Indian Journal of Agricultural Sciences **92** (7): 857–61, July 2022/Article
https://doi.org/10.56093/ijas.v92i7.110113

Evaluating the trade-offs and sustainability of minimum tillage and crop-residue addition for food production in the dryland tropics

KUMARI ADITI[1,2]*, GIRISH CHANDER[1], P LAXMINARAYANA[2], S NARENDER REDDY[2], G PADMAJA[2], S P WANI[1] and S DIXIT[1]

Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana 500 030, India

Received: 03 February 2021; Accepted: 06 April 2022

ABSTRACT

A long-term study was carried out at ICRISAT farm, Patancheru (India) during rainy (*kharif*) season 2009–18 with an objective to evaluate impact of tillage (minimum/conventional) and residue (addition/removal) management practices on production capacity and sustainability of maize-chickpea sequential and maize+pigeonpea intercropping systems. The experiment was laid out in spilt plot design with 4 replications. The effects of residue addition were inconsistent till the third year of experiment. However, yield benefits from residue addition became apparent fourth year onwards. After 7 years, residue addition showed significant yield benefits to the tune of 9–25% during 2016–17 (8th cropping cycle) and 18–31% during 2017–18 (9th cropping cycle) in both cropping systems. Residue addition also resulted in additional net income of ₹16,900/ha to ₹22,980/ha compared to no-residue addition. Minimum tillage in general tended to result in yield loss over normal tillage since beginning. During 8th and 9th cropping cycles, there was net annual loss up to ₹5400/ha under minimum tillage. Alongside productivity and economic benefits, at the end of 8th year i.e. 2016–17, residue addition showed improved soil health and sequestered around 300 kg carbon/ha/year.

Keywords: Biomass, Carbon-sequestration, Crop residue, Cropping systems, Tillage

Global warming induced climate change is one of the major challenges of the 21st century causing serious implications on food security of rapidly increasing population. Agricultural ecosystems, especially in the drylands, are vulnerable to the projected changes (Xue *et al*. 2015). Management practices like minimum tillage and recycling of crop-residues are often advocated as one of the adaptation and mitigation strategies for climate change. Minimum tillage needs to be evaluated for its expected benefits in improving soil quality and sustainable management *vis-à-vis* trade-offs. It is established to have several land and water conservation benefits, and improved biochemical properties of soil (Martínez *et al*. 2016, Schmidt *et al*. 2018). By contrast, there are many studies that show lower or no significant benefits under minimum tillage (Pittelkow *et al*. 2015).

Addition of crop residues on the soil surface may positively influence processes like soil aggregation, porosity, reduced evaporation and increased ion exchange (Chander *et al.* 2018). Linkages of organic matter with soil health and yield are well established, hence investments in terms of organic inputs are likely to benefit sustainable productivity. Choice of cropping system decides the fate of residue and its recycling for building soil health and improving crop productivity. Maize+pigeonpea is a predominant intercropping system of semi-arid tropics and maize-chickpea cropping sequence is a prevalent cereal-legume cropping system in India.

There are divergent views on the trade-offs of minimum tillage and crop-residue addition and there is limited conclusive long-term data in the semi-arid tropics and with crops like pigeonpea, chickpea in a maize-based cropping system. In this scenario, the long-term experiment in Vertisol during 2009 with objectives to study the impact of tillage practices, residue management on soil health and system resilience, understand the scalability of minimum tillage, residue addition in the semi-arid tropics was conducted. After 7 years of the experiment, during 2016–17 (8th year) and 2017–18 (9th year), a detailed evaluation was undertaken to understand the long-term scalability and sustainability of minimum tillage and residue addition in two cropping systems under study.

MATERIALS AND METHODS

A long-term field experiment was conducted during rainy (*kharif*) season 2009 on ICRISAT farm (17.50ºN, 78.26ºE and altitude 545 m) at Patancheru, India. The soil

[1]International Crops Research Institute for Semi-Arid Tropics, Patancheru, Telangana; [2]Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Telangana.*Corresponding author email: mishra.aditi20@gmail.com

of experimental site was Vertisol. The local climate of the study area was semi-arid with average rainfall of 898 mm, of which ~781 mm rainfall was distributed over June–October and ~87 mm was distributed over November–March. Experiment was laid out on broad-beds and furrows (in 1.05 m wide raised bed followed by 0.45 m wide furrow) in a split design with four replications under rainfed conditions.

