Agropedology 2021, 31 (02), 138-148
doi.org/10.47114/j.agroped.2021.dec4

Assessment of Productivity, Energy Balance and Soil Fertility under Conservation Tillage in Soybean-Chickpea Sequence on Vertisols under Rainfed Condition

R. S. Patode*, V.V. Gabhane, V. P. Pandagale, M. M. Ganvir, A. B. Turkhede and G. Pratibha[1]

All India Coordinated Research Project for Dryland Agriculture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola - 444 104
[1]Division of Resource Management, ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad-500 059

Abstract: Conservation agriculture is characterized by three principles which are linked to each other, namely; continuous minimum mechanical soil disturbance, continuous organic soil cover, diversified crop rotations in the case of annual crops or plant associations in case of perennial crops. Excessive tillage of agricultural soils may result in short term increases in fertility, but will degrade soils in the medium term. Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation. The logical approach to this has been to reduce tillage. The experiment on conservation tillage was undertaken at AICRP for Dryland Agriculture, Dr. PDKV, during 2018-19 and 2019-20. The results indicated higher soil moisture status at various crop growth stages and highest yield of soybean and chickpea was observed in reduced tillage as compared to other treatments. It was also observed that reduced tillage has given higher net returns and B:C ratio of soybean and chickpea than other treatments. Reduced tillage with BBF and crop residue mulch helped in slight build up in organic carbon and available nutrients in soil. The average energy use efficiency **(**6.62**)** and energy productivity (2.98) was found highest in reduced tillage with BBF**.**

Keywords: *Conservation tillage, energy balance, soil fertility, Vertisols.*

Introduction

Minimum tillage is an ecological and science-based approach for resource conservation and sustainable production. Minimum tillage includes reduced frequency and intensity of tillage operation, use of those implements that loosen the soil without turning over and do not excessively pulverize it and perform the needed tillage operations when soil conditions are within the optimum soil condition range to produce the desired tilth. It facilitates intensive cultivation with minimum risk of degradation. The conservation agriculture and its components have been associated with many benefits including greater soil water storage (Page *et al*. 2019), improved soil quality (Jat *et al*. 2019; Somasundaram *et al*. 2019), decreased erosion (Montgomery 2007), and in some instances, greater yield and net farm income (Pradhan *et al*. 2018). It is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment and maintaining soil health.

*Corresponding author: (Email: rspatode@gmail.com)

In general, the CT practice produced higher maize growth and yield, lower production cost, and higher tillage operation cost than those are planted using RT and ZT practices (Gomez *et al*. 1999). Zero tillage resulted in higher infiltration rates, initial as well as steady state (0.120 and 0.029 mhr^{-1} where residue retained; 0.108 and 0.028 m hr^{-1} where residue removed). Although zero tillage optimized water use by 14 and 12% in maize and mustard, respectively as compared to conventional tillage, maximum water-use efficiency was obtained in conventional tillage with residue incorporation, mainly because of maximum yield in maize (2.93 tonnes ha^{-1}) and mustard (1.83 tonnes ha^{-1}) obtained under the treatment. (Saha *et al*. 2010). Crop yields and water use efficiency have increased (with up to 35%) following the implementation of reduced tillage practices. In order to fully exploit the advantages of conservation tillage, systems have to be adapted to regional characteristics. Farmer's adoption of conservation tillage is still limited (Wang *et al*. 2007). Conservation tillage in sub-tropical regions offers advantages over conventional tillage, but also poses significant challenges. New procedures and equipment modifications are required. Planting and weed control are difficult (Wiedenfeld 2006). The average yield from the no-tillage plots was slightly higher than under conventional tillage, while a slightly lower yield was found under reduced tillage (Yao *et al*. 2004). In view of the above and considering the importance of conservation agriculture, a field experiment on conservation tillage was undertaken at AICRP for Dryland Agriculture, Dr. PDKV, Akola, to study the effect of various conservation tillage treatments on soil fertility, energy balance and productivity of soybean-chickpea sequence on Vertisols under rainfed conditions.

