Vol. 21, No. 1, pp. 197-215 (2021)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Special Issue Article

Conservation Agriculture and Ecosystem Services: Potential, Contribution and Approaches

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ABSTRACT

Agriculture is one of the key sources of ecosystem services (ES) by provisioning food, fuel and fiber that are essential to sustain life on earth, and also a recipient of ES. With growing global population, pressure on agriculture to provide food, feed, fiber and fuel has increased many folds which necessitated farmers to intensify production practices. Intensification can disrupt many of the regulating and supporting ES, including nutrient cycling, climate regulation, regulation of water quality and quantity, pollination services, pest control, etc. There is an urgent need to balance the provisioning services to provide enough food to the growing population while maintaining healthy ecosystems and vibrant habitats. Conservation agriculture (CA) can act as an alternative system to improve ES and sustain high productivity. The CA system influences several ES like provisioning, supporting, regulating and cultural services directly or indirectly. Maximization of the provisioning services from agro-ecosystems can result in tradeoffs with other ecosystem services, but thoughtful management of agro-ecosystem can substantially reduce or even eliminate these tradeoffs. Although the idea of ecosystem services has been well developed scientifically, debate continues about how to measure, monitor and place a value on many goods and services provided by the ES. There are number of economic principles which are applied for measuring the ecosystem services of conservation agriculture. Production function model, transaction cost models, hedonic, travel-cost approaches are some of the methods used in estimation of the economic benefit-cost of the ES. Thus, the eco-system service accounting under conservation agriculture would require both monetary and non-monetary approaches for estimation of benefit and cost for its wider impact. This paper highlights the effects of CA on some of the ES such as climate regulation as related to soil carbon sequestration and greenhouse gas emissions and the provision function of maintaining high productivity and regulation of water and nutrients through modification of several soil properties and processes.

Key words: Conservation agriculture, ecosystem, ecosystem services, monetization, climate regulation, ES accounting

Provision of food is a primary function of agriculture and is one of the key sources of ecosystem services that are essential to sustain life on planet earth. However, there is a growing recognition that agricultural systems are both dependent on ecosystem services (ES) that support production functions and also a source of

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important agricultural and non-agricultural ecosystem services. ES are natural processes through which the environment produces natural resources that humans and other living species require for life (Dillaha *et al.*, 2010). ES include the benefits that human derive directly or indirectly from ecosystem functions (Costanza *et al.*, 1997). ES are frequently grouped into four broad categories of provisioning (e.g., food, feed, timber and fiber), supporting (e.g., nutrient and water cycling), regulating (e.g., water purification, gaseous exchange) and cultural services (e.g., aesthetic experiences). Off-late scientists and policy makers are making increasing use of the concept of ES to describe the tangible and intangible benefits that society obtains from our environment, and holding on to all these benefits depends on how well we look after ecosystems that support the humanity. Although the idea of ecosystem services has been well developed scientifically, debate continues about how to measure, monitor and place a value on many goods and services provided by the ecosystems. Modern agriculture has brought vast increases in productivity to the world's farming systems and it is widely recognized that much of this have come at the price of sustainability. Though, agricultural systems have the potential to improve the environment; but our production systems have not been developed to do so, in recent history. With growing global population, pressure on agriculture to provide food, feed, fiber and fuel have increased many folds which necessitated farmers to intensify their production practices. Increased urbanization, use of external inputs and utilization of marginal lands for cropping can compromise ES obtained from agriculture. Intensification can disrupt many of the regulating and supporting ES, including nutrient cycling, climate regulation, regulation of water quality and quantity, pollination services, and pest control (Power, 2010). It can also alter the biological diversity underpinning many of these ES. Increasing food production at the expense of ES can undermine agro-ecosystem sustainability including crop production. While some agricultural practices can decrease ES delivery (tradeoffs) others can enhance or maintain ES (synergies).

