Ind. Jn. of Agri. Econ.
Vol.74, No.3, July-Sept.2019

Determinants and Impacts of Conservation Agriculture in South Asia: A Meta-Analysis of the Evidences

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ABSTRACT

Rice-wheat cropping system in the Indo-Gangetic plains is pivotal in ensuring food and livelihood security in South Asia. However, the productivity of the system is threatened by factors like climate change, urbanisation and excessive resource use. Conservation agriculture (CA) practices provide the scope for curbing the consequences of climate change by its resource saving and carbon emission as well as cost reducing potential. To analyse the effectiveness of CA under different crops, soil, and climatic conditions, a meta-analysis was conducted by synthesising the results of various experimental studies. Adoption of only zero/minimum/reduced tillage without integrating it with mulching and crop rotation in CA provided lesser yield as compared to conventional tillage. In contrast, crop yields were higher in CA when all the three practices, viz., conservation tillage practices, mulching and crop rotation were followed as compared to the conventional tillage. Crop yields were higher under reduced/minimum tillage as compared to zero tillage for all the crops considered for the study. Wheat, maize and pulses performed better in CA system as compared to rice in terms of water saving and yield. It was found that irrigation, soil cover and application of nitrogen were the crucial inputs in improving the performance of conservation tillage. Further, adoption of CA practices lead to significant reduction in the cost and at the same time provided better returns as compared to the conventional system. Training, targeting to irrigated, sub-tropical regions and fiscal incentive are critical for the successful implementation of CA in the region.

Keywords: Conservation agriculture; Climate change; South Asia; Conventional agriculture.

JEL: O3, Q2, Q4, Q25

I

INTRODUCTION

South Asia has a fairly good rate of economic growth and 14 per cent of the global agricultural land. However, the region is suffering from extreme poverty, malnutrition, and deterioration of natural resources. There is a great pressure on the agricultural sector to meet the present as well as future demands for safe and nutritional food (Joshi, 2012). Conventional agricultural system though advantageous in terms of higher economic benefits but it leads to excessive utilisation of fossil fuel, excessive use of chemical inputs, soil degradation and water pollution (Foley *et al.*, 2011). These factors coupled with changing climate further aggravate the challenge

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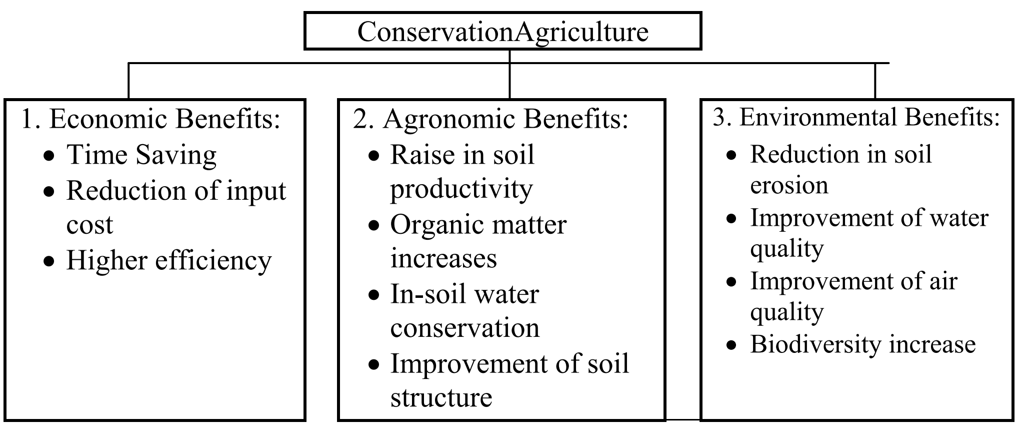
The paper is part of Professional Attachment Training (PAT) done by the first and second author, at ICAR-National Institute of Agricultural Economics and Policy Research (NIAP), New Delhi-110 012.

of sustainable production. Given the adverse environmental consequences of conventional agricultural practices (Foley *et al*., 2011; Tilman *et al*., 2011; Godfray and Garnett, 2014), there is a need to shift emphasis on conservation agriculture. As elaborated by FAO, Conservation agriculture (CA) is *'an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security, while preserving and enhancing the resource base and the environment'*. Conservation agriculture represents a set of three crop management principles: (1) direct planting of crops with no or minimum soil disturbance, (2) permanent soil cover by crop residues or cover crops, and (3) crop rotation (FAO, 2014).