Materials and Methods

The crops were grown following normal packages of practices except for tillage and residue management practices. The recommended doses of fertilizers [soybean- (30:75:30 NPK kg ha^{-1}); chickpea (20:40:30 NPK kg ha^{-1})] were applied to the crops. The details of various treatments imposed during *kharif* and *rabi* seasons are given below.

Kharif – (Treatments for soybean crop)

T_1: Conventional tillage (CT) - Ploughing once in 3 years + 2 pre-sowing harrowings + one hand weeding + opening of furrow with hoe in each row at 30-35 DAS + crop residue mulch

T_2: Conventional tillage (CT) - Ploughing once in 3 years + 2 pre-sowing harrowings + one hand weeding + opening of furrow with hoe in each row at 30-35 DAS without crop residue mulch

T_3: Reduced tillage (RT) – Pre-sowing harrowing +Broad Bed and Furrow every year + pre and post-emergence herbicide application + crop residue mulch

T_4: Zero tillage + crop residue mulch

T_5: Permanent BBF furrow after every 4 rows + crop residue mulch

Rabi – (Treatments for chickpea crop)

T_1- Conventional tillage (CT)- Pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch

T_2- Conventional tillage (CT) – pre-sowing harrowing + one hoeing + one hand weeding + no crop residue mulch

T_3- Reduced tillage (RT) – Pre-sowing harrowing + BBF every year + pre-emergence herbicide application + crop residue mulch

T_4- Zero tillage + crop residue

T_5- Zero tillage (ZT) - Permanent BBF+ pre-emergence herbicide application + crop residue mulch

The moisture content in soil (0-15 and 15-30 cm) was recorded at various growth stages of crops and the treatment wise surface (0-20 cm) soil samples were collected after the harvest of chickpea. The samples were air dried, ground to pass through <2 mm sieve for all soil chemical properties except OC (<0.5 mm sieve) and analysed for various soil properties. The soil organic carbon was determined by wet oxidation method (Nelson and Sommer 1982). The available N in soil was determined by modified alkaline potassium permanganate method as described by Subbiah and Asija (1956). Available phosphorus (Olsen P) was measured using sodium bicarbonate ($NaHCO_3$) as an extractant (Watanabe and Olsen 1965). Soil available K was extracted by shaking with neutral normal ammonium acetate for 5 minute (Hanway and Heidel 1952) and potassium in the extract was estimated by flame photometer. Total energy input and output of crops and cropping systems were estimated by using the energy equivalents and the procedure given in Research Manual on Energy Requirement in Agricultural Sector by De (2000).

Results and Discussion

Soil moisture during kharif soybean

The soil moisture content (Table 1) was higher during flowering and maturity stages than early growth stages of the crop during 2019-20. It was higher during flowering stage of crop, in all treatments combinations at 0-15 and 15-30cm depth. However, reduced tillage (RT) – pre sowing harrowing + broad bed and furrow every year + Pre-emergence herbicide application + crop residue mulch (T_3) recorded higher moisture content as compared to other treatments at all crop growth stages. Basha *et al*. (2020) found that the analysis of variance was significant for soil moisture in reduced tillage. The relatively higher moisture content at the end of the season was found to be beneficial for *rabi* chickpea crop.

Table 1. Soil moisture content at different growth stages during *kharif* soybean

Treatments	Depth (cm)	Soil moisture content (%)		
		Vegetative stage (24/07/19)	Flowering stage (22/08/19)	Maturity stage (25/09/19)
T_1	0-15	25.17	28.32	32.02
	15-30	27.20	29.38	32.40
T_2	0-15	24.07	27.02	30.52
	15-30	26.40	27.78	31.00
T_3	0-15	27.10	30.60	33.12
	15-30	28.20	31.28	34.36
T_4	0-15	26.22	29.12	32.22
	15-30	27.58	29.80	33.50
T_5	0-15	26.32	29.00	32.60
	15-30	27.63	29.50	33.68

Soil moisture during rabi chickpea

The soil moisture content was good during early stages but started declining from flowering stage onward of chickpea crop growth. However, treatment reduced tillage (T_3) had higher moisture content than other treatments at all the crop growth stages. The good moisture (Table 2) in reduced tillage has beneficial effect on growth of the chickpea.

