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Special Issue Article

India's Consortia Research Platform on Conservation Agriculture: Recent Advancements and Lessons Learnt in Rainfed Semi-arid Ecologies

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ABSTRACT

Conservation agriculture (CA) is a key climate resilient and resource saving technology for higher productivity while reversing soil degradation in rainfed regions. In India, CA in the rice -wheat system of the Indo-Gangetic Plains (IGP) of south Asia has been extensively studied. However, relatively less attention was given to develop strategies to overcome the constraints in the adoption of CA in rainfed regions. Therefore, studies were initiated in rainfed regions under different cropping systems and soil types to standardize the best management practices and to address various constraints related to adoption of CA. Based on the results of experiments conducted in various agro ecosystems it has been found that the effect of CA on crop productivity and soil properties in different experiments are variable, depending on the management factors and duration of the study. Adoption of CA resulted in improvement in crop yield to the extent of 9-36.7% under different cropping systems, increase in net monetary returns by 14-87% and rain water productivity by 4-25%. The water infiltration rate was increased by 53.2 -56.8 %, soil organic carbon content increased by 5-45.1% under different cropping systems at different soil depths. The available soil moisture content increased by 1.8-46.8% and the available soil nitrogen, phosphorus and potassium increased by 2.7-41.6,0.6-64.8 and 6.1-26.2%, respectively. The energy input under CA decreased by 0.9-57.6%, energy saving increased by 0.9- 34.88% and the energy use efficiency increased by 9.47-66.8%. The runoff and soil loss also decreased by 17.6-37.9% and 44.7-56.5%, respectively under CA as compared to conventional tillage (CT). Furthermore, we have observed that CA integrated with complementary practices like *in situ* moisture conservation (through permanent conservation furrow or permanent raised bed and furrow) in maize/horse gram-pigeonpea, maize-pigeonpea system, weed and nutrient management practices in maize-pigeonpea, pearl millet-pigeonpea and cotton-pigeonpea improved the crop productivity and soil health in rainfed agro-ecosystems. Increase

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in crop residue retention either through manipulation of harvest height to 30-60 cm in cereals and live mulch with *dhaincha* in pigeonpea-castor system, improve soil health, resilience to climate change, productivity and profitability. These technologies have feasibility of adoption by the farmers.

Key words: Conservation agriculture, crop residue management, soil loss, soil health, sustainable agriculture, environmental benefits

Introduction

India has achieved self-sufficiency in food grain production courtesy green revolution technologies. However, the sustainability of our production systems remains endangered owing to the burgeoning population and increased pressure to meet the food production demand of the country. To meet the food grain demand of the projected population, agriculture in 2050 will need to produce almost 50 per cent more food, feed and biofuel than it did in 2012. Achieving this projected demand and sustaining the production and productivity levels will be a major challenge in years to come (FAO, 2017). Increased use of fertile land and water for non-agricultural purposes have led to increased use of relatively less fertile soils of rainfed regions for food production, which further aggravated the situation. In recent years the global emphasis has shifted from improving potential yield levels to environmental concerns, soil health, reducing costs of production, improving the nutritional value of foods, reducing post-harvest losses, improving stress tolerance, reducing reliance on chemical crop protection measures (Brodt, 2011). Thus, sustainability of future agricultural systems, in the years to come will pose even greater challenges than the present scenario. Hence, attention has been shifted to increase the crop productivity of the rainfed arid and semi-arid areas of the country in a sustainable manner. India with 71.75 m ha area under rainfed condition ranks first among the rainfed regions in the world, accounting 56% of the country's net sown area contributing around 44% of food grain production and supporting 40% of the population (Srinivasa Rao *et al.*, 2015). Rainfed ecosystems are typically characterized from semi-arid to sub-humid environments, light to heavy-textured red, alluvial and black soils, spread across the country (Srinivasa Rao *et al.*, 2015). The crop productivity in rainfed regions is low due to occurrence of wide variation in amount and distribution of rainfall leading to frequent droughts/floods, terminal heat stress, soil degradation, poor soil health, low farm mechanization, low input use, etc. Furthermore, the qualities of natural resources in the rainfed ecosystems are deteriorating due to poor management of resources, which severely affects land and agronomic productivity (Anonymous, 2019). Soils in the rainfed region have varieties of physical constraints. In Alfisols surface crusting is the main reason for poor infiltration and problems during cultivation which cause high run-off, whereas deep cracks in Vertisols lead to evaporation and bypass flow resulting in lower rain water use efficiency. Due to erratic rainfall and low water storage, even complete infiltration of rainwater early in the season may not be sufficient to avoid moisture stress later. This underlines the importance of enhancing rain water use efficiency through improved infiltration and reduced evaporation losses for reducing the risk of crop failure in semi-arid tropical (SAT) regions. In eastern regions of the country, after rice harvest, around 9.2 m ha remains fallow during winter season due to non-availability of water for irrigation.

Conservation agriculture (CA) involving minimum soil disturbance, better management of crop residues through surface retention, and crop diversification, has emerged as a potential strategy and way forward from the existing unsustainable conventional agriculture (Hobbs, 2007; Hobbs *et al.*, 2008; Foley *et al.*, 2011). But region-specific CA options need to be identified, developed for implementation by resource-poor farmers (Fowler and Rockstrom, 2000). Even though the advantage of CA is largely realized in irrigated area, less attention has been paid in rainfed SAT regions of the country. Non–availability of crop residues, lack of proper machinery for sowing, termites in Alfisols and rodent problem in Vertisols, limited knowledge and capacity of farmers to implement CA systems, lack of profitable crop rotation systems, lack of access to the inputs, etc. are the major constraints in adoption of CA in the rainfed areas. In addition to the three principles of CA, there are range of complementary good agriculture practices which are essential for short- and long–term productivity and profitability of the system (Vanlauwe *et al.*, 2014; Sommer *et al*., 2014). The three principles of CA have wide applicability on different rainfall, soil types and crops (Wall *et al*., 2014; Wall, 2007). In the past, three principles were studied independently but studies with integration of all the three practices were very few in rainfed regions. Hence, range of agricultural practices, tillage including handling of crop residues, sowing and harvesting, water and nutrient management, weeds, insect-pests and disease management, etc. need to be evolved and evaluated. Therefore, studies were initiated to develop location specific CA practices for different soil types and major cropping systems under the aegis of Consortia Research Platform (CRP) on Conservation Agriculture (CA) with the objective to develop appropriate agro-techniques for better adoption of CA, and to study the influence of CA practices on biophysical functioning and their role in improving the productivity, profitability and sustainability in the face of present and future climate variability in rainfed regions.

Material and Methods

Multi-location on-station and on-farm participatory research trials were conducted in rainfed agro ecosystems under different rainfall and soil conditions at different institutes (Indian Council of Agricultural Research (ICAR) - Central Research institute for Dryland Agriculture (CRIDA), Hyderabad; All India Coordinated Research Project for Dryland Agriculture centres (Bengaluru and Akola); ICAR-Indian Institute of Soil Science ICAR-IISS, Bhopal: ICAR-Research Complex for Eastern Region (RCER) Patna). These experimental sites cover soil order of Alfisols, Vertisols and Inceptisols (Table 1) to address the challenges of CA in rainfed regions (Plate 1). The average annual rainfall varies from 750 mm in SAT to 1150 mm in sub-humid zones, out of which, approximately 75% is received during June to September. The average annual rainfall, detailed soil physic-chemical characteristics before the initiation of the experiment, treatment details, etc. are presented in Table 1.

Management practices differ significantly from one place to another under different agro ecosystems depending upon the soil type, crop cultivated and climate. Hence, in some experiments along with the CA practices complementary practices such as nutrient management, *in-situ* moisture conservation and weed management practices were integrated as IV principle since these are required to develop best management practices to enhance the potential benefits of CA (Vanlauwe *et al*., 2014). The crops were grown following standard packages of practices except for tillage and residue management practices. The recommended doses of fertilizers were applied to the crops wherever fertilizer dose was not a treatment. Soil physical, chemical and biological properties, environmental impact, energy balance studies, GHG emissions and carbon footprint were also estimated as per the standard procedures.

Results and Discussion

The results obtained under different agro-ecosystems were analysed, compiled and are presented in this section. The impact of CA practices on soil quality, crop productivity and profitability are variable and depends upon the type of cropping system followed, level of adoption of CA principles (Baudron *et al*., 2015; Mupangwa *et al*., 2016; Mafongoya *et al*., 2016) and duration of the study. The significant findings are presented under suitable headings.

Impact of CA on residue generation, crop productivity, profitability, rainwater use efficiency and sustainability

a. Residue generation

Residue retention is one of the most important components of CA, which is essential for success of CA. However, crop residue generation in

Table 1. Details of the Technical programme of experiments under rainfed conditions

Details	Residue retention				Conservation Agriculture (CA) + IV Principle							Crop diversification
					In-situ moisture conservation			Weed management	Nutrient management			
	CRIDA Hyderabad	CRIDA Hyderabad	IISS Bhopal	AICRP Bengaluru	CRIDA Hyderabad	CRIDA Hyderabad	AICRP Akola	CRIDA Hyderabad	CRIDA Hyderabad	CRIDA Hyderabad	CRIDA Hyderabad	ICAR-RCER Bihar
Cropping system	Pigeonpea-Castor, HRF(P-C)	Sorghum-Blackgram, HRF(S-B)	CT-Sb-W Maize-W (M-W), Maize-Gram (M-G) ZT-Sb-W, Maize-W (M-W), Maize-Gram(M-G)	Fingermillet + Pigeonpea (8:2) (F-P)	Maize-Pigeon pea, HRF (M-P)	Maize-Horsegram/ Pigeonpea, GRF (M-H/P)	Sb– Chick Pea (Sb-C)	Maize-Pigeon pea GRF(M-P)	Maize-Pigeonpea GRF(M-P)	Pearl millet-Horsegram/ Pigeonpea (Pm-H/P)	Cotton-Pigeon pea (Ct-P)	Rice-Fallows (R-F) Rice-Chickpea (R-C) Rice-Lentil (R-L) Rice-Safflower (R-S) Rice-Linseed (R-Ls) Rice-Mustard (R-M)
Year of initiation	2009	2013	2010	2016	2014	2013	2016	2017	2012	2016	2016	2016
Latitude, (N)	17.23°	17.34°	23.3072°	12.97°	17.34°	17.08°	20.7006°	17.08°	17.08°	17.08°	17.08°	25.59°
Longitude, (E)	78.29°	78.59°	77.4050°	77.59°	78.59°	78.66°	77.0371°	78.66°	78.66°	78.66°	78.66°	85.08°
US Soil Taxonomy	Alfisols	Alfisols	Vertisol	Alfisol	Alfisols	Alfisols	Vertisol	Alfisols	Alfisols	Alfisols	Alfisols	
OC (%)			0.55-0.59%	0.31%								
Available Nitrogen (kg ha^{-1})			309	113.24								
Available phosphorus (kg ha^{-1})			13.9	210.42								
Available potassium (kg ha^{-1})			282	97.5								

