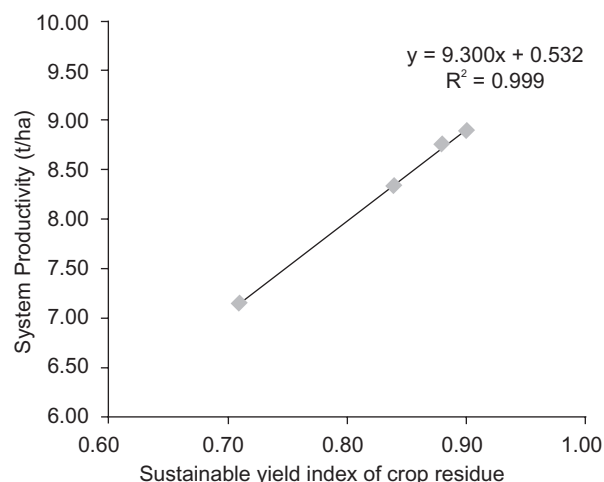


Fig 1 Linear relationship between crop residue application and system productivity of pigeonpea-wheat cropping system

and wheat residue applied @ 3 tonnes/ha may have enhanced the biodiversity of soil organisms, which may be led to increased mineralization and recycling of nutrients. Almost equal net returns were obtained with pigeonpea + wheat residue @ 3 tonnes/ha (₹ 84 500) and sole pigeonpea residue @ 3 tonnes/ha (₹ 84 200) application, but net B: C ratio was higher with pigeonpea residue @ 3 tonnes/ha (2.68) than pigeonpea + wheat residue @ 3 tonnes/ha (2.55) application.

### CONCLUSIONS

Based on the findings, it may be concluded that zero-tillage either with raised bed or flat bed and combined application of pigeonpea and wheat residue @ 3 tonnes/ha can enhance productivity and sustainability of pigeonpea-wheat cropping system over the years.

### REFERENCES

- Chauhan Y S, Apphum A, Singh V K and Dwivedi B S. 2004. Foliar sprays of concentrated urea at maturity of pigeonpea to induce defoliation and increase its residual benefit to wheat. *Field Crop Research* **89** (1): 17–25.
- FAO. 2013. FAO CA website at: [www.fao.org/ag/ca](http://www.fao.org/ag/ca) (accessed 15 March 2013).
- Gathala M K, Ladha J K, Kumar V, Saharawat Y S, Kumar V, Sharma P K, Sharma S and Pathak H. 2011. Tillage and crop establishment affects sustainability of South Asian rice-wheat system. *Agronomy Journal* **103**: 961–71.
- Gnagaiah B, Ahlawat I P S and Shivakumar B G. 2012. Crop rotation and residue recycling effects of legumes on wheat as influenced by nitrogen fertilization. *Agricultural Science Research Journal* **2**(4):167–76.
- Govaerts B, Sayre K D, Ceballos-Ramirez J M, Limon-Ortega A, Deckers J, Denodooven L. 2006. Conventionally tilled and permanent raised beds with different crop residue management: effects on soil C and N dynamics. *Plant and Soil* **298**:143–55.
- Jat M L, Gathala M K, Saharawat Y S, Tatarwal J P, Gupta R and Singh Y. 2013. Double no-till and permanent raised beds in maize-wheat rotation of north-western Indo-Gangetic plains of India: Effects on crop yields, water productivity, profitability and soil physical properties. *Field Crop Research* **149**: 291–9.
- Ladha J K, Fischer K S, Hossain M, Hobbs P R, Hardy B. 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. IRRI discussion paper no. 40, 31.
- Limon-Ortega A, Sayre K D and Francis C A. 2000. Wheat nitrogen use efficiency in a bed planting system in Northwest Mexico. *Agronomy Journal* **92**: 303–8.
- Nyborg M, Solberg E D, Izaurralde R C, Malhi S S, Molina-Ayala M. 1995. Influence of long term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. *Soil and Tillage Research* **36**:165–74.
- Prasad R, Shivay Y S, Kumar D and Sharma S N. 2006. Learning by doing exercises in soil fertility (A practical manual for soil fertility). Division of Agronomy, Indian Agricultural Research Institute. New Delhi.
- Kassam A H, Friedrich T, Derpsch R. 2010. Conservation agriculture in the 21<sup>st</sup> century: A paradigm of sustainable agriculture. Invited paper at the European Congress on Conservation Agriculture, October 2010, Madrid, Spain.
- Saharawat Y S, Singh R K, Malik J K, Ladha M, Gathala M K and Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in north-western IGP. *Field Crops Research*. **116**: 260–7.
- Shivran D R and Ahlawat I P S. 2005. Effect of cropping systems and fertilizers on pigeonpea (*Cajanus cajan*) and wheat (*Triticum aestivum*) in pigeonpea-wheat sequence. *Indian Journal of Agronomy* **45**(4): 669–75.
- Singh R P, Das S K, Rao U M B and Reddy M N. 1990. *CRIDA Report*, CRIDA, Hyderabad, India, 106 p.
- Singh V K and Dwivedi B S. 2006. Yield and nutrient use efficiency in wheat, and soil fertility status as influenced by substitution of rice with pigeonpea in a rice-wheat cropping system. *Australian Journal of Experimental Agriculture* **46**:1 185–94.