Table 2. Soil moisture content at different crop growth stages during *rabi* chickpea

Treatments	Depth (cm)	Soil moisture content (%)		
		(09/11/2019)	(20/12/2019)	(21/01/2020)
T_1	0-15	26.20	25.00	22.00
	15-30	27.68	26.10	23.50
T_2	0-15	26.10	24.90	21.84
	15-30	27.02	26.00	23.06
T_3	0-15	27.20	26.04	23.21
	15-30	28.60	27.34	24.65
T_4	0-15	27.01	25.72	22.41
	15-30	28.00	27.06	23.62
T_5	0-15	26.90	25.86	22.30
	15-30	28.06	27.01	23.72

Yield and economics of soybean-chickpea

The yield and economics of soybean-chickpea during 2018-19 is given in table 3 and 4 respectively. The reduced tillage (RT) – pre sowing harrowing + broad bed and furrow every year + pre-emergence herbicide application + crop residue mulch (T_3) was found significantly superior for soybean yield over other treatments and was at par with conventional tillage (CT)-Pre sowing harrowing + one hoeing + one hand weeding + crop residue mulch (T_1). The rain-water use efficiency was higher in the treatments T_3 and T_1 as compared to other treatments. The conventional tillage - pre sowing harrowing + one hoeing + one hand weeding + no crop residue mulch (T_2) was found significantly superior for chickpea yield over T_4 and T_5 and was found at par with treatment T_1 and T_3. Reduced tillage had higher net returns for soybean but it was higher in conventional tillage without crop residue mulch (T_2) for chickpea. However, Hajare *et al.* (1997) reported higher water use efficiency and yield of chickpea due to millet with available grasses in swelling clay soils.

Table 3. Yield and economics of soybean under different treatments during *kharif* 2018-19

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	RWUE (kg ha^{-1} mm^{-1})	NMR (Rs. ha^{-1})	B:C ratio
T_1	1982	2457	2.50	33391	2.09
T_2	1900	2302	2.41	32992	2.17
T_3	2140	2673	2.68	39080	2.31
T_4	1879	2229	2.33	30858	2.04
T_5	1806	2141	2.24	33785	2.39
S. E. (m)	63.10	70.67	-	-	-
C.D. at 5%	196	220	-	-	-

Table 4. Yield and economics of chickpea under different treatments during *rabi* 2018-19

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	NMR (Rs. ha^{-1})	B:C ratio
T_1	1008	1620	16712	1.66
T_2	1080	1696	21782	1.94
T_3	992	1600	17631	1.75
T_4	812	1280	11047	1.49
T_5	884	1400	14741	1.67
S. E. (m)	30.54	101.66	-	-
C.D. at 5%	95.14	-	-	-

The yield and economics of soybean-chickpea during 2019-20 is given in table 5 and 6 respectively. The reduced tillage (RT) – pre -owing harrowing + BBF every year + pre-emergence herbicide application + crop residue mulch was found significantly superior for soybean yield over other treatments and was at par with conventional tillage - pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch (T_1). The rain-water use efficiency was higher in the treatments T_3 and T_1 as compared to other treatments. The reduced tillage was found significantly superior over T_2, T_4 and T_5 and was found at par with treatment T_1 for grain yield of chickpea. The reduced tillage had higher net return and B:C ratio than other treatments for both the crops.