CRIDA= Central Research Institute for Dryland Agriculture, IISS= Indian Institure of Soil Science , AICRP=All India Coordinated Reseach Project, RCER= Research Complex for Eastern Region OC= Organic Carbon, N= Nitrogen, P= Phosphorus, K= Potassium,P-C= Pigeonpea-Castor, S-B= Sorghum-Blackgram, Sb-Soybean-Wheat, M-W=Maize-Wheat, M-G=Maize-Gram, M-P=Maize-Pigeonpea, Pm-H/P= Pearl millet-Horsegram/Pigeonpea, Ct-P= Cotton-Pigeon pea, R-F= Rice-Fallows, R-C= Rice-Chickpea, R-L= Rice-Lentil, R-S= Rice-Safflower, R-Ls= Rice-Linseed, R-M= Rice-Mustard

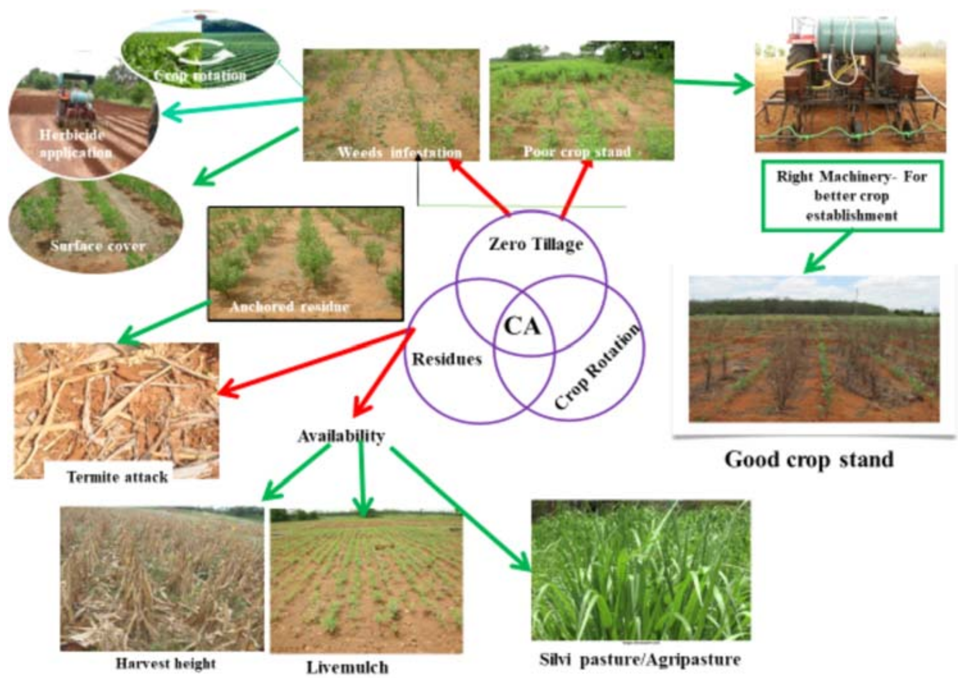


Plate 1. Challenges in implementation of CA agriculture practices and solutions (Red arrows indicates challenges and green indicates solutions)

rainfed agriculture and sparing them for retention in field is a challenge owing to the fact that they are highly valued in rainfed areas and have other competing uses. Crop residue retention is one of the three basic principles of conservation agriculture (CA) *viz*. (a) minimum mechanical soil disturbance, (b) permanent soil cover, and (c) crop rotation. The type and amount of crop residues retained under zero-tillage has diverse effects on soil health, namely, it increases soil organic matter (OM), conserves soil water, promotes biological activity, promotes soil aggregation, strengthens nutrient cycling, reduces abrupt fluctuations in soil temperature, and improves soil tilth and thus reduces land degradation (Yadav *et al*., 2021). Crop residues retention also enhances soil quality by reducing soil erosion and buffering against the effects of pollution (Mickelson *et al*., 2001). The beneficial effects of crop residues on improving soil properties and reducing soil degradation are well known, however, these effects vary, depending on the type and quantity of crop residues applied and the nature of the soil. Hence, efforts were made under CRP-CA to identify the strategies to increase the retention of residues in field so to improve the productivity of different rainfed crops under different soils and cropping systems.

In rainfed areas of Southern India, farmers are generally reluctant towards sparing crop residues to the soil**.** Studies conducted under long term tillage experiments at CRIDA and AICRPDA has shown that ZT without residue retention is more harmful in rainfed regions. In addition to the competing uses of residues, uncontrolled grazing especially in rice-fallows, low biomass production, mono cropping in Alfisols, loss of residues/mulches due to termite infestation are the major challenges for low residue retention in SAT. At Bengaluru, in Alfisols, to improve the residue retention, cultivation of field bean and horse gram as pre monsoon cover crops by utilizing the summer showers before finger millet + pigeonpea (8:2) intercropping helps in generation of crop residues for retention.

In Vertisols of Central India, residue production of different crops *viz*., soybean, maize, wheat and chickpea increased with increasing residue retention levels from 0 to 90% in the ZT system, the yield level increased consistently in all the crops. It has been estimated that soybean crop produced 2.5-2.7 t ha^{-1}, maize crop produced about 7.5-8.0 t ha^{-1}, chickpea crop produced about 2.75-3.0 t ha^{-1} and wheat crop produced about 7.0-8.0 t ha^{-1} residues under rainfed conditions. Retention of higher residue levels of wheat and maize did not have any negative impact on establishment of soybean and chickpea in the cropping system, when the crops were sown using turbo happy seeder under optimal moisture conditions.

b. Crop productivity

Results from experiments conducted in eastern Indo-Gangetic Plains (EIGP), in rice based cropping systems, have shown that conventional puddled transplanted rice (TPR) (5.27 t ha^{-1}) recorded 28 and 18.7% higher yield as compared to zero till direct seeded rice (ZTDSR) (4.10 t ha^{-1}) and conventional tillage direct seeded rice (CTDSR) (4.44 t ha^{-1}), respectively (Table 3). Retention of 30% anchored crop residue on soil surface improved the grain yield and system productivity by 12 and 10%, respectively compared to no residue retention. This is primarily due to better soil moisture conservation with crop residue. The yields of subsequent winter crops after ZTDSR were 22% higher over TPR, primarily due to increased moisture availability for an extended period and improvement in soil health. Among different crop rotations, the productivity of grain legumes (chickpea and lentil) was higher as compared to oilseed crops in rice-fallows following the order chickpea > lentil > safflower > mustard > linseed. Higher productivity in legumes may be attributed to conservation and efficient use of soil moisture and nutrients under water limited conditions owing to better root traits (Hazra and Vohra, 2020) (Table 3). However, the mean system productivity of ZTDSR and TPR were similar to each other. This might be due to fact that winter crops in ZTDSR recorded significantly higher yield as compared to that of winter crop yields with TPR.

In Hill and Plateau region of Ranchi (Jharkhand) and Jashpur (Chhattisgarh) rice-mustard-black gram and rice-linseed-green gram systems were found to be promising with supplemental irrigation. CA practices under rice-mustard-black gram cropping system recorded 20, 15 and 2% higher rice, mustard and black gram yields, respectively over the farmers' practice. Similarly, higher system productivity (19% and 15%) was recorded under rice-mustard-black gram and rice-linseed-green gram, respectively under CA system over conventional farmers' practice.

In Alfisols of southern India at CRIDA, residue retention significantly influenced the yield of pigeonpea, castor, sorghum and black gram in different cropping systems (Table 2). Anchored residue of 30 and 10 cm in pigeonpea and castor recorded significantly higher yields than that in no residue treatments and were at par to each other. Retention of higher level of sorghum residue by manipulation of harvesting height at 60 cm resulted in increased seed yield of black gram (382 kg ha^{-1}) which was 14.8% and 32.8% higher as compared to residue retention at 35 cm height and no residue retention (control), respectively. Similarly, retention of 100% residues of black gram recorded 33% and 16% higher sorghum grain yield, respectively, as compared to no residue control (S_1) and 50% residue retention (S_2). Cultivation of *dhaincha* (*Sesbania bispinosa*) as live mulch in wider rows of castor/pigeonpea in pigeonpea-castor system with anchored crop residues of (10 cm and 30 cm) and application as live mulch recorded 36.7 and 13.1% higher yield under CA (645, 484 kg ha^{-1}) over CT (Peter *et al*., 2019; Garcia-Palacios *et al*., 2019; Page *et al*., 2020). The increase in yields in CA is due to 30% increase in residue production which is due to manipulation of harvest height of main crop as well as growing of live mulch *Sesbania* (*dhaincha*). Apart from crop productivity, live mulch decreased the weed infestation and increased the soil fertility (Ngwira *et al*., 2012; Nyagumbo *et al*., 2016; Kaye and Quemada, 2017). The soils in the experimental site are Alfisols and they have hard setting tendencies and low infiltration rate (Sharma *et*

Table 2. Change in crop productivity (kg ha^{-1}), economics (Net Monetary Returns (NMR) ha^{-1}) and rain water productivity (kg m^{-3}) observed between Conventional Tillage (CT) and Conservation Agriculture (CA) (ZT + residues + crop diversification) in different cropping systems

Location & length of study	Cropping system	Yield (kg ha^{-1})			NMR /B:C ratio ha^{-1}			RWP (kg m^{-3})		
		CT	CA	% increase in CA over CT	CT	CA	% increase in CA over CT	CT	CA	% increase in CA over CT
Residue retention										
CRIDA, Hyderabad, 11 years	Pigeonpea-castor system									
	Pigeonpea	645	1020	36.7	18177	51592	64.7	1.08	1.46	26
	Castor	484	557	13.1	2178	17339	87.4			
CRIDA, Hyderabad, 7 years	Sorghum-blackgram system									
	Sorghum	1447	2173*	33.4				3.75	4.21	10.9
	Blackgram	282	392*	28.1				0.97	1.02*	4.9
AICRP, Bengaluru, 3 years	Fingermillet + pigeonpea (8:2)^{Feq}	2128	1930	-9.3	39606	35958	-9.2	4.54	4.39	-3.3
			2562**	16.9**		54945**	27.9**		6.12**	25.8**
IISS, Bhopal, 6 years	Soybean	1205	1443	16.4						
	Wheat	5053	5910	14.5						
	Maize	4146	5034	17.6						
	Gram	1805	2329	22.4						
Crop diversification										
ICAR-RCER, Bihar, 4 years	Rice-fallows (Rice-chickpea)	9200	10400	11.5	80000	106000	24.5			
IISS, Bhopal-6 years	Soybean-Wheat ^{Sbeqy}	6000	6600	9.0						
	Maize-Wheat ^{Sbeqy}	5600	5200	-7.14						
	Maize-Gram ^{Sbeqy}	5400	6000	10						
CA complementary practices as IV Principle										
i. In-situ moisture conservation										
CRIDA, Hyderabad, 6 years	Maize-pigeon pea system									
	Maize	782	1014	22.8				1.77	2.29	22.7
	Pigeon pea	774	1072	27.7				1.4	1.94	27.8
CRIDA, Hyderabad, 7 years	Maize-Horsegram/pigeonpea ^{Peq}	1847	2453	24.7						
AICRP, Akola, 2 years	Soybean –Chickpea (^{Sbeq})	3119	2797	-10.3	50631	46820	-7.5	2.58	2.3	-10.8
			3300***	5.5***		59059***	14.27		2.74***	5.8***
ii. Weed management										
CRIDA, Hyderabad, 3 years	Maize-pigeon pea system									
	Maize	2134	3445	38.1				3.90	6.29	37.9
	Pigeon pea	532	856	37.8				1.92	3.09	37.8
iii. Nutrient management (Nitrogen management CA+N; CT)										
CRIDA, Hyderabad, 8 years	Maize-pigeonpea			20						
CRIDA, Hyderabad, 4 years	Pearl millet horsegram/Pigeonpea(^{PMeq})	2155	2241	3.8				5.11	5.32	3.9
CRIDA, Hyderabad, 4 years	Cotton-pigeon pea ^{Ceq})	882	874	-0.9				2.09	2.07	-0.9
			946***	6.76***				2.09	2.24***	6.7***

*= Reduced tillage + 100% residue, **=Reduced tillage + Horsegram cover crop ***= Reduced tillage + Residue, RWP= Rain Water Productivity

^{Feq}=Finger millet equivalent yield, ^{Peq} =Pigeonpea equivalent yield, ^{Sbeq} =Soybean equivalent yield, ^{PMeq}=Pearlmillet equivalent yield, ^{Ceq} =Cotton equivalent yield, RCRice-chickpea equivalent yield, ^{Sbeqy} =Soybean equivalent yield.

