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Research Article

Evaluation of Tillage and Crop Establishment Methods on Carbon Sustainability Index and Nutrient Use Efficiency of Cotton-Wheat System

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Abstract

Conservation agriculture-based cotton (*Gossypium hirsutum*L.) wheat (*Triticum aestivum* L.) crop rotations with intensification of mungbean are advocated as alternate to conventional cotton-wheat (CW) system in South Asia due to better strategies for tackling the issues of soil health deterioration, plant nutrients status and over exploitation of underground water resources, particularly in conventional tillage based intensive crop rotations. A field experiment was conducted during 2013-14 and 2014-15 at Borlaug Institute for South Asia (BISA), Ladhowal (Punjab), to evaluate the impacts of tillage and crop establishment techniques significantly maximum C input of cotton wheat system was estimated under CT with 808.55 MJ ha^{-1} during both years compared to sustainable intensification practices. Among sustainable intensification practices, minimum C input was under PB-A and maximum C-output was recorded under PBB-AM. CSI was significantly higher under PB-B (15.23 and 15.06) during 2013-14 and 2014-15, respectively. Significantly a higher value of NUE of cotton was found under PB-B (16.65 kg grain kg^{-1} NPK applied) over all other treatments. Nutrient harvest index was found non-significant.

Keywords: Carbon Sustainability Index, Nutrient use efficiency, Conservation agriculture, Conventional tillage, Nutrient harvest index

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Introduction

Global carbon (C) emission and the use efficiency have engrossed the international concern about the environmental quality, global warming and sustainability of agricultural ecosystems [1]. The sticks of cotton are pulled out, removed from the field and used as fuel. In wheat crop following cotton, the same tillage operations as in cotton are repeated, but the straw of wheat is either removed from the fields or is burnt due to shortage of time between harvesting of wheat crop (mid-April) and sowing of cotton crop (end of April to mid of May) that causes loss of carbon and other nutrients [2, 3]. In diverse agro-ecological conditions, the different tillage and crop sequences act differently on the (C) index of sustainability. The carbon use efficiency is determined by assessing C-based inputs and outputs used in farm operations determining the quantity of soil and efficiency of the agro ecosystems [4, 5] observed that the C-based inputs include estimates of C emissions from primary fuels, electricity, fertilizers, lime, pesticides, irrigation, seed production and tillage practices. Similarly, C-based outputs include the estimates of grain yield, straw yield, and root biomass. Changes in agricultural practices can also cause changes in the C use efficiency [6]. [7, 8] The carbon index of sustainability can be obtained by the adopting practices which minimize the C-based inputs, maximize outputs, increase ecosystem services, improve the C use efficiency, [4, 9, 10] suggesting that the adaptation of the conservation tillage with the reduced frequency of the summer fallowing with the new crop types in the rotation such as pulses may offer opportunities to growers to improve the overall C use efficiency of production systems.

The relationship between farm size and C use efficiency can differ depending on the degree of mechanization and the climatic environments. Shortage of water, labour and energy resources, together with inappropriate crop management practices and the adverse effects of conventional tillage on the carbon-based sustainability index, as well as declining profit margins, are forcing farmers of Indo-Gangetic Plains (IGP) to switch over to conservation agriculture practices. It is, therefore, important to identify the impact of management practices on the C cycle [11, 12]. Similarly, diversification in crop rotations can also affects soil health by affecting carbon contents, due to the difference in chemical composition of different crop residues that are added to soil [13].

Materials and Methods

Experimental site and experimental design

Field experiment on CW system was conducted for two consecutive years (2013-14 and 2014-15) at CIMMYT's Borlaug Institute for South Asia (BISA), Ladhowal (Punjab) located in Trans-Gangetic alluvial plains of India. The soil of the experimental site was sandy loam in texture with alkaline in reaction, poor in organic carbon content. May and June are the hottest month (40–44.8°C), while January is the coldest month (as low as 1.6°C). Seven combinations of CA-based tillage and crop establishment (planting method and crop geometry) were described in **Table 1** and **Figure 1**. The experiment was laid out in a completely randomized block design with three replications. The plot size for each treatment was 450 m^2.