One of the most important issues of the 21st century is to balance the need for providing enough food to growing population while maintaining healthy ecosystems and vibrant habitats (Thorn *et al.*, 2015). Conservation agricultural (CA) practices can act as an alternative system that exploits synergies of crop diversity to improve ecosystem services and sustain high productivity. CA relies on three interlinked principles to increase crop yields by enhancing several regulating and supporting ES. The three key principles along with other good agricultural practices that describes CA are: (i) continuous no or minimal mechanical soil disturbance (implemented by the practice of no-till seeding and direct placing of planting material into untilled soil; and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic); (ii) maintenance of a permanent biomass mulch cover on the ground surface (implemented by retaining crop biomass, stubbles and cover crops and other ex situ sources of biomass); and (iii) diversification of crop species; implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annual and perennial crops, including a balanced mix of legume and non-legume crops (Kassam *et al.*, 2018). The CA system involves a significant change in agricultural practices from the past ways of practices under conventional method. This implies that the whole range of agricultural practices, including handling crop residues, sowing and harvesting, water and nutrient management, disease and pest control, etc. need to be evolved and evaluated. Though CA was originally introduced to regulate wind and water erosion, however, its potential to contribute to various ecosystem services has been realized in the long run and now it is considered to deliver multiple ES. The CA systems are gaining increased attention worldwide as a way to reduce the water footprint of crops by improving soil water infiltration, increasing soil water retention and reducing runoff and contamination of surface and ground water. CA also helps in re-building agro-ecology by improving carbon sequestration, maintaining soil health, checking soil erosion and ground water depletion, energy balance, mitigating climate change related problems etc. through maintaining ecosystem services.

Distribution of Conservation Agriculture in India

Unlike, in the rest of the world, CA technologies in India have been spreading mostly in the irrigated areas of the Indo-Gangetic plains where rice-wheat cropping system dominates. Concerns about stagnating productivity, burning of crop residues, increasing production costs, declining resource quality, declining water tables and increasing environmental problems are the major forcing factors to look for alternative technologies, particularly in the northwest region encompassing Punjab, Haryana and western Uttar Pradesh (UP) (Akhter *et al*., 2004). CA systems have not been extensively tried or promoted in other major agro-eco-regions like rainfed semi-arid tropics, the arid regions and the mountain agro-ecosystems of India. In drylands, Jat *et al.* (2012) opined that the major constraints to the use of CA include insufficient amounts of residues due to water shortage and degraded nature of soil resource, competing uses of crop residues, resource poor smallholder farmers, and lack of in-depth research. Even then, CA holds considerable promise in the arid region, because it can control soil erosion by wind and water, reduce compaction and crusting. Due to limited production of biomass, competing uses of crop residues and shortage of firewood, farmers often find it hard to leave crop residues to cover soil surface in dry-land eco-systems, where only a single crop is grown in a year. With CA (soil cover with crop residues), it is sometimes possible to grow a second crop with residual soil moisture in the profile. Efforts to adopt and promote resource conservation technologies have been underway for nearly two decades, but it is only in the past 5-6 years that technologies are finding acceptance by the farmers. This effort has been spearheaded by Rice–Wheat Consortium for Indo-Gangetic Plains, a CGIAR eco-regional initiative involving several CG Centres, National Agricultural Research Systems of India, Pakistan, Bangladesh and Nepal and Consortia Research Platform (CRP) on CA in India. Besides sustaining a higher level of yield in diversified agro-ecologies CA can help in synergies among different ES which will, in turn, address the climate change related challenges the country will be facing in near future.

Potential Ecosystem Services through Conservation Agriculture

Several ES like, provisioning, supporting, regulating and cultural services are directly or indirectly influenced by CA practices. Field experiments initiated at the ICAR-IARI, New Delhi, ICAR-IISS, Bhopal and ICAR-CRIDA, Hyderabad under the aegis of CRP on CA are investigating the impacts of tillage, residue addition and cropping system on ecosystem services provided by conservation agriculture. At ICAR-IARI, New Delhi, three major non-rice cropping systems, *viz*., cotton-wheat, pigeonpea-wheat and maize-wheat with suitable CA practices were evaluated. At ICAR-IISS, Bhopal ecosystem services under different residue levels were evaluated under soybean-wheat and maize-chickpea cropping system. Some of the ecosystem services, which are positively and directly influenced by CA, are discussed below.