Main plot consisted of two tillage practices (minimum tillage and conventional tillage) and sub-plot of two residue management practices (residue addition and no-residue addition) was evaluated under two cropping systems, viz. maize-chickpea sequence and maize+pigeonpea intercrop. Soil disturbance under minimum tillage was restricted to refreshing of furrows before the start of *kharif* and sowing on raised beds with the help of seed-cum-fertilizer drill. While, in conventional tillage plots, ploughing of field with chisel plough, mould board plough and ridge and harrow as normal farmers' practice was undertaken. The residues were completely removed from the no-residue addition treatments, while entire crop residues were chopped into finer sizes and spread evenly to cover the beds at end of the crop season under residue addition. Total residue added in the system was 10.5 t/ha and 16.1 t/ha in maize-chickpea sequential and maize+pigeonpea intercropping system during 2016–17 while 7.8 t/ha and 16.4 t/ha was added in maize-chickpea sequential and maize+pigeonpea intercropping system during 2017–18. Crop residues are storehouse of major portion of nutrients taken up by the plants, and are a potential source of crop nutrients in residue added plots. No irrigation was provided to the crop at any growth stage.

Maize hybrid HTM-5401 was intercropped with pigeonpea hybrid ICPH-2671 in the maize+pigeonpea intercropping system. In maize-chickpea sequential cropping system, HTM-5401 was grown in rotation with chickpea variety ICCV-2. Plant to plant spacing followed was 30 cm in pigeonpea, 15 cm in maize and 10 cm in chickpea and seeds were sown at a depth of 5 cm. The fertilizer schedule adopted for maize crop was 150, 60 and 40 kg/ha of N, P and K respectively and for chickpea was 25 and 50 kg/ha of N and P respectively. Entire dose of phosphorus and potassium were applied as basal in the form of DAP and MOP respectively. Nitrogen in the form of urea after calculating the proportion supplied through DAP was applied in three splits at 30 days interval. Secondary nutrient S in the form of gypsum and micronutrient B in the form of solubor were applied every alternate year. Destructive samples were undertaken in an area of 3×3 m^2 and yields were interpolated in kg/ha. Post-harvest surface (0–0.15 m) soil samples were analyzed for organic carbon.

An economic analysis was undertaken to evaluate the practices of residue addition and minimum tillage. Yield gain or loss was worked out in monetary terms at prevailing

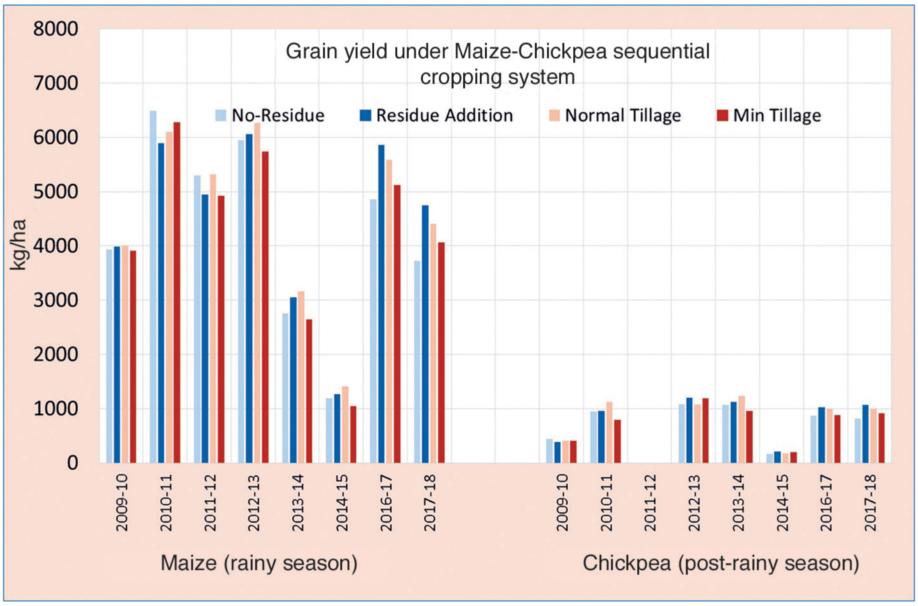

Fig 1 Effect of tillage and residue management practices on crop grain yield (kg/ha) of maize-chickpea sequential cropping system.