Table 5. Yield and economics of soybean under different treatments during *kharif* 2019-20

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	RWUE (kg ha^{-1} mm^{-1})	NMR (Rs. ha^{-1})	B:C ratio
T_1	2003	2424	2.66	34184	2.13
T_2	1897	2312	2.53	32913	2.17
T_3	2149	2570	2.80	39785	2.35
T_4	1773	2205	2.29	27508	1.93
T_5	1818	2245	2.36	30941	2.12
S. E. (m)	54.42	78.74	-		
C.D. at 5%	169.55	245.30	-		

Table 6. Yield and economics of chickpea under different treatments during *rabi* 2019-20

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	NMR (Rs. ha^{-1})	B:C ratio
T_1	1018	1498	16978	1.67
T_2	926	1350	15461	1.67
T_3	1094	1616	21605	1.91
T_4	831	1190	11105	1.48
T_5	887	1279	14196	1.63
S. E. (m)	29.90	45.91		
C.D. at 5%	93.17	143.03		

Pooled analysis

The data of pooled analysis for soybean and chickpea grain yield are presented in table 7. The treatment having reduced tillage had highest pooled mean for soybean and chickpea grain yield and soybean equivalent yield Reduced tillage had highest, (3300 kg ha^{-1}) of pooled mean and it was statistically superior over other treatments. Basha *et al*. (2020) found that the pooled analysis of variance was significant for growth and yield parameters due to tillage methods and crop residue owing to increased soil water content and water use efficiency. Aulakh *et al*. (2012) observed significantly higher uptake of N and P by soybean from crop residue amended treatments due to conservation of water in soil profile, resulting in higher soybean and wheat yield in conservation tillage than conventional tillage.

Table 7. Pooled Analysis and pooled mean of Soybean Equivalent Yield under different treatments during 2018-19 and 2019-20 (Two years)

Treatments	Pooled mean of soybean gain yield (kg ha^{-1})	Pooled mean ofchickpea grain yield (kg ha^{-1})	Pooled mean of soybean equivalent yield (kg ha^{-1})
T_1	1993	1013	3119
T_2	1898	1003	3023
T_3	2145	1043	3300
T_4	1826	821	2739
T_5	1812	885	2797
S. E. (m)	40.875	21.37	47.9
C.D. at 5%	120.017	62.75	140.5

Age *et al*. (2019) reported that the highest soybean seed yield and nutrient uptake in treatment having conservation tillage as compared to conventional tillage in Vertisols.

Energy Balance

The estimation of the energy inputs and outputs in different treatments for the year 2018-19. (Table 8) indicated that the energy input (EI) was more in conventional tillage (CT) with crop residue mulch treatment (T_1) followed by conventional tillage (CT) without crop residue mulch treatment (T_2), reduced tillage **(**T_3**),** permanent BBF after every 4 rows + crop residue mulch treatment (T_5) and zero tillage + crop residue treatment (T_4). However, the energy output (EO) was observed to be highest in reduced tillage followed by conventional tillage with crop residue mulch treatment , conventional tillage without crop residue mulch treatment, zero tillage + crop residue treatment, permanent BBF after every 4 rows + crop residue mulch. The energy use efficiency **(**6.69**)** and energy productivity (2.97) were found to be highest in reduced tillage treatment.

Table 8. Energy balance as influenced by different treatments during 2018-19

Treatments	Energy Input (EI)	Energy output (EO)	Energy use efficiency (EUE)	Specific energy	Energy productivity
T_1	11230	66806	5.95	5.66	2.65
T_2	11136	63240	5.68	5.86	2.56
T_3	10575	70751	6.69	4.94	2.97
T_4	9697	60387	6.22	5.16	2.84
T_5	9713	58020	5.97	5.37	2.73

The data on energy balance (Table 9) during 2019-20, indicated that the energy input was more in conventional tillage with crop residue mulch treatment followed by conventional tillage without crop residue mulch treatment, reduced tillage, permanent BBF after every 4 rows + crop residue mulch and zero tillage + crop residue treatment. However, the energy output (EO) was observed to be highest in reduced tillage followed by conventional tillage with crop residue mulch treatment, conventional tillage without crop residue mulch treatment, permanent BBF after every 4 rows + crop residue mulch treatment and zero tillage + crop residue treatment. The energy use efficiency (6.54) and energy productivity (2.98) were found highest in reduced tillage treatment.