Providing food, fuel and fibre

The most important service provided by agriculture is provision of food, fuel, and fibre. CA system can play a significant role in ecosystem service by providing a sustainable high yield level of crops. Das *et al.* (2014) observed that permanent broad beds with 20% cotton residue and 40% wheat residue retention had significantly higher economic profitability and crop productivity than farmers' practice under a conventional tillage (CT) cotton-wheat cropping system. From the study, they reported that 2-year mean seed cotton yield under zero tillage (ZT) permanent broad-bed sowing with residue retention was about 24% and 51% greater compared with ZT narrow-bed sowing without residue retention (2.91 Mg ha^{-1}) and CT (2.59 Mg ha^{-1}), respectively.

The predominant rice-wheat cropping system in the Indo-Gangetic Plains (IGPs) has encountered a host of problems. A remunerative non-rice crop is required to diversify this system. Thus, a study was carried out involving three major non-rice cropping systems, viz., cotton-wheat, pigeon pea-wheat and maize-wheat with suitable CA practices. All CA-based systems performed better than CT system. Cotton-wheat, maize-wheat and pigeonpea-wheat under ZT-based permanent broad bed (PBB) with 100% N resulted in higher system productivity in term of wheat equivalent yield compared to that in CT. The study further revealed the superiority of cotton-wheat system among the others that gave 32% (~3.1 t/ha) higher system productivity than CT followed by maize-wheat and pigeonpea-wheat. All ZT-based permanent broad, narrow and flat beds with residue retentions were superior to conventional till practice on system productivity. Cotton-wheat system under ZT-based permanent broad bed with residue retention gave significantly higher system productivity than conventional till system. The system productivity was comparable between 100% N and 75% N under this cotton-wheat and PBB system, which could lead to save up to 67.5 kg N/ha annually in cotton and wheat together. The sustainable yield index was higher under maize-wheat system followed by cotton-wheat and pigeon pea-wheat system. Thus, these CA-based systems have the potentials of replacing the existing rice-wheat system and are important adaptation and mitigation strategies under changing climatic conditions. CA-based management practices such as dry direct-seeded rice (DSR), zero tillage and residue retention may hold potential to increase yields, reduce costs and increase farmers' profits in rice-maize system (RMS).

Crop performances in different CA based systems were also evaluated in a Vertisol of central India and it was found that there is positive correlation between reduction in tillage and crop yield under soybean-wheat cropping system. The system productivity increased from 5.7 Mg/ha under conventional tillage system to 6.4 Mg/ha under zero tillage. Similarly water productivity increased from 1.04 kg/m^3 under conventional tillage system to 1.17 kg/m^3 under conservation agriculture which was 12.5% higher as compared to conventional tillage (Fig. 1).

Crop performances under different residue levels also showed a positive correlation between residue level and crop yield under both soybean-wheat and maize-chickpea cropping system. The system productivity in terms of maize equivalent yield (MEY) increased by 50.5% under CA with 90% residue retention as compared to CT. Similarly, in soybean–wheat cropping system, a system yield increase of 31.3% was recorded under CA with 90% residue retention as compared to conventional system. Similarly, Somasundaram *et al.* (2019) reported that the maize-chickpea cropping system had significantly (P < 0.05) higher soybean grain equivalent yield (4.65 t ha^{-1}) followed by soybean + pigeon pea (2:1) intercropping (3.50 t ha^{-1}) and soybean–wheat cropping systems (2.97 t ha^{-1}) under CA. They concluded that CA practices could be a sustainable management practice for improving soil health and crop yields of rainfed Vertisols in central India.

Climate regulation through carbon sequestration and greenhouse gas emission mitigation

Agricultural activities and land use changes contribute to about one-third of total greenhouse gases (GHG) emissions and are the largest source of N_2O emission (FAO 2007). GHGs emissions from agriculture can be reduced by minimizing fossil fuel consumption in agricultural activities, increasing soil carbon sequestration as well as decreasing emissions of N_2O from soil (Mosier *et al.*, 2005). Some of the potential solutions include a shift from intensive tillage operation to zero or minimum tillage where at least 30% crop residue is left after crop harvest. Increased carbon sequestration through residue retention can be a key practice for climate change adaptation. CA practices decrease the exposure of organic substances to the microbial processes, thus reduce SOM decomposition and CO_2 emission.