Table 3. Effect of crop establishment methods and residues management on yields (t ha^{-1}) of rice and winter season crops in rice-fallows and system productivity (t ha^{-1}) and economics of rice-fallows (mean of four years)

CERM	Crop yields (t ha^{-1})						System productivity (t ha^{-1})						System net returns (INR ×10^3 ha^{-1})						System B:C ratio					
	ZTDSR		CTDSR*		TPR		ZTDSR		CTDSR*		PTR		ZTDSR		CTDSR*		PTR		ZTDSR		CTDSR*		PTR	
Cropping systems	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$	R$^-$	R$^+$
Rice	3.96^c	4.24^b	4.28^b	4.60^c	5.08^a	5.45^a	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rice-chickpea*	1.77b	2.01a	1.54c	1.75b	1.35d	1.54c	9.39c	10.4a	9.01c	9.9ab	9.2bc	10.2a	92.4	106.0	84.0	97.5	80.0	93.4	2.20	2.38	2.04	2.21	1.88	2.03
Rice-lentil*	1.75b	1.99a	1.51c	1.73b	1.31d	1.48c	9.21c	10.2a	8.82c	9.8ab	9.0bc	9.9a	95.0	107.5	85.3	99.1	81.0	93.3	2.31	2.49	2.12	2.30	1.94	2.09
Rice-safflower*	1.67b	1.95a	1.26c	1.47b	1.14d	1.28c	9.09c	10.2a	8.18c	9.2ab	8.7bc	9.4a	90.9	106.0	74.7	87.9	74.9	85.2	2.37	2.60	2.07	2.26	1.94	2.07
Rice-linseed*	1.05b	1.26a	0.97c	1.15b	0.92d	1.02c	6.13c	6.84a	6.28c	6.9ab	6.9bc	7.55a	52.2	61.0	51.9	61.1	55.7	62.7	1.87	2.01	1.81	1.95	1.75	1.85
Rice-mustard*	1.58b	1.77a	1.48c	1.66b	1.39d	1.53c	8.39c	9.19a	8.40c	9.24ab	8.97bc	9.72a	81.2	91.3	78.7	89.9	80.5	90.3	2.23	2.39	2.13	2.29	2.01	2.13

*Winter crop yields

Initially 2 years ZTTPR: zero tillage transplanted rice and later on CTDSR, ZTDSR: zero till direct seeded rice, CTDSR: conventional till direct seeded rice, PTR: Transplanted rice, R+=30% Residues retention, R-: Without residues/control. Crop establishment and residue management (CERM)

al., 2005). Growing of any green manure legume crop (daincha, sunhemp/horse gram) as live mulch between the widely spaced crops or after harvest of short duration crops like maize/pearlmillet/ black gram along with residue retention improved utilization of off-season rains (Kundu *et al*., 2013).

At Bengaluru, in Alfisols, to improve the residue retention, cultivation of field bean and horse gram as pre monsoon cover crops by utilizing the summer showers before finger millet + pigeonpea (8:2) intercropping. Among the pre-monsoon cover crops, finger millet equivalent yield was higher with horse gram as pre-monsoon cover crop. Horse gram and french bean recorded 16 and 7% higher yields over no cover crop, respectively. Horse gram recorded higher RWUE (5.44 kg ha-mm^{-1}) than field bean (4.62 kg ha-mm^{-1}) and control (4.26 kg ha-mm^{-1}).

In Vertisols of central India at ICAR-IISS, Bhopal average yields of different crops *viz*., soybean, maize, wheat and chickpea yields increased with increasing residue cover from 0 to 90% in the ZT system, the yield level increased consistently in all crops. Moreover, the higher residue levels did not have any negative impact on *Rabi* crop establishment, when the crops were sown using turbo happy seeder under residual moisture conditions. Furthermore, by using a suitable variety, sowing can be advanced by 15-20 days using the residual profile soil moisture and one irrigation could be saved in a situation when residual moisture is not enough for proper crop establishment. A light irrigation needs to be applied after dry seeding to ensure proper germination. In soybean - wheat cropping system with different levels of residue retention, ZT with 90% residue retention was found to be superior in terms of grain yield (14.43 & 59.10 q/ha) as compared to ZT without residue retention (12.05 & 50.53 q/ha) (Table 2). Similarly in maize – chickpea cropping system, with different levels of residue retention, ZT with 90% residue retention was found to be superior in terms of grain yield (50.34 & 23.29 q/ha) as compared to ZT without residue retention (41.46 & 18.05 q/ha) (Table 2).

c. Water use efficiency

In Alfisols of southern India at CRIDA, the increase in RWUE in S_2 and S_1 was 33.04 and 16.08% respectively over control in sorghum, 31.39 and 13.95% over control in black gram, respectively. In pigeonpea, ZT with residues recorded 26% higher rain water use efficiency than CT whereas, in castor the rain water use efficiency in CT and ZT were similar to each other. Increase in residue levels increased the rain water productivity compared to no residue levels in both crops (Table 2). Similar trend was observed in rain water use efficiency (RWUE) as that of grain yield in different cropping systems. Anchored residue of 30 and 10 cm in pigeonpea and castor recorded significantly higher yields than no residue treatments and were at par to each other. Retention of higher level of sorghum residue by manipulation of harvesting height at 60 cm resulted in increased seed yield of black gram (382 kg ha^{-1}) which was 14.8% and 32.8% higher as compared to residue retention at 35 cm height and no residue retention (control). Similarly, retention of 100% residues of black gram recorded 33% and 16% higher sorghum grain yield respectively as compared to no residue control and 50% residue retention.

In Vertisols of central India, under soybean - wheat cropping system higher level of residue retention (90%) resulted in significantly higher soil moisture content as compared to no residue, 30%, and 60% residue retention levels. On dry weight basis at 0–5 cm soil depth lowest soil moisture was recorded (18.0 g 100 g^{-1} soil) under no residue retention treatment, while maximum soil moisture content (35.8 g 100 g^{-1}) soil with 90% residue retention. The soil moisture content with 90% residue retention was (31.61% & 30.13%) higher as compared to 60% residue retention at 0–5 and 5–10 cm soil depth respectively (Yadav *et al.*, 2021). Adoption of conservation agricultural practices in farmers field resulted in reduced irrigation water requirement by 20%. The water productivity of the system increased from 1.08 kg/m^3 in conventional tillage system to 1.34 kg/m^3 under conservation agriculture with balanced fertilizer application, indicating a gain of 24.67% in water productivity under conservation agriculture as compared to conventional agriculture.

d. Profitability

Results from various experiments across the agro-climatic regions have shown that conservation agriculture has been found to be more profitable as compared to conventional tillage systems. In rainfed ecologies of eastern IGP, ZTDSR recorded system productivity at par to TPR based system. This might be due to fact that winter crops in ZTDSR recorded significantly higher yield as compared to that of winter crop yields with TPR. Similarly, ZTDSR recorded significantly higher net returns and B: C ratio (2.3) than TPR (1.97) and CTDSR (2.11). Hence, CA-based rice-legume system was more productive and remunerative for sustainable intensification of rice-fallows (Table 3).

In vertisols, under soybean-wheat cropping system the net profit of Rs. 20000 ha^{-1} and 60000 ha^{-1} were obtained under conventional tillage system and increased to Rs. 28000 ha^{-1} and 75000 ha^{-1} under conservation agriculture, which were 40% and 25% higher as compared to conventional system in case of soybean and wheat, respectively. Similarly, B: C ratio analysis shows that it was higher under CA (2.30 and 3.08) as compared to conventional agriculture (1.79 and 2.50), which was 28.49 and 23% higher in soybean and wheat, respectively.

Complementary practices: Fourth principle

Some of the studies have shown that the yield reduction in CA system in rainfed regions, particularly in the southern region, were due to limitations in nutrient, water, residue and weed management in these regions. These factors, either alone or in combination, reduce the yields of the crops. Hence, CA with three principles alone is not sufficient for its success in rainfed regions of India. Therefore, CA practices needs to be integrated with other complementary practices like *in-situ* moisture conservation, nutrient and weed management. Hence, studies were initiated under CRP-CA to identify the feasible complementary practices to integrate along with the CA practices and assess the beneficial effects and challenges in adopting these practices.

Integration of in-situ moisture conservation

In rainfed regions, *in-situ* moisture conservation has increased the crop yields by 10-20% besides reducing the soil erosion by 70-80%. Hence integration of *in-situ* moisture conservation practices is essential for success of CA in rainfed areas. In Alfisols of SAT regions, it was observed that integration of *in-situ* moisture conservation with CA practice in maize-pigeonpea annual rotation either through conservation furrow or raised bed and furrow in both CT and CA recorded higher yield than conventional practices. Permanent conservation furrow or permanent raised bed and furrow method were similar to CT + *in-situ* conservation treatments. In another study on maize-pigeonpea cropping system, CA practices along with permanent ridge and furrow system with 100% residue retention (2453 kg ha^{-1}) recorded 14.1 and, 24.7% higher pigeonpea equivalent yields than CA without moisture conservation (2108 kg ha^{-1}) and CT without moisture conservation (1847 kg ha^{-1}), respectively (Table 2).

In Vertisols of Akola, soybean-chickpea system under RT with *in-situ* moisture conservation and retention of residues recorded significantly higher soybean yield and profits as compared to CT + in-*situ* moisture conservation with and without residue but chickpea yields were on par with each other and were significantly superior over ZT with and without residue. The system productivity, profitability and B:C ratio of the soybean-chickpea system were higher in RT+ residue+ *in-situ* moisture conservation and were superior over CT and ZT with *in-situ* moisture conservation (Table 2).