Table 9. Energy balance as influenced by different treatments during 2019-20

Treatments	Energy Input (EI)	Energy output (EO)	Energy use efficiency (EUE)	Specific energy	Energy productivity
T_1	11318	66626	5.87	5.65	2.66
T_2	11224	63345	5.64	5.91	2.54
T_3	10611	69369	6.54	4.94	2.98
T_4	9733	58477	6.01	5.49	2.68
T_5	9769	59726	6.11	5.37	2.73

Average energy balance

The data on average energy balance for the years 2018-19 and 2019-20 (Table 10) indicated that the average energy input (EI) was more in conventional tillage with crop residue mulch treatment followed by conventional tillage without crop residue mulch treatment, reduced tillage, permanent BBF furrow after every 4 rows + crop residue mulch treatment and zero tillage + crop residue treatment. However, the average energy output (EO) was observed to be highest in reduced tillage followed by conventional tillage with crop residue mulch treatment, conventional tillage without crop residue mulch treatment, permanent BBF furrow after every 4 rows + crop residue mulch treatment and zero tillage + crop residue treatment. The average energy use efficiency (6.62) and energy productivity (2.98) was found highest in reduced tillage treatment. Borin *et al*. (1997) noticed that (reduced tillage) is intermediate, but nearer to CT than NT for energy costs and energy productivity.

Table 10. Average Energy Balance as influenced by different treatments

Treatments	Energy Input (EI)	Energy output (EO)	Energy use efficiency (EUE)	Specific energy	Energy productivity
T_1	11274	66716	5.91	5.66	2.66
T_2	11180	63293	5.66	5.89	2.55
T_3	10593	70060	6.62	4.94	2.98
T_4	9715	59432	6.12	5.33	2.76
T_5	9741	58873	6.04	5.37	2.73

Nutrient status of soil

The data on nutrient status of soil as influenced by different treatments are given in table 11.

Table 11. Organic carbon and available nutrient status of soil as influenced by various conservation tillage treatments during 2019-20

Treatments	**Organic carbon (%)**	**Available nutrients (kg ha^{-1})**		
		N	**P**	**K**
T_1	0.57	181.27	19.65	297.59
T_2	0.56	180.56	18.95	295.79
T_3	0.59	183.70	20.55	298.50
T_4	0.56	178.91	18.90	295.24
T_5	0.56	179.85	18.98	295.62
SE(m±)	0.01	1.00	0.42	0.74
CD (5%)	NS	3.09	NS	2.29

Organic carbon

The data on organic carbon content in soil as influenced by different treatments was found to be non-significant. However, numerically higher organic carbon content (0.59%) was recorded under reduced tillage– pre-sowing harrowing + Broad Bed Furrow every year + pre-emergence herbicide application + crop residue mulch followed by conventional tillage - pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch. The lowest organic carbon (0.56%) was recorded with zero tillage + crop residue mulch and permanent broad bed and furrow + pre-emergence herbicide application + crop residue mulch. It is reported that the reduction in tillage levels increased the organic carbon build-up but the degree of increase in organic carbon was dependent on the length of study, quality of CA implementation, such as 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).

Available nutrients

The available nitrogen content in soil as influenced by various treatments was found to be significant. The significantly higher available nitrogen content (183.70 kg ha^{-1}) was recorded under reduced tillage– pre-sowing harrowing + BBF every year + pre-emergence herbicide application + crop residue mulch followed by conventional tillage - pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch. The lowest available nitrogen (178.91kg ha^{-1}) was recorded with zero tillage + crop residue mulch. Kumar *et al.* (2018) reported that the tillage and nutrient management increased organic carbon content and reduced tillage with application of NPK + FYM (2.0 t ha^{-1}) increased the amount of available N in soil.