CA and soil carbon sequestration

Soil carbon sequestration provides additional ecosystem services to agriculture itself, by conserving soil structure and fertility, improving soil quality, increasing the use efficiency of agronomic inputs, and improving water quality

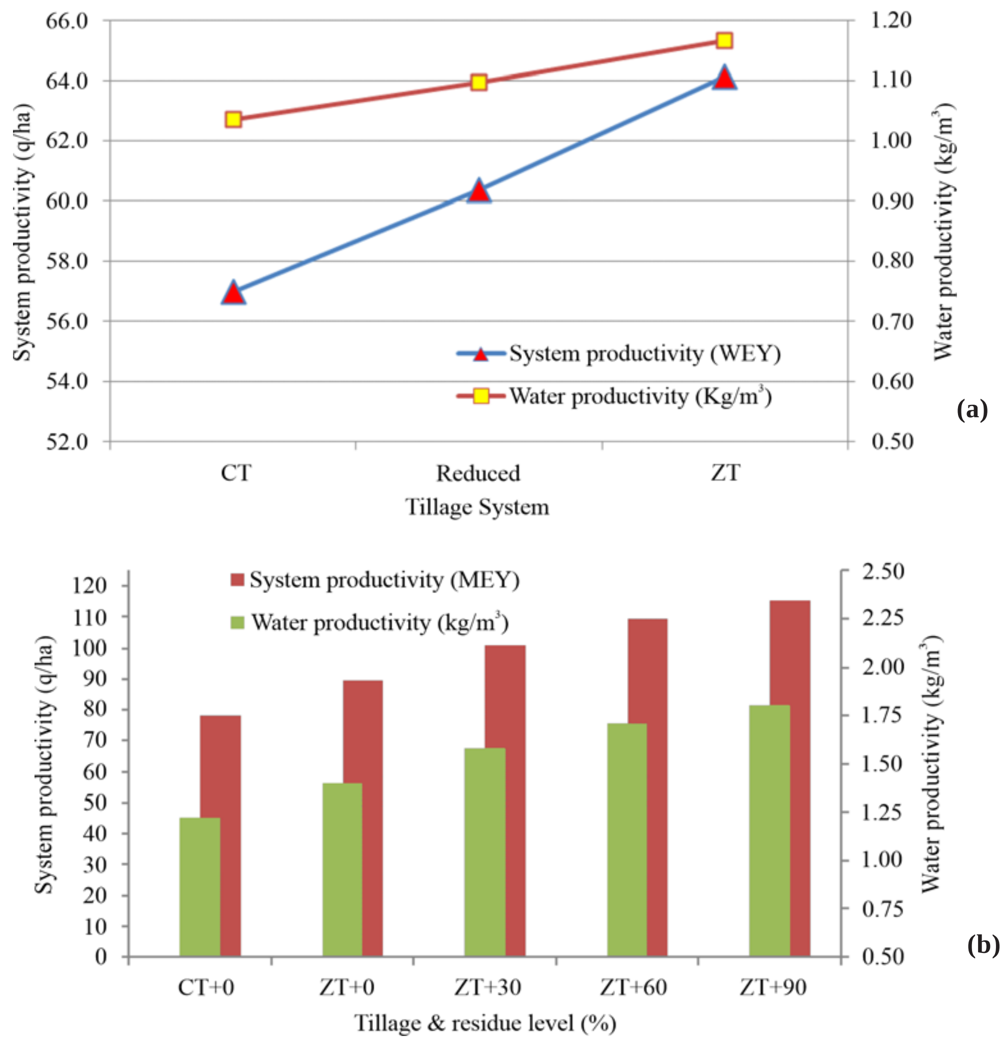

Fig. 1. Effect of different residue levels on yearly system productivity and water productivity of maize-chickpea cropping system under different conservation agriculture based (a) tillage and (b) residue level in central India

by filtration and denaturing of pollutants (Smith *et al.*, 2008). Results from a long-term tillage experiment conducted at ICAR-IARI, New Delhi showed a decrease in the soil organic carbon concentration with the increase in soil depth indicating stratification of soil organic carbon. The stratification ratio under CA was higher than that under CT (Table 1). Among the cropping systems, the stratification ratio was maximum for pigeon pea-wheat system (2.03) and minimum for maize-wheat system (1.71). Among the tillage methods, it was maximum for zero tillage with residue retention (2.19) and minimum for conventional flat bed system (1.65). Among the CA systems, retention of residues could increase the stratification ratio by 35.7, 20.8 and 12.9% in cotton-wheat, maize-wheat and pigeon pea-wheat systems, respectively.