Table 1 Description of treatments

Treatment abbreviation	Cotton	Wheat
CT	Conventional tillage (CT)	Conventional tillage
PNB	Permanent narrow raised bed (PNB) of 67.5 cm (42.5 wide from top and separated by furrow of about 25 cm wide and 15 cm deep).	Relay seeded on PNB (2 rows/bed on either side of cotton row) with high clearance tractor using ZT disc opener relay seeder.
ZTNF	ZT narrow (67.5 cm) flat	ZT narrow on flat with two rows
ZTBF	ZT broad spacing (102 cm) flat	Relay sowing (4 rows/102 cm spacing with paired rows)
PBB	Permanent broad (102 cm) raised bed (PBB) and cotton planted in the centre of 102 cm wide beds.	Relay sowing (4 rows/bed; two paired wheat rows on either side of cotton row)
PBBc	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed.	Relay sowing (3 rows/bed) on the opposite side of the cotton row on the bed).
PBBc+MB	Permanent broad (102 cm) raised bed. Cotton planted at alternate side of the bed. Mungbean (3 rows/bed) planted after wheat harvest in the same rows.	Relay sowing (3 rows/bed) of wheat on the opposite side of cotton row on each bed.

Figure 1 Relay sowing (4 rows/102 cm spacing with paired rows)

Crop establishment and management

Cotton After harvest of uniform crop of wheat in mid-April, Bt cotton hybrid (MRC 7017) was planted in the end of May under two geometries. Seed drill having inclined plate seed-metering system was used for planting cotton with a seed rate of 3 kg ha^{-1}. Recommended doses of 150 kg N, 30 kg Pand 25 kg K ha^{-1}were applied. Mungbean (SML-668) was sown in last week of April in both years using high clearance tractor with a seed rate of 20 kg ha^{-1}. Three rows of mungbean were planted in PBBc + MB treatment on alternate side of beds. A basal dose of 100 kg ha^{-1} of

DAP (18% N and 46 % P_2O_5) was applied at the time of sowing. Wheat var. HD-2967 was sown with a seed rate of 100 kg $ha^{-1}$and uniform fertilizer dose of 120 kg N, as urea 26 kg P as DAP and 33 kg K as MOP kg ha^{-1} was applied to wheat on all plots. The amounts of wheat, cotton and mungbean residues retained in the plots averaged (for the two years) were about 2.0, 0.6, and 3.0 Mg ha^{-1}, respectively. Some important pictures of the experiment which showed over all view of crop expression in conservation tillage practices (**Figure 2**).

Figure 2 Cotton planted on ZT broad spacing (102 cm) flat (ZTBF), Relay sown of wheat (3 rows/bed) on the opposite side of the cotton row on the bed) and Ralay sown of Mungbean in wheat (PBBc+MB)

Carbon Sustainability Index

The carbon sustainability index and carbon efficiency of different tillage practices and cropping systems was calculated as per the formula of [4] shown below:

$$Cs= (Co – Ci)/Ci$$

$$CE = Co/Ci$$

Where; Cs= sustainability index, CE= Carbon efficiency, Co= Carbon output and Ci= Carbon input

Nutrient-use efficiencies and harvest index:

The following nutrient use efficiencies (NUE) were computed with the formulae given below:

$$\text{Nutrient use efficiency (kg grain kg}^{-1}\text{ nutrient)} = \frac{\text{Economical yield (kg ha}^{-1}\text{)}}{\text{Nutrient applied (kg ha}^{-1}\text{)}}$$

$$\text{Nutrient harvest index (\%)} = \frac{\text{Uptake of a particular nutrient by the grain/seed cotton}}{\text{Total uptake of that nutrient in biomass}} \times 100$$

Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique [14] for randomized block design using SAS 9.1 software (SAS Institute, Cary, NC).

Results and Discussion

Conservation agriculture (CA) based management practices showed significant effect on carbon sustainability index in cotton-wheat sequence after two-year studies. The total C-input output and CSI estimated for cotton were significantly ($P< 0.05$) influenced by effect of tillage and crop establishment techniques (**Table 2**). The maximum C-input was estimated under CT with 374.34 and 378.69 MJ ha^{-1} during 2013 and 2014, respectively. Among the various treatments, lowest carbon input was estimated in PBB-AM. Maximum C-output was recorded under PB-B (3482.62 and 3241.16 MJ ha^{-1} during 2013 and 2014, respectively), whereas minimum under PBB-AM (2647.57 and 2424.02 MJ ha^{-1} during 2013 and 2014, respectively). Carbon sustainability index was also higher under PB-B during both the years. [6] also reported similar finding.