The available phosphorus content in soil as influenced by various treatments was found to be non-significant. However, relatively higher available phosphorus content (20.55 kg ha^{-1}) was recorded under reduced tillage–pre-sowing harrowing + BBF every year + pre-emergence herbicide application + crop residue mulch followed by conventional tillage – pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch. The lowest available phosphorus (18.90 kg ha^{-1}) was associated with zero tillage + crop residue mulch.

The available potassium content in soil as influenced by various treatments was found to be significant. The significantly higher available potassium content (298.50 kg ha^{-1}) was recorded under reduced tillage– pre-sowing harrowing + BBF every year + pre-emergence herbicide application + crop residue mulch and was on par with conventional tillage- pre-sowing harrowing + one hoeing + one hand weeding + crop residue mulch. The lowest available potassium (295.24 kg ha^{-1}) was recorded with zero tillage + crop residue mulch. In general, reduced tillage with BBF and crop residue mulch helped in slight build up in organic carbon and available nutrients in soil. Das *et al.* (2020) also reported significantly higher available nitrogen (5.7%), phosphorus (7.3%) and potassium (3%) in 0-15 cm depth were recorded under conservation tillage than those under conventional tillage in rice-rapeseed cropping system.

Conclusion

The highest energy output (70060), average energy use efficiency **(**6.62**)** and energy productivity (2.98) was found in the treatment having reduced tillage (pre-sowing harrowing + BBF every year + pre and post-emergence herbicide application + crop residue mulch. Highest pooled mean of soybean and chickpea grain yield (2145 kg ha^{-1} and 1043kg ha^{-1}) and highest pooled mean of soybean equivalent yield (3300 kg ha^{-1}) was also observed in the reduced tillage treatment. Thus, it can be concluded that in soybean-chickpea sequence under rainfed condition, the reduced tillage was found to be beneficial in terms of crop productivity, energy balance and soil fertility under Vertisols.

Acknowledgments

The authors are thankful to the Director and Principal Investigators, ICAR-CRIDA, Hyderabad, Government of India for their financial support under Consortia Research Platform (CRP) on Conservation Agriculture Project.

References

Age, A.B., Kadu, P.R. Gabhane, V.V. Jadhao, S.D. and Zodge, S.D. (2019). Effect of various conservation practices on yield and nutrient uptake by soybean under soybean-cotton rotation in Vertisol. *Journal of Pharmacognosy and Phytochemistry* **8**, 3272-3277.

Aulakh, M. S., Manchanda J.S., Garg, A. K., Shravan Kumar, Dercon, G. and Nguyen, Minh-Long (2012). Crop production and nutrient use efficiency of conservation agriculture for soybean–wheat rotation in the Indo-Gangetic Plains of Northwestern India. *Soil and Tillage Research* **129**, 50-60.

Basha, S. J., Jayalakshmi, V., Ahammed, S. K. and Kamakshi, N. (2020). Response of chickpea (*Cicer arietinum* L.) to conservational agricultural practices for enhancing productivity under rainfed conditions in vertisols. *Tropical Plant Research* **7**, 472–475.

Borin, M., Menini, C. and Sartori, L. (1997). Effects of tillage systems on energy and carbon balance in north-eastern Italy. *Soil and Tillage Research* **40**, 209-226.

Das, A., Layek, J., Idapuganti. R.G., Basavraj. S., Rattan Lal, Rangappa, K., Yadav, G.S., Subhash Babu and Ngachan Shishomvanao. (2020). Conservation tillage and residue management improves soil properties under a upland rice–rapeseed system in the subtropical eastern Himalayas. *Land Degradation and Development* **31,** 1775-1791.

De, Dipankar. (2000). Concepts of energy use in Agriculture, Research Report, CIAE Bhopal.

Hajare, T.N., Mandal, D.K., Jagdish Prasad and Gaikawad, S.T. (1997). Water use efficiency of gram as affected by mulch in typical shrink-swell soils of Central India. *Journal of the Indian Society of Soil Science* **45**, 377-380.