Soil organic carbon stock at 0-30 cm soil depth was maximum in pigeon pea-wheat system (35.16 Mg/ha) and minimum in the maize-wheat system (28.47 Mg/ha) after 10 years of experimentation. Among the tillage practices the soil organic carbon stock at 0-30 cm depth was maximum for zero tillage with residue retention (33.15 Mg/ha) and minimum for conventional flat cultivation (26.88 Mg/ha). Among the CA systems, retention of residues improved soil organic carbon stock at 0-30 cm soil depth by

Table 1. Soil organic carbon stratification ratio under conservation and conventional agriculture practices after wheat

Treatments	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	1.86	1.60	1.65	1.70
ZT + Residue	2.77	1.95	1.86	2.19
Broad bed (BB)	1.50	2.02	1.60	1.71
BB + Residue	2.52	2.10	1.91	2.18
Narrow bed (NB)	1.86	2.04	1.60	1.83
NB + Residue	1.79	2.80	1.70	2.09
Flat Bed	1.60	1.68	1.68	1.65
Mean	1.99	2.03	1.71	

6.4, 3.3 and 12.1% in cotton-wheat, maize-wheat and pigeon pea-wheat system, respectively. Carbon sequestration potential of CA practices compared to conventional tillage was maximum for pigeon pea-wheat system (6.64 Mg/ha) and minimum for cotton-wheat system (3.46 Mg/ha) (Table 2). Among the CA practices, the carbon sequestration potential was maximum for zero-tillage with residue retention (6.27 Mg/ha) and minimum for broad-bed and residue removal (3.06 Mg/ha).

A long-term (10 years) study with soybean-wheat cropping system conducted on a Vertisol of central India idicated that conservation tillage practices which include no tillage (CT) and reduced tillage (RT) significantly improved the organic carbon stock in top 15 cm soil layer and also improved the soil physical properties and aggregate stability. The organic carbon content of the soil up to 30 cm depth after ten crop cycles in a Vertisol was higher in conservation tillage (NT and RT) treatments compared to the conventional tillage treatment. At the 0-5 cm soil depth, the SOC content was the highest in NT followed by RT, mould-board tillage with wheat residue retention (MB) and conventional tillage without wheat residue retention (CT) whereas, at 5-15 cm depth, SOC content in NT, RT and MB showed no significant difference but it was significantly higher than that in CT. However, at 15-30 cm soil depth the difference in SOC content was not conspicuous. Conservation tillage, particularly no-tillage lead to a higher concentration of SOC in the top layer of the soil (0–5 cm) and altered its distribution within the soil profile. Higher stratification ratio was registered under NT (2.11) and RT (1.77) compared to CT (1.53). The total carbon stock up to 30 cm depth was also higher in three residue retention treatments than in conventional tillage treatment (Table 3).

Similarly, a study conducted on a Vertisol with two tillage treatments viz., no tillage (NT) and conventional tillage (CT) and five nutrient management practices showed that after three years of experimentation, soil organic carbon

Table 2. Carbon sequestration potential (Mg/ha) at 0-30 cm soil depth under CA practices after wheat 2018

Treatments	Cotton-wheat	Pigeon pea-wheat	Maize-wheat	Mean
Zero tillage (ZT)	2.72	2.51	5.45	3.56
ZT + Residue	4.68	2.84	11.28	6.27
Broad bed (BB)	3.94	2.84	2.38	3.06
BB + Residue	7.30	4.75	5.92	5.99
Narrow bed (NB)	0.95	6.22	5.92	4.36
NB + Residue	1.19	6.81	8.89	5.63
Mean	2.72	2.51	5.45	