The maximum C input was estimated under CT with 430.85 and 433.22 MJ ha^{-1} during 2013-14 and 2014-15, respectively (**Table 3**). [16, 18] also reported similar finding. PBB-A practice recorded lowest C input during both the years of study. Maximum C output was recorded under PB-B (5876.33 and 6114.95 MJ ha^{-1} during 2013-14 and 2014-15, respectively), whereas lowest under CT (4068.45 and 4409.90 MJ ha^{-1} 2013-14 and 2014-15, respectively). CSI was significantly higher under PB-B (17.10 and 17.64 during 2012-13 and 2013-14, respectively) as compared to all other treatments and lowest was under CT (8.45 and 9.18 during 2013-14 and 2014-15, respectively) practices.

Table 2 Effect of tillage and crop establishment techniques on carbon sustainability index of cotton

Treatments	Total C-input (MJ ha^{-1})		Total C-output (MJ ha^{-1})		Carbon sustainability index (CSI)	
	2013	2014	2013	2014	2013	2014
PB-N	302.62	304.13	3190.85	2958.01	9.54	8.73
ZT-N	313.48	315.91	3142.74	2892.80	9.03	8.16
CT	374.34	378.69	3076.86	2838.32	7.22	6.50
ZT-B	311.90	314.45	3272.07	3037.35	9.49	8.66
PB-B	289.81	293.26	3482.62	3241.16	11.02	10.05
PBB-A	284.32	286.50	2859.03	2512.10	9.05	7.77
PBB-AM	279.81	285.41	2647.57	2424.02	8.46	7.49
SEm±	1.09	1.45	95.50	76.39	0.35	0.25
LSD (P=0.05)	3.37	4.48	294.24	235.34	1.07	0.76

Table 3 Effect of tillage and crop establishment techniques on carbon sustainability index of wheat

Treatments	Total C-input (MJ ha^{-1})		Total C-output (MJ ha^{-1})		Carbon sustainability index (CSI)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
PB-N	334.32	339.96	5285.64	5670.82	14.81	15.68
ZT-N	341.40	346.93	4869.48	5309.31	13.26	14.30
CT	430.85	433.22	4068.45	4409.90	8.45	9.18
ZT-B	342.95	344.07	5626.35	5876.37	15.41	16.08
PB-B	324.71	328.13	5876.33	6114.95	17.10	17.64
PBB-A	323.62	327.80	4985.33	5337.28	14.40	15.28
PBB-AM	323.79	328.63	5072.81	5447.32	14.67	15.58
SEm±	1.35	0.81	71.93	82.43	0.20	0.23
LSD (P=0.05)	4.15	2.53	221.61	253.97	0.62	0.72

Significantly maximum C input was estimated under CT with 805.20 and 811.91 MJ ha^{-1} during 2013-14 and 2014-15(**Table 4**), respectively as compared to effect of tillage and crop establishment techniques. Among effect of tillage and crop establishment techniques, minimum C input was under PB-A followed by PBB-AM. Maximum C-output was recorded under PBB-AM (9805.74 and 9908.31 MJ ha-1), whereas minimum under CT (7145.31 and 7248.22 MJ ha-1). CSI was significantly higher under PB-B (15.23 and 15.06) during 2013-14 and 2014-15, respectively.[6]also reported that tillage practices and production systems have significant effects on CSI and carbon efficiency.Therefore, the total amount of organic C stored in the soil is the difference between C input (crop residues) and C output (C loss through gases from decomposition of crop residues, with few exceptions such as soil erosion). Therefore, one would expect a dramatic increase in organic C in soil from a combination of ZT, straw retention and proper/ balanced fertilization [15].Total soil organic carbon content (SOC) was affected significantly due to conservation tillage, permanent beds with residue management and diversified crop rotations on total soil organic carbon in soil [16-18].

Nutrient use efficiency and nutrient harvest index of cotton, wheat and cotton-wheat system

Nutrient (N+P+K) use efficiency (NUE) in cotton was significantly influenced with different effect of tillage and crop establishment techniques (**Table 5**). Significantly highest value of NUE was found under PB-B (17.67 and 15.63) kg seed/kg NPK applied during 2013 and 2014, respectively over all other treatments followed by ZT-B. Nutrient harvest index was not affected significantly by effect of tillage and crop establishment techniques during both years of study.