One of the major challenges for low adoption of CA by the farmers in the rainfed regions is crop-weed competition. Weeds reduce the crop yields up to 90% in rainfed agriculture. The benefits of CA systems in rainfed regions may be offset by heavy weed infestation and shifts in weed communities. The dynamics of the weed population under CA is entirely different from conventional systems. Substantial shifts in the weed flora of crop lands from annual weed species (easily controllable) to perennial weeds (difficult to control), broad-leaved weeds (better adaptable to disturbed habitat) to grasses are observed in pigeonpea - castor system (Pratibha *et al.*, 2015). Moreover, larger weed diversity is observed with tillage which prevents the domination of a few problematic weeds, hence the weed control options also differ. The weed shift may affect competitive interactions between crops and weeds which is a major reason for non-adoption of CA system by the growers.

A major criticism of CA is its enhanced reliance on herbicides compared to conventional practices. But in rainfed regions of India the major problems of herbicide use is reduce efficacy of the herbicide since it depends on the amount and distribution of rainfall, lack of availability of herbicides and knowledge about its proper use. Pre-emergence herbicide like pendimethiline requires optimum soil moisture within 7-14 days after application to dissolve the herbicide in soil water solution so that it can be absorbed by the emerging weeds after germination. Hence inadequate or delayed precipitation after pre emergence application resulted in reduced herbicide efficacy and poor weed control. Contrary to this, high precipitation events (*i.e.* greater than 25 mm), especially within 24 hrs after the application in light soils, can cause herbicides to leach through the soil profile and consequently reduce efficacy. In Vertisols of central India, after 6 crop cycles, weed shift and resistance in some of the species against non-selective and selective herbicides and reduced control of perennial weeds and sedges was observed. This may be attributed to the fact that CA system are over relying on herbicide application for weed control, however, no herbicide provides 100% weed control and some weed population always escapes herbicide application and multiplies seeds of escaped population, which in turn results in shift of weed species and their densities as CA system do not allow removal of weeds through hand weeding. Therefore, effective and economical alternative i.e. integrated weed management strategies with cautious use of herbicides are required to reduce the herbicide resistance and weed shift and reduce species richness to sustain the crop productivity under CA. Hence, in rainfed regions CA systems would require inclusion of removal of escaped weeds at least during initial phase of adoption to tackle the problem of weed shift and resistance development. Considering these challenges, integrated weed management options are proposed as the 4th pillar of CA. Studies at CRIDA have shown that introduction of *dhaincha* as live mulch between the crop rows, apart from increasing the residue contribution, reduced the weed infestation considerably. Similar results were reported by Mafongoya *et al*. (2016). The use of a herbicide in weed management in CA may reduce the labour requirement, but not a pre requisite for adoption of CA in rainfed regions (Thierfelder *et al*., 2013b). In rainfed rice system glyphosate @ 1.0% just 3 days before sowing followed by pendimethalin at 1.0 kg ai/ha next day of sowing + one hand weeding at 30-35 DAS recorded higher yields. Studies at CRIDA in Alfisols has shown that weed control with pre-emergence herbicide+post-emergence herbicide and removal of escaped weeds mechanically has reduced the weeds as well as increased the seed yield. Similar results were also reported in central India in black soils. The weed growth in CA has reduced over time with use of herbicides, and the use of herbicides can be reduced with reduction in weed pressure over the years.

Nutrient management

The rainfed soils are not only thirsty but hungry also. Nitrogen is the most limiting nutrient for cereals in rainfed regions. Hence, good fertilization in general and nitrogen in particular is essential for higher yield and residue generation. In general, crop residues that are retained in CA system are cereal residues which have higher C: N ratio and may result in immobilization of nitrogen for a short time. Hence a different fertilization strategy like higher nitrogen fertilizer or change in timing of fertilizer may be required. But the challenge for higher nitrogen use in rainfed regions would be the availability of soil moisture.

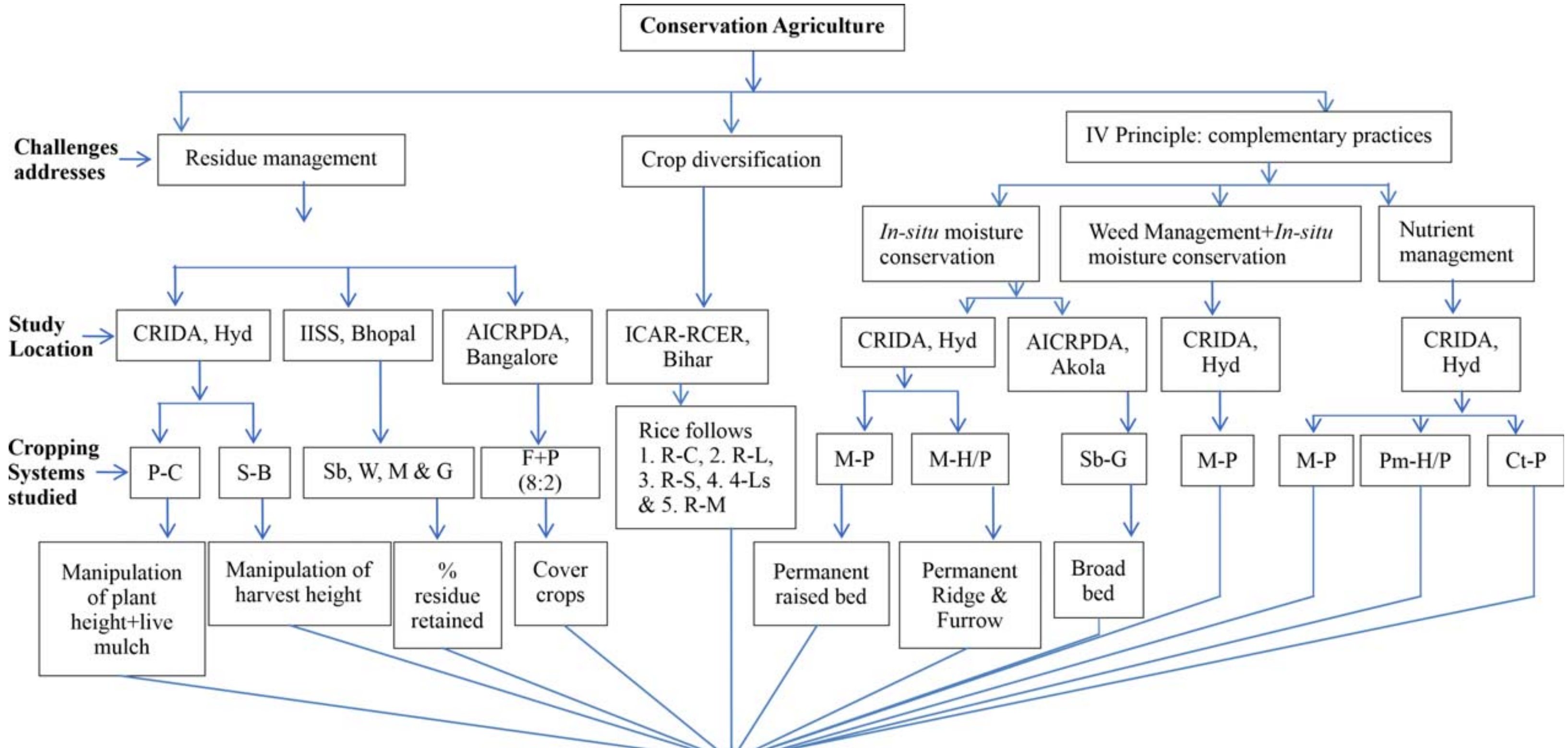
The 4 crop cycle studies in pearlmillet-pigeonpea and cotton-pigeonpea cropping systems in Alfisols of south India have shown that the grain yield of pearlmillet and pearlmillet equivalent yield of pigeonpea, cotton and cotton equivalent yield of pigeonpea (Table 2) and 9 crop cycles of maize-pigeonpea were significantly influenced by both tillage practices and nutrient management. The maize and pigeonpea yields in ZT with 125% recommended dose of nitrogen (RDN) recorded 20% increase in yield compared to CT. The pearl millet and cotton residues have wide C:N ratio. This leads to prolonged nitrogen immobilization by micro-organisms, rendering the nitrogen unavailable for crop growth in the short term. Hence, high nitrogen inputs are required when poor quality crop residues are used as mulch. The residual and cumulative beneficial effect of legume crop residues on cereal crop increased the yield attributes and its continuous rotation finally reflected in the grain yield.

Termite infestation and management

The major challenge for maintenance of surface cover with residues in Alfisols is termite infestation. The residues retained on soil surface were decomposed by termites within 2-3 months after harvest of the crop. The studies revealed that termite infestation varied with the residue quality and their placement. The severity of termite infestation was higher on flat residues (residues on the soil surface) than the anchored ones. Application of chlorpyriphos 20 EC @ 5 ml per liter water helps in controlling termites up to 90-120 days, later the efficacy of the pesticide decreased. Application of cow dung slurry @ 5 t ha^{-1} resulted in decrease intermites’ infestation, it has also been observed that the termite infestation was restricted only on the dung but not on the residues which resulted in retention of residue cover for a longer period (Fig. 2).

Implements are key to the success for good crop stand establishment in conservation agriculture

Permanent surface cover with recycling of crop residues is a prerequisite and an integral part



Benefits	
1. **Productivity**	Crop and system productivity
2. **Profitability**	NMR, B:C Ratios
3. **Physical**	
a) Bulk density	Core sampler method (Ref :
b) Infiltration	Double ring infiltrometer method (Ref)
4. **Chemical**	
a) OC	Modified Walkley and Black method-1934
b) N	Alkaline permanganate method-1956
c) P	Olsen's method-1954
d) K	Neutral Normal Ammonium Acetate method-1963
5. **Biological**	Microbial count and enzymatic analysis
6. **Environmental**	Energy balance, GHG emissions, Runoff, Soil loss and Nutrient loss

Fig. 1. Challenges, adoption of location specific technologies/suitable cropping systems in rainfed conditions under conservation agriculture

P-C= Pigeonpea-Castor, S-B= Sorghum-Blackgram, Sb-Soybean-Wheat, M-W=Maize-Wheat, M-G=Maize-Gram, M-P=Maize-Pigeonpea, Pm-H/P= Pearl millet-Horsegram/Pigeonpea, Ct-P= Cotton-Pigeon pea, R-F= Rice-Fallows, R-C= Rice-Chickpea, R-L= Rice-Lentil, R-S= Rice-Safflower, R-Ls= Rice-Linseed, R-M= Rice-Mustard

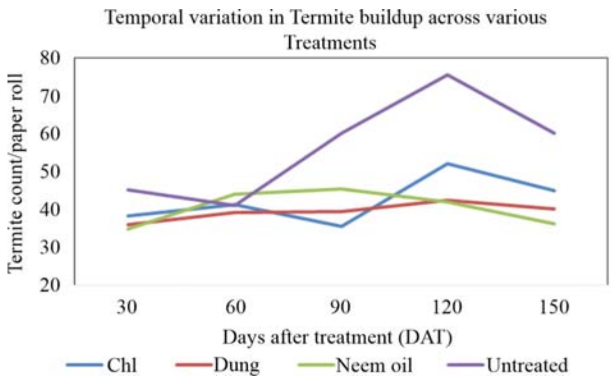


Fig. 2. Temporal variation in termite build-up across various treatments

of CA. However, sowing of a crop in the presence of preceding crop residues is a problem. Hence, suitable planters which included zero-till seed-cum fertilizer drill/planters such as Happy Seeder, Turbo Seeder and Rotary-disc drill for direct drilling of seeds even in the presence of surface residues are pre-requisites for success of CA to ensure proper crop establishment (loose and anchored up to 10 t ha^{-1}).The real success of CA in irrigated area is due to these implements. These machines are very useful for managing crop residues for conserving moisture and nutrients as well as for controlling weeds. Happy seeders perform well for sowing of crop with 4-6 tonnes of residues during the winter season. But during the rainy season when the sowing window is narrow, difficulty arises for sowing of crops when the residues are moist. Besides this, the Happy Seeder could not be used in undulated topography of Alfisols and also the coulters do not work when the residues are low. In rainfed regions, seeds require covering due to low residues unlike in irrigated regions. Hence an energy and fuel-efficient implement which support CA systems in rainfed agriculture was fabricated at CRIDA.