Benefits of Conservation Agriculture

Conservation agriculture has numerous benefits and advantages over the conventional tillage which cause negative effects on the environment. The benefits of CA can be grouped as below:



Source: http://www.fao.org/conservation-agriculture/impact/benefits-of-ca/en.

In recent years, a large number of studies have been carried out comparing the practices of CA with the conventional tillage in South Asia. The studies have been conducted under diverse conditions like climate, soil, input management, cropping system etc. The diverse environmental and input management scenarios in various studies create problems in framing some generalised conclusions regarding the suitability of CA based practices for the region. Thus, a better understanding is required of which CA principles/practices and their interactions contribute to the desired effects on crop productivity. The objective of this study is to synthesise the results of the studies on conservation agriculture in the framework of meta-analysis and in particular, to assess the impacts of CA on crop yields and economic benefits. The impacts were further explored in relation to crop grown, annual precipitation, soil characteristics, irrigation, climate and years of practicing conservation agriculture. The study is confined to South Asia and meta-analysis is done on CA studies with respect to factors influencing its impacts, so as to better target the technology.

II

METHODOLOGY

2.1 *Data Collection*

A literature search was conducted to collect data on the effect of CA practices in South Asian region using Google Scholar, Scopus and Science Direct till the end of May 2018. The list of publications consisting of 625 studies was further screened as per the criteria of Pittelkow *et al*. (2015): (1) studies had conducted field experiments containing side-by-side comparisons of conservation tillage (zero tillage or/and minimum/reduced tillage) and conventional tillage practices; (2) crop yields were reported; (3) the location of the experiment was stated. The database was further strengthened using the criteria of Lundy *et al.* (2015): (1) studies for which crop rotation information was available; (2) duration of the experiment was reported; (3) information on crop residue management practices was stated. After removing the outliers using inter quartile range (IQR), a total of 1195 observations from 159 studies from 24 crops were selected for final analysis. This means observations per study were based on the number of crops, treatments, soil types and type of mulch included etc. The data set used for analysis is summarised in Table 1.

TABLE 1. DATA-SET USED FOR ANALYSIS IN THE STUDY

Category (1)	Observations (2)	Studies (3)	Number of crops (4)
Rice	163	30	1
Wheat	676	110	1
Maize	126	33	1
Pulses and oilseeds	145	28	13
Other crops	85	18	8
Total	1195	159	24

Note: Zero tillage and minimum /reduced tillage has 920 and 275 observations respectively.

2.2 *Data Analysis*

The effect of conservation tillage practices on crop yield was analysed using natural log of response ratio (i.e., natural log of the ratio of conservation tillage yield to conventional tillage yield from the paired comparison of individual studies) (Hedges *et al*., 1999). Paired ‘t’ test was used to examine the mean difference of different attributes under CA over the conventional practice.

Taking the natural logarithm of the response ratio [ln(RR)] (Toliver *et al*., 2012) as the dependent variable, a multilevel mixed effect model was estimated in STATA

14.2 to examine the role of crop, soil and environment specific factors in influencing the impact of conservation agriculture over conventional system in crop yield in South Asia:

$$\ln(RR) = W\alpha + U\beta + \varepsilon \quad \text{….(1)}$$

where, α and β are vectors of unknown fixed and random effects, respectively, and W and U are given known and incidence matrices, respectively (McLean *et al*., 1991). The factors influencing the relative yield of conservation tillage over conventional tillage were identified by the sign and significance of the parameter estimates (Toliver *et al.*, 2012). The random intercepts for regions (n=13) was added to account for the inter-regional variability in the explanatory variables (Table 2).