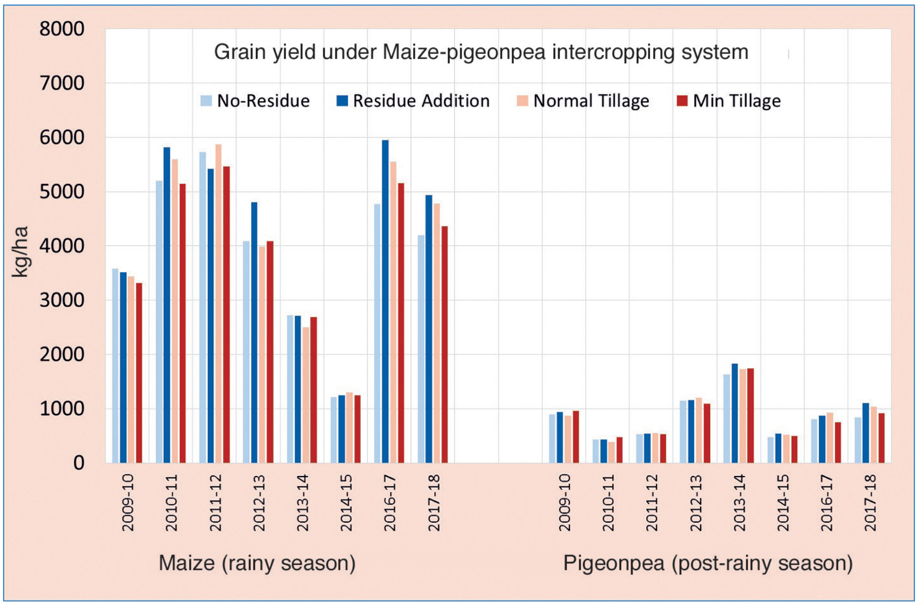

Fig 2 Effect of tillage and residue management practices on crop grain yield (kg/ha) of maize-pigeonpea sequential cropping system.

market prices at the rate ₹1365 per quintal for maize, ₹4000 per quintal for chickpea and ₹5050 per quintal for pigeonpea in 2016–17 and ₹1425, ₹4400 and ₹5450 per quintal for maize, chickpea and pigeonpea, respectively in 2017–18. In residue addition, additional cost of chopping and spreading of biomass at the rate ₹2700/ha was taken. In minimum tillage, savings of ₹8500/ha on account of reduced tillage and cultural operations was considered. Net gain or loss was worked out considering additional cost or savings under residue addition and minimum tillage. Data collected were analyzed statistically using the technique of analysis of variance for split design and significance was tested by F-test (Snedecor and Cochran 1989).

RESULTS AND DISCUSSION

Yield response during initial year: During initial years of the experiment, crop yield did not show any significant difference in response to both the treatments under any of the cropping systems (Fig 1, 2). From 4th year *i.e.* since 2012–13, residue addition started showing yield benefits, while minimum tillage tended to decrease the yield. Some earlier studies also reported yield improvement with the advancement of the experiment in the later years (Sharma *et al*. 2005). Apparently, improved soil structure along with enhanced soil biophysical activity and nutrient cycling with the addition of residue led to improvement in crop yields over the period (Verhulst *et al*. 2010). Reduction in yield under minimum tillage is probably due to the strongly established weeds observed in the plots as a result of reduced disturbance and uprooting that happens under the normal tillage practice. Decline in yield with minimum tillage also occurred due to poor stand establishment owing to a denser top soil (Martínez *et al*. 2016). Denser top soil also reduces infiltration and consequently low moisture availability in the root zone cause a decline in the yield (Ndoli *et al*. 2018). Pittelkow et al. (2015), in a global meta-analysis also observed a negative yield response to minimum till irrespective of residue addition and crop rotation.