Table 4 Effect of tillage and crop establishment techniques on carbon sustainability index of system

Treatments	Total C-input (MJ ha^{-1})		Total C-output (MJ ha^{-1})		Carbon sustainability index (CSI)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
PB-N	636.94	644.08	8476.49	8628.83	13.31	13.40
ZT-N	654.88	662.84	8012.23	8202.11	12.23	12.37
CT	805.20	811.91	7145.31	7248.22	8.88	8.93
ZT-B	654.85	658.51	8898.42	8913.72	13.59	13.54
PB-B	614.52	621.40	9358.95	9356.11	15.23	15.06
PBB-A	607.94	614.29	7844.36	7849.37	12.90	12.78
PBB-AM	698.41	709.37	9805.74	9908.31	14.04	13.97
SEm±	1.95	2.06	125.79	122.99	0.20	0.18
LSD (P=0.05)	6.01	6.34	387.52	378.93	0.61	0.56

Table 5 Effect of tillage and crop establishment techniques on nutrient (N+P+K) use efficiency and nutrient harvest index of cotton

Treatment	NUE (kg seed cotton/ kg NPK applied)		NHI (%)	
	2013	2014	2013	2014
PB-N	16.26	13.98	66.50	63.62
ZT-N	16.05	13.26	66.75	62.74
CT	15.64	13.15	67.02	63.39
ZT-B	16.44	14.22	66.56	63.68
PB-B	17.67	15.63	66.21	64.46
PBB-A	15.05	11.76	67.80	63.24
PBB-AM	13.74	11.62	67.19	64.25
SEm±	0.35	0.32	0.92	1.05
LSD (P=0.05)	1.07	0.97	NS	NS

Nutrient (N+P+K) use efficiency (NUE) and nutrient harvest index in wheat was significantly influenced by different effect of tillage and crop establishment techniques (**Table 6**). There was significantly maximum nutrient use efficiency under PB-B (24.60 and 25.31) practice in 2013-14 over all other treatments but in 2014-15, it was at with ZT-B treatment. Significantly higher values of nutrient harvest index was found under PB-B (48.60 and 48.10) over CT and remained at par with all other treatments during 2013-14 and 2014-15.

Nutrient (N+P+K) use efficiency (NUE) and nutrient harvest index of cotton-wheat/mungbean system as influenced by different effect of tillage and crop establishment techniques (**Table 7**) showed that it was highest in effect of tillage and crop establishment techniques than CT. The maximum nutrient use efficiency was recorded under PB-B (16.97 and 16.47) during both the years, respectively, which was at par with PBB-AM and ZT-B during both years of study, respectively. Lowest nutrient use efficiency was recorded in CT (13.60 and 13.14) during both years of study. Significantly a lower value of nutrient harvest index was found under PBB-AM (50.50 and 47.38) over all other treatments during both years of study. The higher amount of SOC in surface soil layer in CA is due to higher accumulation of crop residue which also increases nutrient availability [19].

Table 6 Effect of tillage and crop establishment techniques on NPK use efficiency and NPK harvest index of wheat

Treatments	NPK use efficiency		NPK harvest index	
	2013-14	2014-15	2013-14	2014-15
PB-N	21.75	22.41	47.69	45.77
ZT-N	20.31	20.69	48.20	45.32
CT	16.33	16.89	46.47	45.12
ZT-B	23.23	23.65	48.28	46.95
PB-B	24.60	25.31	48.60	48.10
PBB-A	20.61	20.85	47.81	45.47
PBB-AM	20.97	21.49	48.16	46.06
SEm±	0.43	0.54	0.49	0.67
LSD (P=0.05)	1.32	1.68	1.50	2.05

Table 7 Effect of tillage and crop establishment techniques on NPK use efficiency and NPK harvest index of cotton-wheat system

Treatment	NPK use efficiency		NPK harvest index	
	2013-14	2013-14	2013-14	2014-15
PB-N	15.32	14.68	56.44	54.44
ZT-N	14.67	13.76	55.95	53.29
CT	13.60	13.14	55.99	54.00
ZT-B	16.04	15.43	57.26	55.26
PB-B	16.97	16.47	57.44	55.64
PBB-A	14.51	13.43	57.98	55.13
PBB-AM	16.86	16.06	50.50	47.38
SEm±	0.35	0.32	0.60	0.61
LSD (P=0.05)	1.00	1.00	1.84	1.88

Conclusion

Our study showed that CSI was higher by 15.31%, 13.98% and13.40% with PB-B of cotton, wheat and cotton-wheat systemrespectively (average both years) over CT. Significantly higher values of NUE of cotton was found under PB-B (16.65 kg grain^{-1} kg NPK applied) over all other treatments. Significantly higher by 50.24% nutrient use efficiency of wheat and 5.59% harvest index was recorded under PB-B than other treatments. Significantly a lower value of nutrient harvest index was found under PBB-AM over all other treatments during both years of study.Thus, these results are of tremendous importance in terms of identification of a suitable sustainable management practice under non-rice based cotton–wheat system, and are very novel in the South Asia.