Table 3. Effect of tillage systems on soil organic carbon (SOC) content, stratification ratio (0-5 cm) /(15-30 cm) and SOC stock of the top 30 cm soil

Treatment	SOC content (g kg^{-1})			Stratification ratio	SOC stock (0-30 cm) (Mg ha^{-1})
	0-5 cm	5-15 cm	15-30 cm		
Tillage system					
NT	10.4a	6.3b	5.0a	2.11a	24.96
RT	9.1b	6.6b	5.1a	1.77b	24.85
MB	8.3c	7.4a	5.4a	1.54b	26.08
CT	7.8d	5.9c	5.1a	1.53b	23.26

Note: Different letters within a column indicate significant difference between values at P<0.05 (*Source:* Hati *et al.*, 2015a)

Table 4. Effect of short-term tillage treatment on soil organic carbon (SOC) concentration and SOC stock of the top 30 cm soil in a Vertisol

Tillage System	SOC concentration (g kg^{-1})			Total SOC stock (0-30 cm depth) on soil equivalent mass (Mg ha^{-1})
	0-5 cm	5-15 cm	15-30 cm	
CT	9.8	7.6	5.7	28.18
NT	11.9	8.9	5.5	30.79
LSD (P =0.05)	1.6	1.1	NS	1.82

(*Source:* Hati *et al.*, 2015b)

(SOC) concentration of the top 15 cm soil depth and SOC stock of the top 30 cm soil increased significantly under NT compared to CT (Table 4). Soil organic C stock of the top 30 cm soil was 9.2% higher under NT compared to CT practice.

Soil aggregation, aggregate-associated carbon (C), and carbon pools

A study comprised of three tillage systems (TS), reduced tillage (RT), no tillage (NT) with retention of crop residue and conventional tillage (CT), together with four cropping systems (CS), namely soyabean (*Glycine max* L.) +pigeon pea (*Cajanus cajan* L.) (2:1), soya bean–wheat (*Triticum durum* L.), maize (*Zea mays* L.) +pigeon pea (1:1), and maize–chickpea (*Cicer arietinum* L.) was conducted in the deep Vertisols of central India. Results showed that at depths 0–5 and 5–15 cm, tillage and cropping system had a significant effect on aggregate mean weight diameter (MWD). The MWDs of 0.97 and 0.94 mm were larger for NT than CT (0.77 and 0.83 mm) at 0–5- and 5–15-cm depths, respectively (Fig. 2). Water-stable aggregates (WSAs) were also larger for NT (70.74%) and RT (70.09%) than CT (59.50%) at 0-5 cm. Tillage practice, cropping system and their interaction had a greater effect (P<0.05) on the content of aggregate-associated C for large macroaggregates (LM) (Fig. 3). There was more aggregate-associated C for NT and RT at 0–5-cm depth than for CT. Cropping system also had a significant effect (P<0.05) on aggregate-associated C at 0–5-cm depth. Soil organic C (%) fractions were in the order of non-labile >very labile >less labile >labile for 0–5- and 5–15-cm depths after four crop cycles. Less labile and non-labile C fractions contributed >50% of TOC, indicating a more recalcitrant form of carbon present in the soil. Tillage had no significant effect (P>0.05) on crop yields after four crop cycles. Conservation agriculture can have a positive effect on aggregate stability, aggregate-associated C and different carbon pools in a Vertisol (Somasundaram *et al.*, 2018).

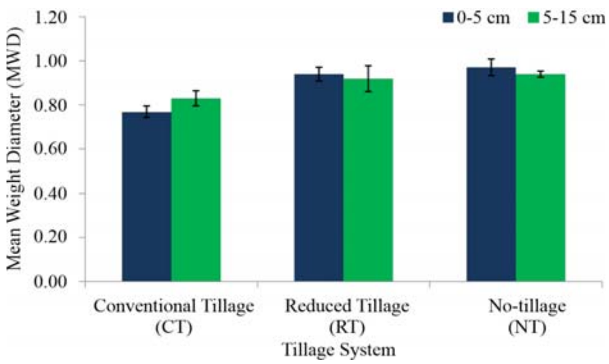

Fig. 2. Effect of different tillage practices on soil aggregation (MWD) after four crop cycles [Averaged over four cropping system]