Yield response during 8th and 9th year: Addition of residue led to a significant increase in maize yield over no residue addition by around 21–28% in maize-chickpea system and by 18–25% in maize+pigeonpea intercropping system (Fig 1, 2). Higher maize yield was recorded in maize+pigeonpea intercropping system compared with maize-chickpea sequence. Yield of chickpea and pigeonpea also showed a similar trend with residue addition. Yields were higher by 18–30% and 10–32% in chickpea and pigeonpea, respectively. However, there was no significant difference in yield with the two tillage treatments in any of the cropping system, but it tended to decline under the minimum tillage compared with the conventional tillage. Interaction of tillage and residue management remained non-significant in both the years.

Increased food grain production under residue addition is apparently due to the carbon sequestered and enhanced availability of micro and secondary nutrients in this study. The linkages of soil organic-C with soil physical, chemical and biological properties, and yield are well established (Lal 2013). With the slow release of additional nutrients through recycled biomass, the yield improvement is on expected lines. Moreover, due to the mulching effect of residue, the evaporation losses are reduced while improving infiltration and conservation of soil moisture (Jat *et al*. 2015). However, yield of crops declined with the minimum tillage probably due to poor crop plant stand establishment owing to a serious weed menace. Pittelkow *et al*. (2015), in a global meta-analysis also observed a negative yield response to minimum till irrespective of residue addition and crop rotation.

With regard to the stover yield, addition of residues during both the years, 2016–17 and 2017–18, led to a significant increase in maize over no-residue addition by around 17–27% in maize-chickpea sequential system and by 17–22% in maize+pigeonpea intercropping system creating an opportunity for higher biomass turnover (Table 1).

Tillage practices did not show any significant impact on maize stover yield in any of the cropping systems. In general, yield tended to decline under minimum tillage. Higher

Table 1 Effect of tillage and residue management practices on stover yield (kg/ha) and soil organic C (%)

Treatment	Stover yield		Soil organic-C (2016–17)
	Maize	Chickpea/ Pigeonpea	
Maize-chickpea			
Residue management			
No-residue addition	4630	2130	0.42
Residue addition	5420	2780	0.54
SEm(±)	68	35	0.023
CD (P=0.05)	241	124	0.080
Tillage			
Conventional tillage	5420	2460	0.48
Minimum tillage	4640	2450	0.48
SEm(±)	390	137	0.026
CD (P=0.05)	NS	NS	NS
Maize+pigeonpea			
Residue management			
No-residue addition	4300	10480	0.46
Residue addition	5240	11760	0.59
SEm(±)	165	284	0.023
CD (P=0.05)	571	980	0.081
Tillage			
Conventional tillage	4930	11760	0.56
Minimum tillage	4620	10480	0.50
SEm(±)	414	173	0.019
CD (P=0.05)	NS	772	NS

maize stover yield was recorded from maize+pigeonpea intercropping over sole maize stover yield from maize-chickpea sequence. Similarly, the stover yield of chickpea increased by 30–50% with the addition of residue and the yield of pigeonpea increased by around 11–12%. Thus, residue addition recorded more food grain production and also produced more biomass C for recycling into soil.

Similar to the grain yield as explained earlier, apparently residue addition showed a positive influence on stover yield. Lower bulk density coupled with high organic matter and availability of nutrients probably led to better stand establishments and vigorous growth of plants (Ndoli *et al*. 2018) resulting in higher stover yields under residue added treatments. The two cropping systems experienced a reduction in plant density and growth under minimum tillage leading to a significant loss in stover yields of the crops.