TABLE 2. EFFECT OF CONSERVATION AGRICULTURE (CA) PRACTICES ON CROP YIELD

(*tonnes/ha*)

Particulars (1)	Practice (2)	NT (3)	NT+R (4)	NT+M (5)	NT+M+ R (6)
Mean yield (t/ha)	CA	3.743	3.734	4.128	3.757
	CT	4.153	3.798	4.172	3.679
	Difference	- 0.409***	- 0.063***	- 0.043	0.077***
Median	CA	3.83	3.82	2.36	3.83
	CT	4.03	3.90	4.08	3.70
Standard deviation	CA	1.426	1.947	3.138	2.002
	CT	1.742	1.889	3.022	1.985
Minimum	CA	0.55	0.30	0.70	0.48
	CT	0.69	0.29	0.53	0.43
Maximum	CA	9.05	21.17	10.46	8.93
	CT	9.63	21.01	9.57	8.79
Response ratio		0.92	0.97	1.00	1.02
Total counts		88	617	49	441

Note: *** indicate 1 per cent level of significance; CT= Conventional Tillage, NT= No-tillage/Reduced tillage, NT+R=No-tillage with Rotation, NT+M= No-tillage with mulch, NT+R+M= No-tillage with mulch and rotation.

The final model used to evaluate mean yield differences between conservation and conventional tillage was specified as:

$$\begin{aligned} \ln RR = {} & crop_i + soil_j + climate_k + cropping\ system_l + till + irrigation + rotation \\ & + soil\ cover + napplication + rainfall + duration\ log + (1 \mid region) \quad \text{….(2)} \end{aligned}$$

where, crop represents one of the four crops (i= wheat, maize, pulses and other crops), soil texture represents one of the four soil textures (j=silty loam, silty clay loam, clay loam, sandy clay loam), climate represents one of the five climate types (k=hot and dry, humid sub-tropical, sub-humid tropical, tropical semi-arid and temperate). The reference categories for crop, soil texture and climate are rice, sandy loam and subtropical semi-arid, respectively. ‘Till’ variable is a binary dummy variable (till=1 for a comparison of conventional tillage with no-till or 0 for a comparison of conventional tillage with reduced tillage). The variables irrigation, rotation and soil cover/mulch/crop residue are binary variables (value=1 if irrigation, rotation and soil cover/mulch/crop residue is applied, 0=otherwise). The variables N application (kg/ha) and rainfall (mm) are continuous variables used to capture the effect of nitrogen application and mean annual rainfall in the relative of conservation tillage over conventional tillage. The variable duration log is a continuous variable that represents the natural logarithm of the year of the experiment. The value of duration log was used to test whether a yield lag existed between conservation and conventional tillage system at the time of start of the experiment and to see if the yield gap has narrowed down with time through improvement in soil quality (Toliver *et al*., 2012). All equations were estimated using the mutli-level mixed model in STATA 14.2. As heteroskedasticity was detected, so the region/location of the experiment was added in the model as a random effect variable and modeled using an identity covariance matrix. Akaike information criteria (AIC) were used to choose a better fitted model.

III

RESULTS AND DISCUSSION

3.1 *Mean Yield Difference*

The parameter estimates in Table 2 are presented as the effect of individual as well as combination of CA practices on crop yield. When only zero tillage/minimum/reduced tillage is practiced, the yield benefit is negative (-0.4 t/ha) and response ratio is less than one compared with the conventional tillage. This result is comparable with the meta-analysis study conducted by Corbeels *et al*., 2014 in sub-Saharan Africa. Further, the mean difference in yield is negative but narrower (-0.06 t/ha) when no-tillage is practiced with rotation as compared with the conventional tillage. However, when all the three principles of conservation agriculture is practiced, i.e., no-tillage is practiced with mulching as well as crop rotation, the yield benefit becomes positive (0.077 t/ha). The mean yield difference and response ratio is intended to be higher than conventional tillage system. The positive yield indicates that the rotation practiced with mulching is the major factor influencing the success of CA system.