Another study evaluated the effect of conservation (reduced) tillage coupled with residue retention under different cropping systems on soil properties and crop yields in a Vertisol of a semiarid region of central India. Two tillage systems – conventional tillage (CT) with residue removed, and reduced tillage (RT) with residue retained – and six major cropping systems of this region were examined after 3 years of experimentation. Results demonstrated that soil moisture content, mean weight diameter (MWD), percent water stable aggregates (>0.25 mm) for the 0–15 cm soil layer were significantly ($P < 0.05$) affected by tillage practices. Soil penetration resistance was significantly higher for RT than CT. Irrespective of soil depth, there was higher soil organic carbon (SOC) for RT than CT. Significant differences in different C fractions were observed between RT and CT. Soil microbial biomass C concentration was significantly higher in RT than CT at 0–15 cm depth (Somasundaram *et al.*, 2019).

CA impact on greenhouse gas emissions

Direct seeded rice (DSR) has an enormous potential to reduce CH_4 emission. DSR is an alternative technology to puddled transplanting, which saves labour, fuel, time and water. Gupta *et al.* (2016) reported from the rice–wheat system in IGP that, among different rice treatments, DSR showed significantly lower global warming.

Quantifying net global warming potential (NGWP) and greenhouse gas intensity (GHGi) of an agricultural activity is a method to assess the mitigation potential of the activity. But there is dearth of information on NGWP of conservation agriculture particularly under rainfed conditions. In a study, crop based $NGWP_{crop}$ and soil based $NGWP_{soil}$ were estimated from the data of an experiment initiated in 2009 in rainfed semiarid region of Hyderabad, India with different tillage practices like conventional tillage (CT), reduced tillage (RT), zero tillage (ZT) and residue retention levels by harvesting at different heights of 0, 10 and 30 cm anchored residue in pigeon pea-castor systems. The results of the study

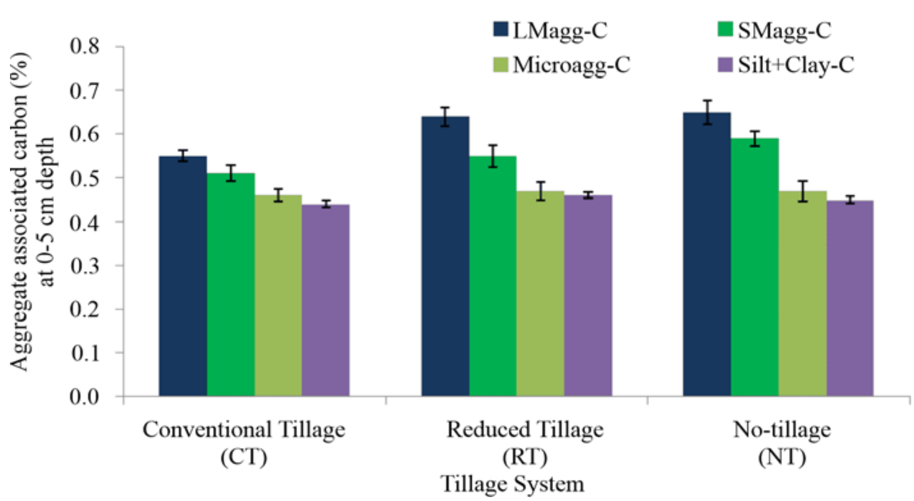

Fig. 3. Effect of different tillage practices on aggregate associated C after four crop cycles [Averaged over four cropping system; LM-Large macro-aggregate (>2mm), SM-Small macro-aggregate (2-0.25 mm), Micro-aggregate (0.25-0.53 mm), Silt+Clay < 0.53 mm]