Hanway, J. J. and Heidel, H. (1952). Soil Analysis Methods, as used in Iowa State. College Soil Testing Laboratory, Iowa, Agriculture **57**, 1-31.

Jat, H.S., Datta, A., Choudhary, M., Sharma, P.C., Yadav, A.K., Choudhary, V. (2019). Climate smart agriculture practices improve soil organic carbon pools, biological properties and crop productivity in cereal-based systems of North-West India. *Catena* **181**, 104059.

Kumar, S., Vishwakarma, D., Lenka, S. and Jain, R.C. (2018). Effects of conservation tillage, organics and inorganics on soil fertility in different aggregate soil classes. *Annals of Plant and Soil Research* **20,** 168-171.

Montgomery, D.R. (2007). Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci. U.S.A. **104**, 13268–13272.

Mupangwa, W., Mutenje, M., Thierfelder, C. and Nyagumbo, I.. (2016). Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? *Renew Agric Food System*, 1–17.

Nelson, D.W. and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In 'Method of soil Analysis', Part 11. (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.). Soil Science Society of America Inc., Madison, Wisconsin, USA.

Page, K.L., Dang, Y.P., Dalal, R.C., Reeves, S., Thomas, G. and Wang, W. (2019). Changes in soil water storage with no-tillage and crop residue retention on a Vertisols: Impact on productivity and profitability over a 50-year period. *Soil Tillage Research* **194**, 104319.

Pradhan, A., Chan, C., Roul, P.K., Halbrendt, J. and Sipes, B. (2018). Potential of conservation agriculture (CA) for climate change adaptation and food security under rainfed uplands of India: a trans-disciplinary approach. *Agriculture System* **163**, 27–35.

Saha, S., Chakraborty, J.V., Sharma, A.R., Tomar, R.K., Bhadraray, S., Sen, U., Behera, U.K., Purakayastha, T.J., Garg, R.N. and Kalra, N. (2010). Effect of tillage and residue management on soil physical properties and crop productivity in maize (*Zea mays*) Indian mustard (*Brassica juncea*) system. *Indian Journal of Agricultural Sciences* **80**, 679-685.

Sevilla-Guzman, E., Woodgate, G. (1997). Sustainable rural development: from industrial agriculture to agroecology. In 'The international handbook of environmental sociology'. (Eds. Redclift, M. and Woodgate, G.) Edward Elgar, Cheltenham.

Somasundaram, J., Salikram, M., Sinha, N.K., Mohanty, M., Chaudhary, R.S., Dalal, R. C. (2019). Conservation agriculture effects on soil properties and crop productivity in a semiarid region of India. *Soil Research* **57**, 187–199.

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for the determination of available N in soils. *Current Science* **25,** 259-65.

Wang, X.B., Cai, D.X., Hoogmoed, W. B., Oenema, O. and Perdok, U.D. (2007). Development in conservation tillage in rainfed regions of north china. *Soil and Tillage Research* **93**, 239-250.

Watanabe, F.S. and Olsen, S.R. (1965). Test of anascorbic acid method for determining phosphorus in water and NaHCO3 extracts from the Soil. *Soil Science Society of America Journal* **29**, 677-678.

Wiedenfeld, B. (2006). Conservation *vs* conventional tillage for double cropping and cover crop effects on crop water use in subtropical south texas. *Conservation Systems Conference, Amarillo TX, June 26-28.*

Yao, Y., Schiettecatte, W., Lu, J., Wang, Y., Wu, H., Jin, K., Cai, D., Gabriels, D., Hartmann, R., Cornelis, W.M., Baert, M. and Buysse, T. (2004). Influence of tillage practices on yield, water conservation and soil loss: results of field experiments in the eastern loess plateau (Henan Province, China). *13th International Soil Conservation Organization Conference – Brisbane, Conserving Soil and Water for Society: Sharing Solutions* **233**, 1-5.

Received: July, 2021 *Accepted: October: 2021*