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References

[1] R. Lal, J.M. Kimble, R.F. Follett and Stewart B.A., Assessment Methods for Soil Carbon. Lewis Publishers, Boca Raton, FL., 2000, 696 p.

[2] V., Beri, B.S., Sidhu, A.P., Gupta, R.C., Tiwari, R.P., Pareek, O.P., Rupela, R., Khera, J., Singh, Organic resources of a part of Indo-Gangetic Plain and their utilization, Department of Soils, PAU, Ludhiana, India, 2003, p. 93.

[3] S.K. Jalota, G.S. Buttar, A. Sood, G.B.S. Chahal, S.S. Ray, S. Panigrahy, Effects of sowing date tillage and residue management on productivity of cotton (Gossypiumhirsutum L.)–wheat (Triticumaestivum L.) system in

northwest India. Soil and Tillage Research, 2008, 99: 76–83.
[4] R., Lal, Soil carbon sequestration impacts on global climate change and food security. Science, 2004, 304:1623-1627.
[5] West, T.O., Marland, G., King, A.W., Post, W.M., Jain, A.K., and Andrasko, K., Carbon Management Response curves: estimates of temporal soil carbon dynamics. Environmental Management, 2004, 33(4): 507-518.
[6] A, Dubey, R. Lal, Carbon Footprint and Sustainability of Agricultural Production Systems in Punjab, India, and Ohio, USA. Journal of Crop Improvement, 2009, 23: 332 – 350.
[7] P.R., Adler, S.D., Grosso, and W.J., Parton, Life-Cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. Applied Ecology, 2007, 17: 675-691.
[8] Clair, S.St., Hillier, J. and Smith, P., Estimating the pre-harvest greenhouse gas costs of energy crop production. Biomass Bioenergy, 2008, 32: 442-452.
[9] Gill, R.A, Polley, H.W., Johnson, H.B, Anderson, L.J., Maherali, H. and Jackson, R.B., Nonlinear grassland responses to past and future atmospheric CO (2). Nature, 2002, 417: 279 -282.
[10] Jat, M.L., Saharawat, Y.S., Gupta, R., Conservation agriculture in cereal systems of south Asia: Nutrient management perspectives. Karnataka Journal of Agricultural Sciences,2011, 24(1): 100–105.
[11] Lal, R., Carbon Emission from Farm Operations. Environmental International, 2004, 30: 981-990.
[12] Choudhary, R., Singh, P., Sidhu, H.S., Nandal, D.P., Jat, H.S., Singh, Y. and Jat, M.L., Evaluation of tillage and crop establishment methods integrated with relay seeding of wheat and mungbean for sustainable intensification of cotton-wheat system in South Asia. Field Crop Research,2016, 190: 31–41.
[13] Srinivasarao, C., Venkateswarlu, B., Lal, R., Singh, A. K., Kundu, S., Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. Advances in Agronomy, 2013, 121: 253–325.
[14] Gomez, K.A., Gomez, A.A., Statistical procedures for agricultural research. Second Edition. An International Rice Research Institute Book. A Wiley-Inter- science Publication. John Wiley & Sons, 1984, New York.
[15] Malhi, S.S., Nyborg, M., Goddard, T., Puurveen, D., Long-term tillage, straw and N rate effects on some chemical properties in two contrasting soil types in Western Canada. Nutrient Cycling in Agroecosystems, 2011, 90: 133–146.
[16] Thomson, A. M., Izaurralde, R. C., Rosenberg, N. J. and He, X., Climate change impacts an agriculture and soil carbon sequestration potential in the Huanghai Plain of China. Agriculture, Ecosystems and Environment, 2006, 114:195-209.
[17] Kaiser, M., Piegholdt, C., Andruschkewitsch, R., Linsler, D., Koch, H., Ludwig, B., Impact of tillage intensity on carbon and nitrogen pools in surface and subsurface soils of three long-term field experiments. European Journal of Soil Science, 2014, 65(4): 499–509.
[18] Sarkar, R. Kar, S., Temporal changes in fertility and physical properties of soil under contrasting tillage-crop residue management for sustainable rice-wheat system on sandy -loam soil. Journal of Crop Improvement, 2011 25(3): 262–290.
[19] Marahatta, S., Sah, S.K., MacDonald, A., Timilnisa, J., Devkota, K.P., Influence of conservation agriculture practices on physicaland chemical properties of soil. International Journal of Advanced Research, 2014, 12(2): 43–52.

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