CRIDA precision planter (zero till planter with herbicide and fertilizer applicator) was designed and developed at CRIDA. This planter had a herbicide tank, and the wide furrow openers are replaced with inverted T type openers to place seeds and fertilizers in narrow slits with minimal soil disturbance (Pratibha *et al.*, 2015). The advantage of this implement is that the seed has better seed-soil contact than traditional disc openers, and germination was better when this planter was used for sowing the crop. Besides this, the planter works very well under undulated topography also, since it has individually operated hinge type shank mechanism. Apart from the CRIDA precision planter, bed planter and CRIDA paired row planter were developed at CRIDA for integration of soil moisture with other three principles of CA. These planters can be used to reshape the bed and furrow every year and sow the crop without disturbing the beds and furrows.

Impact of CA on soil physical properties

There were number of studies on the effect of tillage and residue management practices on the physical, chemical and microbiological environment of soil, reduction in soil erosion and mitigation of climate change (Hobbs, 2001; Malik *et al*., 2004; Sidhu *et al*., 2007). But all the reports are considerably diverse and contradictory which may be due to soil and climatic variability and the duration of the study. One of the immediate positive effects of CA observed is on soil structure. Similar observations were made by Thierfelder and Wall (2009). Results of the experiments conducted in Alfisols of CRIDA, AICRPDA centres and Vertisols of ICAR- IISS in central India with different cropping systems (pigeonpea-castor, sorghum-black gram, Finger millet + pigeonpea (8:2)) revealed that, in general, in all the cropping systems, ZT recorded slightly lower BD as compared to CT. This decrease in BD was higher in ZT with residues (CA) than ZT without residues. The lower BD is generally due to less soil disturbance and subsequent retention of crop residues in ZT, and lack of repeated trafficking of the soil by agricultural machinery (Blanco-Canqui and Ruis, 2018). Khorami *et al.* (2018) recorded similar observations. In Alfisols with maize- pigeonpea cropping system, nitrogen management as complementary practice along with tillage recorded 2.9, 8.5 and 13.3% decrease BD in CT, RT and CA (ZT+crop residues), respectively, whereas, 4.8, 14.9 and 21.9% increase in porosity was observed in CT, RT and NT as compared to the initial values. In this study also, slight increase in BD was noticed in ZT (in the initial 4 years) compared to the CT and RT and a slight decrease in porosity (1.8%) was observed in ZT compared to CT and RT (Table 4).

The steady state infiltration rate is significantly influenced by CA and CT practices. CA and RT with residue increased the rate of infiltration by 53.5% in pigeonpea-castor system (Table 4). In sorghum–black gram system RT with 100% and 50% residue retention recorded 56 and 51% higher infiltration rate, respectively over CT without residue. The increased infiltration rate is due to improved soil structure associated with surface residue accumulation and lack of soil disturbance. Hundred percent and 50% residue treatments increased the infiltration rate by 75 and 33%, respectively, over no residue retention treatment. Similar results were reported by Thierfelder and Wall (2009). In vertisols of central India, soil profile water content was 5-15% higher during the most part of the cropping season during the *rabi* season in treatments where no or RT with residue retention was followed for more than four years.

Periodic measurement of soil temperature showed that ZT, RT with residue retention has favorably moderated soil temperature especially during winter season compared to CT without residue (Somasundaram *et al*., 2019). The aggregate stability, water-stable aggregation, aggregate associate–C and different carbon pools increased in CA in both Alfisols and Vertisols. Increase in water stable aggregates, aggregate stability was observed in CA compared to only ZT, and CT in pigeonpea-castor system. Similarly, CA+complementary practices like nutrient management increased the soil aggregation in maize-pigeonpea system. The aggregate associated enzyme activity-dehydrogenase, urease, acid and alkaline phosphatase were higher in CA compared with CT and RT.

In Vertisols at Bhopal under soybean- wheat cropping system, soil moisture content was significantly higher under 90% residue retention as compared to no residue, 30%, and 60% residue retention. The soil moisture content with 90% residue retention was higher than 60% retention

Table 4. Change in bulk density (g cm^{-3}) and infiltration (cm hr^{-1}) observed between Conventional Tillage (CT) and Conservation Agriculture (CA) (ZT + residues + crop diversification) in different cropping systems

Location & length of study	Cropping system	Bulk density (g cm^{-3})			Infiltration rate (cm hr^{-1})		
		CT	CA	% increase / decrease in CA over CT	CT	CA	% increase in CA over CT
Residue retention							
CRIDA, Hyderabad, 11 years	Pigeonpea-castor system	1.45	1.35	-6.9	4.34	9.34	53.5
CRIDA, Hyderabad, 7 years	Sorghum-blackgram				6.9	16	56.8
	0-7.5 cm	1.50	1.32	-12			
	7.5-15 cm	1.78	1.58	-11.2			
AICRP, Bengaluru, 3 years	Fingermillet + pigeonpea (8:2)	1.45	1.41	-2.75			
			1.37**	-2.8**			
CA complementary practices as IV Principle - iii. Nutrient management (Nitrogen management CA+N; CT)							
CRIDA, Hyderabad, 8 years	Maize-pigeonpea	1.57	1.40	-11			

**=Reduced tillage + Horse gram cover crop by 8.6 g and 8.8 g at 0–5 and 5–10 cm, respectively. Residue retention resulted in reduction in soil BD and increased soil porosity at 0–5 and 5–10 cm soil depths. BD with 90% residue retention was reduced by 0.05, 0.04, and 0.03 Mg m^{-3} over no residue, 30% and 60% residue, respectively. Soil porosity at 90% residue retention was 3.4, 2.1, and 1.2% higher than no residue, 30% and 60% residue, respectively at 0–10 cm.

In Vertisols of central India, ZT with residue retention under maize-chickpea cropping system, CA had a significant influence on BD at 0–5 and 5–10 cm soil profile. The BD declined by 3.0–8.8% and 3.7–10.2% at 0–5 and 5–10 cm soil depth, respectively, in ZT-based residue retained plots as compared to CT. ZT with 90% residue retention recorded lowest BD of 1.24 Mg m^{-3} at 0–5 cm soil depth, while the highest BD of 1.33 Mg m^{-3} was recorded in CT plots (Kumawat *et al*., 2020).

Impact of CA on soil chemical properties

Soil organic carbon governs a number of physical, chemical and biological processes in the soil ecosystem. Besides this, it also helps in making soil more resilient. A gradual buildup of organic carbon was observed in all the experiments, the degree of increase in organic carbon was dependent on the length of study, quality of CA implementation, the level and type of crop rotation used, the quantity and quality of residue that could be retained in the soil (Mupangwa *et al*., 2016).

After completion of 4crop cycles, in Vertisols, organic carbon (%) fractions followed the order non-labile>very labile>less labile>labile for 0-5 cm and 5-15 cm depth (Somasundaram *et al*., 2018). Perhaps because more SOC was sequestered within macro-aggregates under CA compared to CT that helped to stabilize these aggregates. The improvement in soil aggregation and decrease in bulk density and improvement in physical health is observed due to increase in organic carbon.

In rainfed rice-based cropping systems rice and winter crops establishment methods influenced the soil organic carbon (SOC) content after 4 years of study. Irrespective of the winter crops, ZTDSR had higher SOC followed by CTDSR and PTR. Among the winter crops, rice followed by chickpea had higher SOC than the other crops. There was an increase of 45.1% SOC was observed in CA over CT after 4 years (Table 5a). Except in chickpea, retention of 30% anchored crop residues on soil surface significantly improved SOC contents than without crop residues in CA system (ZTDSR).

In short term studies conducted on Alfisols and Vertisols of CRIDA, AICRPDA in sorghum-black gram, finger millet + pigeonpea (8:2) the organic carbon was not significantly influenced by the tillage practices but residue levels increased the organic carbon content significantly after 4 years in 0-15 cm (Table 5a). Long term studies conducted in different cropping systems in both Alfisols and Vertisols reported that organic carbon was significantly higher in CA than CT system. The SOC in RT/ZT with higher residue content recorded higher SOC but this was similar to all the other treatments. Similar observations were recorded in finger millet + pigeonpea (8:2). The organic carbon was significantly influenced by pre-monsoon cover crops in top. Among the cover crops, horse gram recorded significantly higher organic carbon content (0.49%) compared to control (0.41%). In a short-term study in Vertisols at Akola in soybean-chickpea system, the SOC was not significantly influenced by the tillage systems and integration of *in-situ* soil moisture conservation. In a 9 year long-term study in Vertisols of Central India, the SOC content increased when compared to initial values and decreased with increase in depth due to lower addition of organic matter through crop residues as well as roots. CA practices significantly increased the SOC content in both 0-5 and 5-15 cm layers compared to the CT. This higher SOC in CA practices is due to minimum soil disturbances coupled with retention of residues. SOC increase in the 0-10 cm soil depth was 50 and 25% in CA and CT systems compared to the initial SOC. SOC increase was observed in almost all cropping systems in CA over CT (Table 5a). CA practices have shown

Table 5a. Change in organic carbon (OC) (%) observed between conventional tillage (CT) and conservation agriculture (CA) (ZT + residues + crop diversification) in different cropping systems

Location & length of study	Cropping system	OC (%)		
		CT	CA	% increase in CA over CT
Residue retention				
CRIDA, Hyderabad,11 years	Pigeonpea - Castor system			
	0-7.5 cm	0.42	0.46	8.6
	7.5-15 cm	0.41	0.50	21.95
	15-30 cm	0.38	0.40	5
CRIDA, Hyderabad, 7 years	Sorghum-blackgram system			
	0-7.5 cm	0.45	0.55*	17.9
	7.5-15 cm	0.41	0.46*	10.2
	15-30 cm	0.34	0.41	16.3
Crop diversification				
ICAR-RCER, Bihar, 4 years	Rice-fallows (winter crops)			
	Chickpea-	0.58	0.84	30.9
	Lentil-	0.45	0.82	45.1
	Safflower-	0.56	0.85	34.1
	Linseed-	0.54	0.81	33.3
	Mustard-	0.53	0.79	32.9
IISS, Bhopal, 7 years	Soybean-Wheat	0.5	0.61	18
	Maize-Wheat	0.48	0.61	21.3
	Maize-Gram	0.54	0.65	16.9
CA complementary practices as IV Principle				
i. *In-situ* moisture conservation				
CRIDA, Hyderabad, 6 years	Maize-pigeon pea system			
	0-7.5 cm	0.25	0.47	46.8
	7.5-15 cm	0.32	0.53	39.6
	15-30 cm	0.26	0.42	38.1
CRIDA, Hyderabad, 7 years	Maize-horsegram/pigeonpea	0.433	0.541	19.9
AICRP, Akola, 2 years	Soybean –chickpea	0.56	0.57	1.8
iii. Nutrient management (Nitrogen management CA+N; CT)				
CRIDA, Hyderabad, 4 years	Pearl millet-horsegram/pigeon pea	0.5	0.54	7.4

*= Reduced tillage + 100% residue

positive impact on the aggregate-associated C and different carbon pools in Vertisols of Central India. After completion of 4 crop cycles, the organic carbon (%) fractions followed the order non-labile>very labile >less labile >Labile for 0-5 cm and 5-15 cm depths (Somasundaram *et al.*, 2018).