Economics of food production: Residue addition incurred an additional cost of residue chopping and spreading on the fields, but the extra cost was offset due to the additional yield and monetary benefits (Table 2). Addition of residue led to a net gain of ₹16,940 to ₹16,950/ha during 2016–17 and ₹22,050 to ₹22,980/ha during 2017–18. Cost of cultivation was low in minimum tillage as the number of operations were less. Minimum tillage also ensured fuel savings upto 60 litre/ha over conventional tillage. This led to a saving of ₹8500/ha in the minimum tillage over conventional tillage. However, this benefit was offset due to loss of yields in minimum tillage. The losses in grain yield in maize-chickpea sequence, during 2016–17 were 470 kg/ha in maize and 120 kg/ha in chickpea, whereas maize crop yield loss in maize+pigeonpea intercrop was 390 kg/ha and 170 kg/ha in pigeonpea. During 2017–18, the respective losses were 340 kg/ha and 80 kg/ha under maize-chickpea and 420 kg/ha and 120 kg/ha under maize+pigeonpea system.

The practice of residue addition, despite increase in cost of cultivation on account of unavailability of otherwise available stover for sale, additional cost of chopping and labor cost incurred in application (Tui *et al*. 2015), prove to be a scalable option due to reasonably higher additional yield and monetary benefits. Minimum-tillage practices have the potential to decrease energy and labor requirements, due to the elimination of seedbed preparation and disturbance-based weeding approaches (Mirsky *et al*. 2013) but does not prove to be an effective option to offset the reduction in gross and net returns due to loss in yield.

Post-harvest soil health and carbon-sequestration: After 8 years of crop cycle, residue addition recorded a significant increase in soil organic C under both the systems at the rate of 300 kg/ha/year. Addition of residue led to a significant increase in the organic C in the upper layers (Table 1) because of added residues and root concentration in this layer. The practice of residue addition sequesters carbon due to continued accumulation of organic matter, enhanced biomass generation and recycling (Corbeels *et al*. 2006). Under this study, C-sequestration of 300 kg/ha/year observed under residue addition is comparable to the sequestration recorded under other studies in the semi-arid tropics (Wani *et al*. 2003). This is a very significant environmental impact through residue management component in addition to productivity and economic benefits. However, no significant changes in soil organic C were observed with minimum tillage probably due to decline in biomass production due to weed menace and soil crusting. The apparent gain in soil C due to positively influencing aggrading and reduced

Table 2 Effect of tillage and residue management practices on economics of maize-chickpea sequential cropping and maize+pigeonpea intercropping system

Treatment	Additional Yield gain/loss (kg/ha)		Additional Yield gain/loss in monetary terms (₹/ha)		Additional cost and intervention (₹/ha)	Additional savings through intervention (₹/ha)	Net gain/loss (₹/ha)	
	Gain	Loss	Gain	Loss			Gain	Loss
2016–17								
Maize-chickpea								
Residue addition	1000+150*	-	19,650	-	2700	-	16,950	-
Minimum tillage	-	470+120*	-	11,220	-	8,500	-	2,720
Maize+pigeonpea								
Residue addition	1180+70**	-	19,640	-	2700	-	16,940	-
Minimum tillage	-	390+170**	-	13,910	-	8,500	-	5,410
2017–18								
Maize-chickpea								
Residue addition	1030+250*	-	25,680	-	2700	-	22,980	-
Minimum tillage	-	340+80*	-	8,370	-	8,500	130	-
Maize+pigeonpea								
Residue addition	740+260**	-	24,720	-	2700	-	22,050	-
Minimum tillage	-	420+120**	-	12,530	-	8,500	-	4,030

*Maize+chickpea yield; **Maize+pigeonpea yield degrading processes under minimum tillage are probably undone by declining crop biomass (shoot and root).

Yield is the one most important parameter to determine scalability of any technology. After 7 years, we found yield advantage of around 10–30% in residue added plots. In crops like pigeonpea, chickpea and maize, generally, some portion of straw/residue (10–20%) i.e. leaves have competitive use as cattle fodder, but majority of biomass i.e. stubbles in maize, chickpea and pigeonpea, have potential opportunity for recycling with or without composting. There is more carbon sequestration (around 300 kg/ha/year) with residue addition, proving it to be a potential C-sequestration option. As regard to minimum tillage, it did not improve soil C or other soil health parameters. At the same time, under minimum tillage, there is reduction in plant stand by 15–25% in individual crops, ultimately reflecting in yield loss by around 7–22%. The savings in reduced energy cost in cultivation is not off-setting loss due to yield, rather there are issues of weed menace and crop emergence in minimum tillage plots. In this scenario, crop residue addition having little competitive uses seems a scalable proposition, but with business models of arrangements for chopping biomass for addition into soil. On the other hand, minimum tillage seems a losing proposition.