3.2 *Impact of Agronomic and Climatic Factors on Yield Performance of CA*

The model as described in (2) was used for identifying the impact of crop, soil and environmental factors on the relative yield difference in conservation and conventional tillage system. The parameter estimates in Table 3 are presented as the effect of a variable on the natural logarithm of the ratio of the conservation to conventional tillage yields [ln (yield CA_i / yield CT_i)] relative to that of rice produced on a sandy loam soil in the sub-tropical semi-arid climate. If the sign of a coefficient for a variable is positive (/negative) it means that in comparison to rice grown on a sandy loam soil in the sub-tropical semi-arid climate, conservation tillage yields are better (/inferior) than conventional tillage yields.

TABLE 3. PARAMETER ESTIMATES OF THE MIXED MODEL FOR MEAN YIELD DIFFERENCE

ln (RR) (1)	Coefficient (2)	Robust S.E. (3)
Wheat	0.0905***	0.0187
Maize	0.0977**	0.0421
Other crops	0.2006***	0.047
Silty clay loam	0.0764***	0.0298
Silty loam	0.0743***	0.0184
Clay loam	0.0472***	0.0187
Sandy clay loam	0.0506**	0.0274
Irrigation	0.1017***	0.0331
Till	- 0.0547***	0.0164
Rotation	0.0029	0.0482
Residue management	0.0376***	0.01
N application	0.0005*	0.0003
Rainfall	0.0002	0.0003
Hot and dry	0.0119	0.0244
Humid sub-tropical	- 0.0086	0.0395
Sub-humid tropical	- 0.1108	0.0772
Tropical semi-arid	0.0171	0.0793
Temperate	0.0474	0.0419
Duration log	0.0195**	0.0091
Maize-wheat	0.0222*	0.0144
Rice-maize	- 0.0391	0.0499
Pulse based cropping system	- 0.0162	0.0318
Other cropping system	- 0.0547	0.0391
Constant	- 0.3037***	0.0958
N	1034	
AIC	- 1305.983	
BIC	- 1177.512	
Log Likelihood	678.99	

Note: ***, ** and * indicate 1, 5 and 10 per cent level of significance, respectively.

Crops respond differently to conservation and conventional tillage systems. The differences in relative yield of conservation and conventional tillage [ln(RR)] for wheat, maize as well as in other crops (pulses and oilseeds) were found to be larger than rice crop with all other factors being equal. Increased soil organic carbon, better soil physical health, conservation of soil moisture, complementary effect of additional nutrients are the general explanations for the improvement in the yield in wheat and maize also in other crops (Jat *et al*., 2013; Kaiser *et al*., 2014; Parihar *et al*., 2016). Conservation agriculture performs better in loamy soils; the relative crop yield differences were found to be significantly higher than in sandy loam soils. These results coincide with the previous studies that conservation tillage performs better on well drained soils which has good infiltration rate (Corbeels *et al*., 2014; Toliver *et al*., 2012).The non-suitability of sandy soils under CA could be attributed to poor soil drainage, lower water holding capacity, lower soil moisture generally observed in sandy soils (Thierfelder and Wall, 2012).

Crop rotation practices though leads to improvement in yield under CA system by reduction of pest and diseases, good soil health and better water infiltration (Hernanz *et al*., 2002; Kureh *et al*., 2006), but surprisingly the present study failed to establish a statistical significant impact of crop rotation on relative yield ratio [ln(RR)]. However, the results confirm the hypothesis that addition/ retention of crop residue has a positive and significant effect on crop growth and relative yield ratio [ln(RR)] through enhancing conservation of soil moisture, soil organic carbon, etc. (Corbeels *et al*., 2006). Further, the results of present study also substantiate that CA perform better in irrigated condition. It was found that the reduced/minimum till yields are significantly higher than the zero till system.

Nitrogen application has positive and significant impact on the yield performance of conservation tillage. These results are also in coincidence with studies conducted by Rusinamhodzi *et al*., (2011) and Nyamangara *et al*., (2014). The crop yield in CA system under rainfed condition was not found significant. Many of the previous studies also reported that relative crop yield [no-till to tillage yield] was higher in dry years than in wet years (Rusinamhodzi *et al*., 2011; Toliver *et al*., 2012; Nyamangara *et al*., 2014). The duration has positive and significant effect on the performance of crop yield under conservation tillage. This confirms that as the time period of conservation tillage experiment increases, the yield gap between conservation and conventional tillage will be narrowed down. This result also supports the findings of Brouder and Gomez-Macpherson (2014) and Pittelkow *et al*., (2015) that no-till/reduced-till yield increased over time with CA practices.