After 10 crop cycles of pigeonpea–castor system SOC was significantly higher in CA than CT and RT in the 0-7.5 cm, 7.5-15 cm and 15-30 cm. In this study deep rooted crops like pigeonpea and castor were cultivated furthermore, the no tillage might have reduced the oxidation of organic matter hence the OC might be higher in deeper layers unlike in other studies. Whereas, in the 30-60 cm depth, RT recorded higher SOC content. Increase in residue levels increased the SOC content. ZT without residues decreased SOC content by compared to CT.

After completion of 6 crop cycles, integration of complementary practices like *in-situ* moisture conservation in maize–pigeonpea system also significantly influenced the SOC content. Permanent conservation furrow has recorded significantly higher SOC content (0.47, 0.53 and 0.42%). This was followed by permanent raised bed and furrow method (0.41, 0.43 and 0.39%) and CA with residues (0.32, 0.41 and 0.33). This was due to addition of crop residues in these treatments whereas, in CT and *in-situ* moisture conservation practices, residues were removed. CT without residues recorded lowest SOC in all depths whereas CT with residues recorded higher organic carbon content in all depths (Table 5a). In maize –pigeonpea cropping system after 4 crop cycles integration of *in-situ* moisture conservation with ridge and furrow along with crop residue recorded higher SOC content. The SOC increased with increase in residue retention levels. Complete residue retention (only cobs were harvested) recorded significantly higher SOC content and this was followed by harvesting at 30 cm height and no residue retention.

After 4 years of study in pearl millet-horsegram sequence-pigeonpea rotation system, at CRIDA, Hyderabad where nutrient management was added as complementary practice, ZT and MT (5.6 g/kg) recorded significantly higher soil OC as compared to CT in 0-15 cm soil depth. Higher SOC was observed in 125% RDF due to higher biomass production and higher amount of residue retention. There was a slight buildup (increase compared to initial years) of available N, P and K (kg/ha) after 5 years of experimentation.

Effect of CA practices and residue levels on chemical properties was studied in both Alfisols and Vertislos. Among the available nutrients, RT recorded significantly higher available N than CT in the 0-5, 5-15 and 15-30 cm soil layers, while, RT recorded significantly higher available P and K concentrations only in the top 5 cm soil depth. Among the micro-nutrients, the DTPA extractable Zn concentration was significantly higher in RT than CT up to 45 cm soil depth. However, for DTPA extractable Mn and Fe, the differences were significant only up to a soil depth of 30 cm and 15 cm, respectively (Somasundaram *et al.*, 2020). In a 4 crop cycle in soybean-chickpea system, Akola, Maharashtra in Vertisols, RT– pre sowing harrowing + broad bed and furrow every year + Pre-emergence herbicide application + crop residue mulch (T_3) recorded higher available nitrogen, phosphorus (180.25, 20.38 kg ha^{-1}) and available potassium content in soil (297.36 kg ha^{-1}) nitrogen and phosphorus content in different treatments were on par with each other but available potassium was significantly higher than other treatments.

In Alfisols after completion of 3 crop cycles of finger millet + pigeonpea (8:2) cropping system, pearlmillet – pigeonpea cropping system and 7-year sorghum-black gram system the available nutrients were not significantly influenced by different tillage methods but were significantly influenced by residue levels through cover crops. The cover crops recorded significantly higher available nitrogen and phosphorus but available potassium was not significantly influenced either by tillage or cover crops. Among the cover crops horse gram recorded significantly higher available nitrogen, than field bean and no cover crop. Available phosphorus was not influenced by the cover crops but they were significantly superior to no cover crops (Table 5b). In sorghum-black gramsystem, RT recorded 22% and 16% higher available nitrogen, phosphorus, respectively over CT. But the available macro and micro nutrients in soil significantly increased with the increase in the level of residue retention. 50% and 100% black gram residue retention recorded 19% and 40% higher nitrogen and 13.3% and 25.91% over control respectively.

In a 6-year crop cycle in maize-pigeonpea, integration of *in-situ* moisture conservation along with CA practices has revealed that CA has recorded higher available nutrients and this was similar toon par with integration of *in-situ* moisture conservation practices along with CA.

In another study conducted at Vertisols of central India at IISS Bhopal under soybean- wheat cropping system, the soil organic carbon (C)

Table 5b. Change in available nitogen (kg ha^{-1}), available phosphorus (kg ha^{-1}) and available potassium (kg ha^{-1}) observed between Conventional Tillage (CT) and Conservation Agriculture (CA) (ZT + residues + crop diversification) in different cropping systems

Location & length of study	Cropping system	Available N (kg ha^{-1})			Available P (kg ha^{-1})			Available K (kg ha^{-1})		
		CT	CA	% increase in CA over CT	CT	CA	% increase in CA over CT	CT	CA	% increase in CA over CT
Residue retention										
CRIDA, Hyderabad,11 years	Pigeonpea-Castor system									
	0-7.5 cm	159	163.4	2.7	11.4	18.2	37.3			
	7.5-15 cm	165.1	174.6	5.4	12.3	18.3	32.7			
CRIDA, Hyderabad, 7 years	Sorghum-Blackgram system									
	0-7.5cm	147.3	252.3*	41.6	28.5	41.3*	30.9	106.1	137.2*	22.6
	7.5-15cm	123.6	182.7*	32.3	17.9	29.5*	64.8	94.5	117.4*	19.5
	15-30cm	96.1	144.3*	33.4	10.3	17.5*	41.4	76.4	102*	25
AICRP, Bengaluru, 3 years	Fingermillet + Pigeonpea (8:2)	155.8	193.54	19.5	148.4	157.28	5.6	94.5	128.20	26.2
CA complementary practices as IV Principle										
i. *In-situ* moisture conservation										
CRIDA, Hyderabad, 6 years	Maize-pigeon pea system									
	0-7.5cm				9.9	13.5	26.7	143	193	25.9
	7.5-15cm				9.1	12.2	25.4	149	193	22.8
	15-30cm				8.4	11.6	27.6	141	130	-7.8
AICRP, Akola, 2 years	Soybean –Chickpea	179.8	180.2	0.2	19.8	20.3	2.5	296.9	297.3	0.1
iii. Nutrient management (Nitrogen Management CA+N; CT)										
CRIDA, Hyderabad, 4 years	Pearl millet-horsegram/pigeon pea	150	152.5	1.4	15.8	15.9	0.6	142.7	152	6.1

*= Reduced tillage + 100% residue

increased from 6.7 g C kg^{-1} soil to 10.2 g C kg^{-1} soil due to 90% residue retention over 5 years, while it remained stable where no residue was retained. Soil carbon increased significantly by 3.4, 2.2, and 1.4 g C kg^{-1} over the original soil due to different levels (90%, 60%, and 30%) of residue retention, respectively. The POM-C also increased with increasing crop residues levels. The level of POM-C, has risen to 2.3, 1.8, and 1.5 g kg^{-1}soil due to 90, 60 and 30% residue retention, respectively, while it remained almost the static (1.05 g kg^{-1}) with no residue’s retention. The soil labile carbon has increased from 470.0 mg kg^{-1} with no residue retention to 608.0 mg kg^{-1} with 90% residue retention, which was significantly higher as compared to 60% (544.0 mg kg^{-1}) and 30% (523.0 mg kg^{-1} soil) residue retention.

In another study conducted at Vertisols of central India at IISS Bhopal under maize-chickpea cropping system, varied residue retention levels (90%, 60%, and 30%) had significant effect on different organic carbon fractions *viz.* soil organic carbon (SOC), SOC stock, labile carbon and particulate organic matter-carbon (POM-C). The SOC content significantly increased by 13.6–61.7% at 0–10 cm soil depths in ZT with residue-retained plots over CT. Similarly, significant improvement in SOC stock and POM–C was also observed in the ZT-based residue retained plots as compared to CT. The soil labile carbon also increased by 6.0–22.0% in the ZT-based residue retained plots over CT.

Impact of CA on Soil Biodiversity

Soil microbial biomass carbon

CA recorded higher microbial biomass and microbial activity in relation to CT and ZT in all cropping systems. In CA practices, higher residue retention increased SOC and soil aggregation. SOC is an energy source and creates more favorable environment for the microbial population. Furthermore, higher microbial diversity was observed in CA. In pigeonpea–castor cropping system, higher fungal population were observed in ZT with residue retention (Fig. 5). Bacterial, fungal and actinomycetes population was highest with *in-situ* moisture conservation through permanent bed along with CA in Alfisol. However, the microbial population was not significantly influenced by the herbicide application. Among the weed management practices, pre+post+IC recorded significantly higher bacterial and fungal population than pre+post, pre+IC and control treatments. Whereas, pre+IC treatment recorded higher actinomycetes population, however, it was at par with pre+post treatment.