REFERENCES

Anapalli S S, Reddy K N and Jagadamma S. 2018. Conservation tillage impacts and adaptations in irrigated corn production in a humid climate. *Agronomy Journal* **110**(6): 1–14.

Chander G, Wani S P, Pardhasaradhi G, Patil M and Rao A N. 2018. Building soil health, improving carbon footprint and minimizing greenhouse gas emissions through CSR. *Win-Win proposition for community and corporates through CSR (CABI 2018)*, pp. 35-54. Wani SP and Raju KV (Eds). CABI, Wallingford.

Corbeels M, Scopel E, Cardoso A, Bernoux M, Douzet J M and Neto M S. 2006. Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil. *Global Change Biology* **12**(9): 1773–87.

Jat R A, Wani S P, Pathak P, Singh P, Sahrawat K L, Chander G and Sudi R. 2015. Evaluating climate change mitigation and adaptation potential of conservation agriculture in semi-arid tropics of southern India. *British Journal of Environment and Climate Change* **5**(4): 324–38.

Lal R. 2013. Food security in a changing climate. *Ecohydrology and Hydrobiology* **13**(1): 8–21.

Mirsky S B, Ryan M R, Teasdale J R, Curran W S, Reberg-Horton C S, Spargo J T, Wells M S, Keene C L and Moyer J W. 2013. Overcoming weed management challenges in cover crop–based organic rotational no-till soybean production in the eastern United States. *Weed Technology* **27**(1): 193–203.

Martínez I, Chervet A, Weisskopf P, Sturny W G, Etana A, Stettler M, Forkman, J and Keller T. 2016. Two decades of no-till in the Oberacker long-term field experiment: Part I. Crop yield, soil organic carbon and nutrient distribution in the soil profile. *Soil and Tillage Research* **163**: 141–51.

Ndoli A, Baudron F, Sida T S, Schut A G, van Heerwaarden J and Giller K E. 2018. Conservation agriculture with trees amplifies negative effects of reduced tillage on maize performance in East Africa. *Field Crops Research* **221**: 238–44.

Pittelkow C M, Liang X, Linquist B A, Van Groenigen K J, Lee J, Lundy M E, Van Gestel N, Six J, Venterea R T and Van Kessel C. 2015. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **517**: 365.

Schmidt R, Gravuer K, Bossange A V, Mitchell J and Scow K. 2018. Long-term use of cover crops and no-till shift soil microbial community life strategies in agricultural soil. *PloS one* **13**(2): 1–19.

Sharma K, Mandal U K, Srinivas K, Vittal K, Mandal B, Grace J K and Ramesh V. 2005. Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil & Tillage Research* **83**(2): 246–59.

Snedecor G W and Cochran W G. 1989. Statistical methods, 8th edn. Ames: Iowa State University, Iowa, USA.

Tui S H K, Valbuena D, Masikati P, Descheemaeker K, Nyamangara J, Claessens L, Erenstein, O, Van Rooyen A and Nkomboni D. 2015. Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe. *Agricultural Systems* **134**: 48–60.

Verhulst N, Govaerts B, Verachtert E, Castellanos-Navarrete A, Mezzala M, Wall P, Deckers J and Sayre K D. 2010. Conservation agriculture, improving soil quality for sustainable production sysytems? *Advances in Soil Science: Food security and soil quality,* pp. 137–208. Lal R, Stewart B A (Eds). CRC press, Florida.

Wani S, Pathak P, Jangawad L, Eswaran H and Singh P. 2003. Improved management of Vertisols in the semiarid tropics for increased productivity and soil carbon sequestration. *Soil Use and Management* **19**(3): 217–22.

Xue J F, Pu C, Liu S L, Chen Z D, Chen F, Xiao X P, Lal R and Zhang H L. 2015. Effects of tillage systems on soil organic carbon and total nitrogen in a double paddy cropping system in Southern China. *Soil & Tillage Research* **153**: 161–68.