Among the cropping systems considered in the study, the relative yield only under maize-wheat cropping system was found to be significantly higher than rice-wheat system. However, for the remaining cropping systems (viz., rice-maize, pulse-based and other systems) there was no statistically significant difference in the relative yield ratio over rice-wheat system.

3.3 *Economics of Conservation Agriculture*

Is conservation agriculture an economically viable technology for the farmers? The results indicate that the cost of production was significantly lower in conservation tillage as compared to conventional tillage in all the crops undertaken in the study (Table 4). A significant reduction in the cost of production could be due to saving in the cost of tillage, irrigation water, lower weed infestation, and saving on seeds and inputs (Das *et al.*, 2018; Parihar *et al.*, 2016). Similarly the net returns under CA was found to be significantly higher in all the crops except rice (Table 5). Several other studies also reported decrease in cost and increase in net returns in cereal based cropping systems (Singh *et al*., 2016; Laik *et al*., 2014).

TABLE 4. COST OF CULTIVATION OF CONSERVATION AGRICULTURE (CA) AND CONVENTIONAL TILLAGE (CT) SYSTEM

Particulars (1)	Practice (2)	Rice (3)	Wheat (4)	Pulses (5)	Other crops (6)	Rice-wheat (7)
Cost of cultivation	CA	441	389	234	356	968
(USD/ha)	CT	563	453	294	397	1112
	Difference	- 122*	- 64*	- 61*	- 40	- 144*
Median	CA	508	353	253	241	974
	CT	573	420	327	315	1126
S.D	CA	292	198	48	379	85
	CT	262	241	71	349	107
Min	CA	112	38	182	38	852
	CT	344	69	217	69	983
Max	CA	1141	965	290	906	1069
	CT	1273	1029	367	889	1211

Note: * indicate 1 per cent level of significance.

TABLE 5. NET RETURNS OF CONSERVATION AGRICULTURE (CA) AND CONVENTIONAL TILLAGE (CT) SYSTEM

Particulars (1)	Practice (2)	Rice (3)	Wheat (4)	Pulses (5)	Other crops (6)	Rice-wheat (7)	Maize-wheat (8)	Cotton-wheat (9)
Net Return	CA	305	615	128	825	861	670	2542
(USD/ha)	CT	333	551	97	780	827	608	1987
	Difference	- 28	65*	31	44	34	62*	556*
Median	CA	295	603	231	353	738	415	2579
	CT	293	487	200	413	742	447	1987
S.D	CA	127	253	261	1029	318	596	380
	CT	86	232	289	970	268	522	376
Min	CA	- 10	196	-156	117	334	127	1944
	CT	215	74	-211	48	245	132	1626
Max	CA	694	1285	400	2005	1654	1826	2991
	CT	603	1108	452	1881	1374	1565	2347

Note: * indicate 1 per cent level of significance.

IV

CONCLUSIONS

This study using meta-analysis has analysed the role of agronomic and climatic factors in influencing the performance of CA in South Asia. The study also examined the economic benefits of CA in South Asia. The results revealed that impact of conservation tillage varies across the crops, soils, climate type and range of other conditions. In a short period CA has yield disadvantage in relation to conventional tillage, but it dilutes with increasing duration of CA practices as soil fertility and nutrient availability is enriched over the period of time. To reap the maximum yield benefits of CA, wheat, maize and pulses should be targeted as compared to rice in South Asia. Further, emphasis could be given to the adoption of minimum/reduced tillage as yield advantage is higher here than zero tillage for wheat and maize crops. Crop diversification, maintaining crop residues coupled with irrigation and nitrogen application are the major drivers of greater yield advantages under CA over the conventional practices. To cope up with the yield disadvantage in the short run, CA should be supported with fiscal incentives for its promotion. Further, training, demonstration, and appropriate policies can lead to rapid adoption of CA. Simple and affordable farm machinery is another important factor which contributes to the success of CA in South Asia.

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