In Vertisols, basal respiration was 7.3% higher in 90% residue retained plot than no residue retention. Similar trend was recorded in the 10-20 cm of soil depth. Vesicular Arbuscular Mycorrhiza (VAM) colonization was also influenced by residue retention in wheat growing season. It was observed the VAM colonization in wheat root was significantly higher in 90% of residue retained plot compared with no residue retained plot. In 90% of residue retained plot, VAM colonization was 46% whereas it was only 26% in 0% residue retained plot under ZT (Plate 2a and 2b). The Shannon diversity index calculated with seven groups of microflora was found highest in CA and the trend increased with increase in surface cover in CA (ZT+90% residue retention). Evenness index or Shanon Equitability (EH) index was also higher for CA. The Shanon diversity and evenness index was lower in ZT and CT without residue whereas the dominance index (Simpson and Berger Parker Index) was

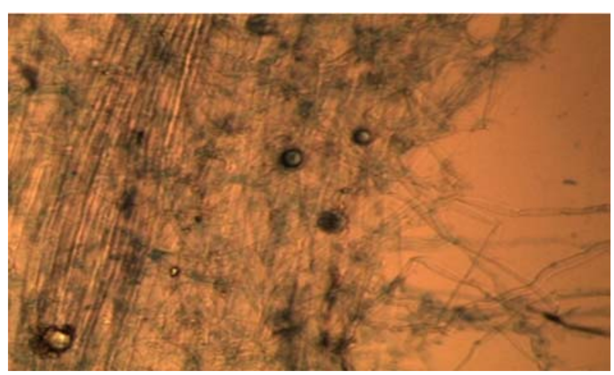


Plate 2a. VAM colonization in 0% of residue retained plot (wheat crop)

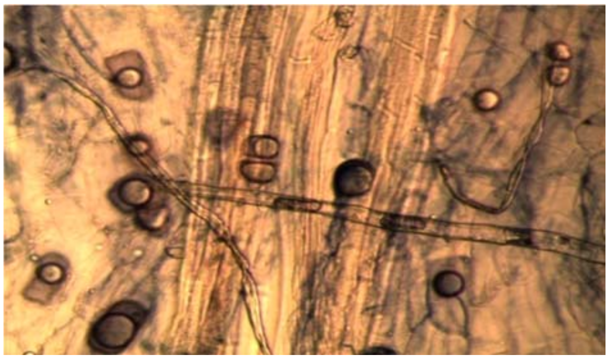


Plate 2b. VAM colonization in 90% of residue retained plot (wheat crop)

higher for these treatments which indicated a comparative disproportioned proliferation of microbes.

Apart from MBC, microbial enzymatic activity was significantly influenced by CA and CT. In Finger millet, CA with horse gram as a cover crop (82.98 µg TPF/g per 24 hr) recorded significantly higher dehydrogenase activity than all other treatments.

Climate change mitigation and adaptation potential of conservation agriculture

Natural resources are more efficiently used in CA than in CT. CA has the adaptation potential to climate change. Cultivation of soils through CT can result in faster degradation of soils through water and wind erosion due to removal of the protective cover of crop residues from the soil surface thus exposing the soil to various degradation processes. Apart from resource conservation, CA has a strong potential to provide adaptation and mitigation strategies to manage extreme climatic events.

Results of different studies have revealed that CA practices reduced the nutrient and soil loss. Studies in Alfisols of Hyderabad in pigeonpea-castor cropping system has revealed that CA (ZT + 30 % anchored crop residue+*sesbania* intercrop) recorded 14.3% higher water losses and 44.7% lower soil loss than CT. Growing of *dhaincha* crop in between the crop rows might have reduced the water loss whereas the sediment and nutrient loss were 22% and 30% lower soil loss than CT and RT respectively. Whereas the ZT without crop residues recorded highest runoff and soil loss.

In maize-pigeonpea cropping system where *in-situ* moisture conservation was integrated with CA *in-situ* moisture conservation through the conservation furrow and raised bed reduced the water loss by 50%. The runoff was 8%, 4% and 1% of total rainfall in CT, CA+permanent, conservation furrow and in permanent raised bed respectively.

In Vertisols in soybean-chick pea system CT without crop residues recorded highest runoff and soil loss (55.5mm, 1.9 t ha^{-1} soil loss) (T_2) respectively whereas, CA recorded lowest runoff and soil loss of 34.45 mm and 0.8 t ha^{-1} respect-ively. ZT+crop residue treatment (T_4) followed by permanent BBF furrow after every 4 rows + crop residue mulch treatment (T_5). The reduced soil and nutrient losses help in reduction of contamination of water bodies and pollution. In soybean-chickpea, AICRP, Akola CA practices reduced the runoff and soil loss by 37.9% and 56.5 t ha^{-1} (Table 7).

The CO_2 emission was higher under CT followed by ZT and RT during the soybean flowering stage (Fig. 3). The CH_4 oxidation rate of soil in soybean-wheat and maize-wheat cropping systems, 1.89 times higher in 90% residue retained treatment than no residue. In soybean–wheat system, abundance of bacterial genes has shown that the bacterial population was dominated by Eubacteria followed by methanotrophs and ammonia oxidizers under both

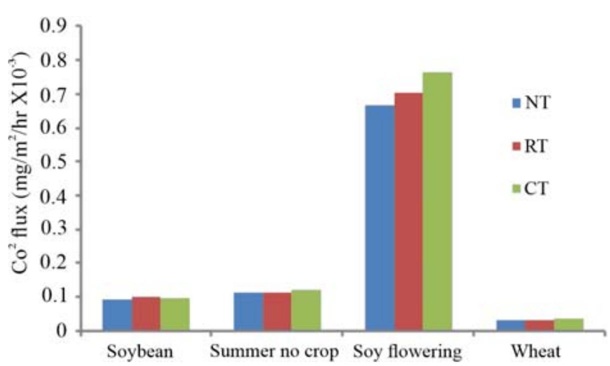


Fig. 3. Effect of tillage practices on CO_2 emissions in soybean-wheat system in rainfed Vertisols in wheat

Table 6. Impact of conservation agriculture practices on energy observed between CT and CA in different cropping systems

Location & length of study	Cropping system	Energy Input			Energy saving			EUE		
		CT	CA	% decrease in CA over CT	CT	CA	% increase in CA over CT	CT	CA	% increase in CA over CT
Residue retention										
CRIDA, Hyderabad, 11 years	Pigeonpea-Castor system									
	Pigeonpea	6238	4062	34.88	-	2176	34.88	4.94	9.81	49.64
	Castor	8671	6546	24.5	-	2125	24.5	2.28	2.87	20.5
AICRP, Bengaluru, 3 years	Fingermillet + Pigeonpea (8:2)	6851	6684	2.4	-	167	2.4	7.2	21.7	66.8
Crop diversification										
ICAR-RCER, Bihar, 4 years	Rice-fallows (*10^3 MJ/ha)	28.9	68.1	57.6						
	Rice-Chickpea									
CA complementary practices as IV Principle										
i. *In-situ* moisture conservation										
CRIDA, Hyderabad, 6 years	Maize-pigeon pea system	7652	7190	6.03	-	462	6.03	3.49	5.52	36.7
	Maize	10428	10331	0.9	-	97	0.9	1.72	1.90	9.47
	Pigeon pea	4876	4050	16.9	-	826	16.9	5.26	9.14	42.4
CRIDA, Hyderabad, 7 years	Maize-Horsegram/pigeonpea									
	Pigeonpea-	5561	4309	22.5	-	1252	22.5	6.61	10.94	39.5
AICRP, Akola, 2 years	Soybean–Chickpea	11180	9715	13.1	-	1465	13.1	5.66	6.11	7.36

Table 7. Change in runoff (mm) and soil loss (t ha^{-1}) observed between CT and CA in different cropping systems

Location & length of study	Cropping system	Runoff (mm) % decrease in CA over CT	Soil loss (t ha^{-1}) % decrease in CA over CT
Residue retention			
CRIDA, Hyderabad, 11 years	Pigeonpea-castor system	17.6	44.7
CA complementary practices as IV Principle - i. *In-situ* moisture conservation			
CRIDA, Hyderabad, 6 years	Maize-pigeon pea system		
	Permanent BBF	< 90; CF : 80	< 70-80
	Every year bed & furrow	CF < 70	CF < 70
AICRP, Akola, 2 years	Soybean –Chickpea system	37.9	56.5

the cropping systems. But no significant difference in bacterial abundance was observed due to retention of crop residue. In pigeonpea-castor cropping system GHG emissions *viz*., CO_2, CH_4 and N_2O fluxes were influenced by tillage and anchored residue (residue levels 0, 30, 60 cm). ZT with 10 cm anchored residue and *dhaincha* as live mulch recorded lower GWP than CT and RT. Methane consumption was observed in all the tillage treatments. ZT recorded highest methane consumption compared to RT and CT. Lower N_2O emissions were recorded in CA (ZT with residue retention) than CT (Fig.4).

Energy balance and carbon footprint

CA is considered as mitigation strategy since it helps in carbon build up and reduces fossil fuel consumption thereby reduce CO_2 emission. In pigeonpea and castor crops in pigeonpea-castor cropping system, CT recorded 30 and 31% higher energy inputs, than CA respectively. This higher energy input is due to 58 and 81% higher fuel consumption in CT in pigeonpea and castor respectively. Furthermore, lower fuel consumption in ZT reduced the GHG emissions by 21 and 23% than CT in pigeonpea and castor, respectively. Low GHG emissions, higher EUE and energy productivity were recorded in ZT with higher residue. Reduction in tillage operations with residue have a minimal impact on the crop yields, but have a substantial environmental benefit by energy saving, higher EUE and lower GHG

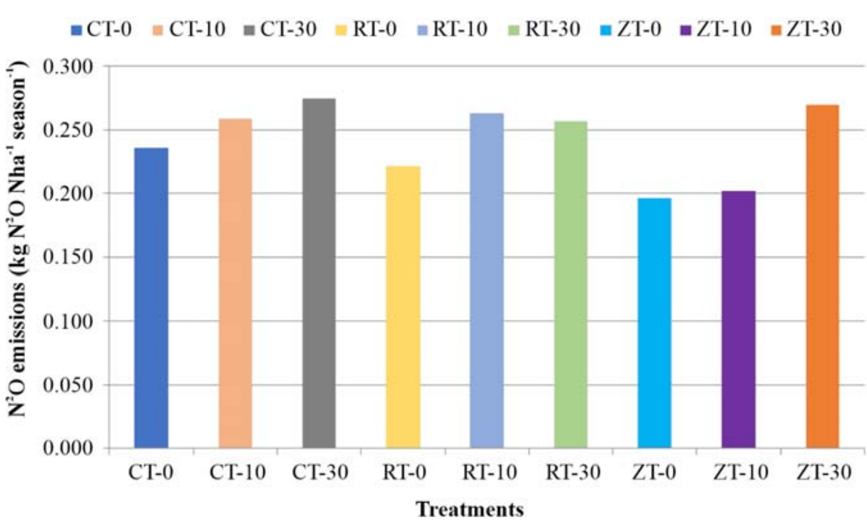


Fig. 4. Effect of tillage and residue management on NO_2 emissions in pigeonpea-castor system in rainfed Alfisols in pigeonpea

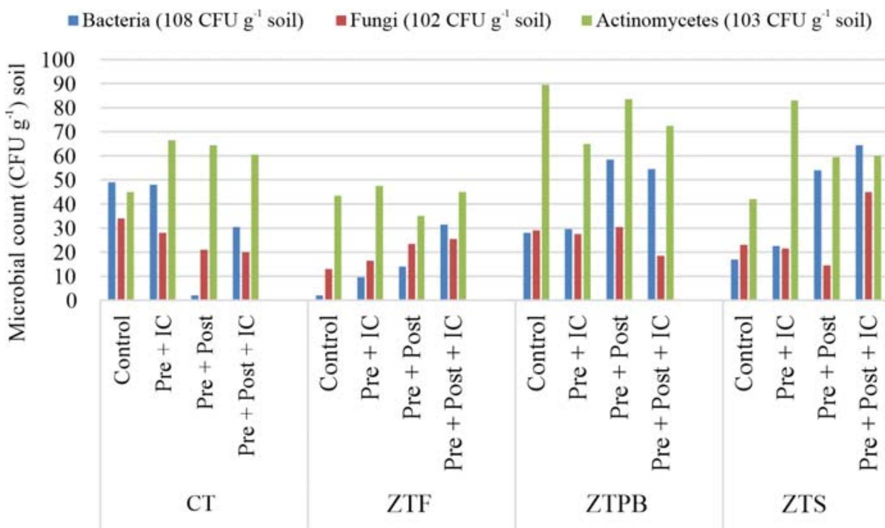


Fig. 5. Effect of tillage and weed management practices on microbial count in the soil

emissions from ZT followed by RT (Pratibha *et al*., 2015).

In finger millet+pigeonpea (8:2), ZT without residues recorded lowest energy input followed by CA (horse gram and field bean). RT with Horse gram as cover crop exhibited highest energy output (174878 MJ/ha), energy use efficiency (25.5), energy productivity compared to CT without cover crops (49517MJ/ha energy output) and CA with horse gram as cover crop (151727 MJ ha^{-1}). In maize-pigeonpea cropping system CA along with *in-situ* moisture conservation has shown that in both maize and pigeonpea crops, the energy input in CA and CA coupled with *in-situ* moisture conservation was low in Alfisol. Among different treatments, the integration of *in-situ* moisture conservation along with CT or ZT recorded higher energy output and EUE. Among different *in-situ* moisture conservation practices, CA integrated with permanent conservation treatment recorded higher energy use efficiency (EUE). The higher EUE in CA+ permanent CF is due to lower energy input and higher energy output.

In soybean-chickpea system, it is observed that the energy input is more in CT with crop residue mulch (T_1) followed by CT without crop residue mulch (T_2) and the lowest energy input was recorded in CA and CA+ permanent raised bed and furrow. But, the energy output (EO), energy use efficiency (6.69) and energy productivity (2.97) were highest in RT+ broad bed and furrow every year + pre-emergence herbicide application + crop residue mulch(T_3).In soybean-wheat in Vertisols of central India, approximately 2500 MJ energy saving was observed in ZT over CT practices.

Lessons learnt in rainfed areas

CA has been recognized as an eco-friendly technology for improving resource use efficiency, sustainability and productivity. The benefits of CA are realized only when all the three principles of CA are adopted and applied simultaneously. Unlike in rest of the world, adoption of CA in India is limited to irrigated regions of the IGP under rice–wheat cropping system. CA systems have not been tried or promoted in other major agro-ecological regions such as rainfed semi-arid tropics, the arid or the mountain agro-ecosystems. The key limiting factors for its widespread adoption and up-scaling are technological barriers, social barriers (attitude, small farm sizes, lack of knowledge, expertise), lack of suitable machinery, lack of diverse CA technologies, high opportunity cost of straw/residues, inadequate financial resources and infrastructure and poor policy support. Hence, studies were conducted and strategies to overcome the challenges were identified (Fig. 1) and these practices increase the yield in a synergistic way.

1. The crop rotation preferably cereal–legume is recommended in CA and it is one of the important pillars of CA for reduction of pest and weeds build up. Lack of functional input and output, markets for various crops and machinery have been highlighted as an impediment to the widespread adoption of crop rotation and mechanization (Thierfelder *et al*., 2013a). However, to have crop rotation it requires a more holistic approach at the government level.

2. Crop residues are key to success of CA, but the availability of residues for soil is poor, due to its competing uses in Southern India, termite infestation, uncontrolled grazing, etc. The problem is more aggravated in developing countries like India where the dependency on livestock increases hence interventions are needed to guarantee enough fodder, while at the same time recycling sufficient residues to the soil for conservation practices. This can be achieved by crop rotation with crops which have low fodder value, as well as manipulation of harvest height of the crop to separate nutritious palatable fodder and unpalatable fodder. In case of cereals like maize and sorghum, the crops can be harvested at 60 cm since the crop residue above 60 cm is nutritious and 30 cm height for crops like pigeonpea and castor (Pratibha *et al.*, 2015)/ growing of live mulch or growing of short duration green manure crop after short duration crops like maize/ growing of pre-monsoon cover crops. In these situations where competition for crop residue use is strong, intercropping with grain legumes/green manures as live mulch can be a viable strategy to achieve surface cover because the legume will cover the area between rows of the main crop and help to conserve moisture. Legumes like horse gram (*Macrotyloma uniflorum*) can be grown if the rainfall is around 70 mm between October – December. In rice fallows, crop rotation can be done with legumes as well as with crops which do not have fodder value, this reduces the risk of loss when returned and applied as surface mulch. And also, this method of residue application has better acceptability of residue retention over fodder value crops as communal grazing plays an important role in small holder farming systems.

3. Integration of complementary practices like *in- situ* moisture conservation through permanent raised bed and furrow in Alfisols, weed and nutrient management can improve the CA yields and reduce the risk of crop failures. Risk of off-season crop failure on account of water scarcity could be minimized through creation of farm ponds in high rainfall regions of Hill & Plateau for need-based supplemental irrigation.

4. Weed management is a major constraint in rainfed ecosystem. Moreover, herbicide efficacy largely depends on the soil moisture. Herbicides use is a pre-requisite for weed control in CA. The existing weeds before sowing of crops need to be managed by applying non-selective herbicides. After sowing, need-based, integrated weed management practices are effective. Integration of herbicides with hand weeding for removal of escaped weeds is an effective strategy which may control weeds in rainfed regions. After 4–6 crop cycles, weed intensity was reduced in many studies mainly due to build of crop residues on soil surface and reduction in soil weed seed bank. Hence, herbicide use can be reduced. We have also observed that growing of a cover crop like *dhaincha* in between the widely spaced crops also reduced the weed infestation in CA.

5. Foliar nutrient management *i.e.* spray of urea or DAP @ 2% at the branching and pod development stage of pulse/oilseed crop is required to supplement plant nutrition in rice-pulse/oilseed sequence. In nutrient deficit soils, adequate fertilization is essential to improve the yields and higher biomass production which in turn help in increasing surface cover. In rainfed regions, the farmers lack the affordability and moreover low doses were applied due to uncertain rainfall. Hence,

the nutrient needs can be achieved through mineral fertilizer, integration of legumes, manure, or compost.

6. Availability of machinery or implements is major constraint for adoption of CA technologies. CA requires a special type of equipment. Implements which can sow the seeds and place the fertilizers at desired depth by cutting the surface retained residue in no tilled fields for good germination and higher nutrient use efficiency is important to make CA an acceptable technology among the farmers. Appropriate location– and crop–specific machinery are to be developed to meet the requirements of small and medium farmers and fragmented land holdings. The machinery may be of animal operated or low power operated which suits small/marginal farmers. Besides, farmers need to be properly trained for the use of new machinery.

7. Lack of long–term studies on the benefits of CA under different agro–climatic conditions: In-depth research is required on different aspects of CA to standardize the crop rotations, machinery, techniques on residue management, nutrient and weed management for CA in different agro-climatic conditions.

8. Generally the success or failure of CA depends on the involvement of all the stake holders. Hence, more on farm studies in a participatory mode should be conducted so that farmers themselves can fine tune the technologies as per their resources to make it more economical.

Policy interventions: Though CA has many proven benefits, adoption is low due to lack of scale-appropriate machinery, policy interventions and un-favorable policy environments. Hence, policy analysis is required to understand the integration of CA technologies with other technologies, and the policy instruments and institutional arrangements to promote CA. These institutional arrangements must be based on a good understanding of the features that distinguish the principles and practices of CA from the conventional research and development approach. Policy indicators should be identified to assess the impacts of CA.

1. *CA should be construed as an investment into soil health, carbon sequestration and climate change mitigation*, which has so far not been recognized by the administrators and policy makers. Above all, farmers need to be made to realize this by incentivizing them appropriately. Furthermore, farmers may be rewarded for having provided the ecosystem services which have great impact on quality of life for all.

2. *Increase in awareness of the advantages of CA to the policy makers.* The policy makers often are unaware of the advantages of CA hence many existing policies are not friendly for the adoption of CA. Some of them are commodity-related subsidies due to which crop rotation is not adopted by the farmers. If the policy makers better understand then they could develop specific strategies and action plans for the promotion of CA. For example, introduction of tractors along with plough could be made into an opportunity by introduction of no-till seeders instead of the plough along with tractors. Hence, policy-makers and institutional leaders can be sensitized.

3. *Developing, improving, standardizing machinery*: In hilly areas, small landholders’ bullock-drawn equipment is highly important. Low cost smaller versions of the machines at the local level are required. For maintaining the quality standards of the CA machinery, there is a need to develop skill in the new and small-scale local manufacturers. Hence, the traders/dealers/local artisans should receive updated information and training on calibration, operation, repair and maintenance of CA machinery so that right services are provided to the farmers and cooperatives may be encouraged to set up service and repair centers for agricultural implements in each block. Furthermore, Custom-Hiring Centers with inclusion of CA machineries need to be increased.

4. The success or failure of CA depends greatly on the flexibility and creativity of the farmers, extension workers and researchers of a location. Hence, successful diffusion of CA can be done if KVKs, NGOs and research organizations work together in technology assessment and refinement (TAR). Promote system based technical advisories to farmers using modern Information and Communication Technologies (ICT).

5. *Convergence with various schemes:* Appropriate technology, policy and institutional supports are prerequisite for promotion of CA practices across different agro-ecologies. For the institutional support investment by the national government is not an issue but making best use of the allocated resources is important. Large investments were made on different schemes like NREGS, NHM, RKVY, NFSM, watershed programme, and for research programmes like RKVY, NAIP, national initiative on climate resilient agriculture (NICRA), ICAR platform on water, etc. There is a need for convergence of these schemes at the local level involving all major stakeholders would definitely contribute towards promotion of CA. Besides convergence, there is a need for integration and complementarities in such schemes with appropriate monitoring and evaluation (M&E) for mid-course correction and greater impact at the field level. Promotion of CA technology on various platforms like TV, Radio, Kisan melas, print media and Capacity building of farmers on aspects of CA. Keeping in view the reduced crop yields during initial years the mechanism could be developed to support the farmers with compensation for 'yield penalty'.

Conclusion

The improvement in crop productivity in CA could be realized in long term and also when all the three principles are adopted. Integration of complementary practices like *in-situ* moisture conservation, nutrient, weed management are essential. Besides, long term studies on the influence of CA on a resource/input use efficiency, soil health, pest dynamics, carbon sequestration, greenhouse gas emissions and environmental benefits including eco system services in different production systems are also needed for large scale adoption and popularization of conservation technologies for sustainable intensification of agriculture.

The studies in the past mainly focused on levels of tillage and crop residue retention, but only few studies were on crop diversity. Pulses require low nutrients but have positive impact on the soil fertility. Thus, future research should emphasize the inclusion of pulses and oilseeds in to the cropping system in conservation agriculture.

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