revealed that under rainfed conditions CT recorded 24% higher yields over ZT, but CT and RT were on par with each other. However, the yield gap between the tillage treatments narrowed down over 5 years of study. ZT and RT recorded 26 and 11% lower indirect GHG emissions (emissions from farm operations and input use) over CT, respectively. The percent contribution of CO_2 eq. N_2O emission is higher to total GHG emissions in both the crops. The fuel consumption in ZT was reduced by 58% and 81% as compared to CT in pigeonpea and castor, respectively. Lower NGWP and GHGi based on crop and soil was observed with increase in crop residues and decrease in tillage intensity in both the crops. The results of the study indicate that, there is scope to reduce the NGWP emissions by reducing one tillage operation as in RT and increase in crop residue by harvesting at 10 and 30 cm heights with minimal impact on the crop yields. However, the trade-off between higher yield and soil health versus GHG emissions should be considered while promoting conservation agriculture. The $NGWP_{crop}$ estimation method indicated considerable benefits of residues to the soil and higher potential of GHG mitigation than by the $NGWP_{soil}$ method and may overestimate the potential of GHG mitigation in agriculture system.

In a study the effects of tillage, residue management and cropping system intensification through the inclusion of green gram on the performance of the rice-wheat (RW) system in NW India was examined. Treatments included were: rice and wheat under conventional tillage (CT) with and without green gram (CTR-CTW, CTR-CTW+GG), both crops under zero-tillage (ZT) with and without green gram (ZTR-ZTW-R, ZTR-ZTW-R+GG) and both crops under ZT plus residues with and without green gram (ZTR-ZTW+R, ZTR-ZTW+R+GG). Based on data of two consecutive years, the net return from the RW system was significantly higher in the ZT than CT systems. Methane emissions were only observed under flooded conditions in CT rice plots; otherwise, emissions were negligible in all other treatment combinations. N_2O emissions were dictated by N fertilizer application with no other treatment effects. Overall, ZT with residue retention resulted in the lowest global warming potential (GWP) ranging from 3301 to 823 kg CO_2-eq ha^{-1} $year^{-1}$ compared to 4113 to 7917 kg CO_2-eq ha^{-1} $year^{-1}$ in other treatments. Operational inputs (tillage, planting, and irrigation) and soil C sequestration had significant effects on total GWP. The water footprint of RW production system was about 29% less in CA-based system compared to CT-based systems. Study concluded that ZTR-ZTW+R and ZTR-ZTW+R+GG in RW systems of northwestern IGP have the potential to be agronomically productive, economically viable with additional benefits for the environment in terms of soil health and GHG emissions.

Nitrous oxide fluxes could be avoided by applying N fertilizer to wet soil or by irrigating the field not later than 1 day after N application. Applying crop residues on soil surface had no significant effect on the seasonal CH_4 and N_2O emissions. It was estimated that switching rice crop establishment method from conventional to

Table 5. GHG emission under different tillage and cropping system

Treatments	Rice season		Wheat season
	CH_4 (kg C ha^{-1})	N_2O (kg N ha^{-1})	N_2O (kg N ha^{-1})
CTR-CTW	23.08	2.20	2.64
CTR-CTW+GG	20.74	2.20	4.23
ZTR-ZTW-R	0.31	2.45	4.37
ZTR –ZTW-R+GG	2.05	1.52	3.26
ZTR-ZTW+R	5.44	2.31	4.53
ZTR –ZTW+R+GG	4.63	3.67	3.15
Treatment Effect	*** (P<0.001)	NS	NS

Source: Sapkota *et al.* (2017)

CA-based practices in Haryana could reduce GWP for rice by 23% or by 1.26 Tg CO_2 eq yr^{-1}. An intensive CA-based rice–wheat and maize–wheat system reduced GWP by 16–26% or by 1.3–2.0 Tg CO_2 eq yr^{-1} compared with the conventional rice-wheat system. However, this reduction in GWP would be from a decrease in diesel and electricity consumption and not from direct reduction in emissions of CH_4 and N_2O, which were higher in the maize–wheat system than in the rice–wheat system. Conservation agriculture has many attributes that can use applied nitrogen more efficiently and reduce the risk of high N_2O emissions from soils.

Water storage and use efficiency

CA system increases the retention and storage capacity of water in soil profile with improvement in structural stability and meso-porosity of the soil. Better soil structure and structural stability helps in drainage of excess water but increases the plant available water retention in the profile. This improves resilience of the crop under rainfed water deficit situation and decrease the irrigation requirement of the crop. Besides this, CA system reduces evaporation loss of soil water from the residue covered surface, which increases the use efficiency of irrigation water and improves water productivity.

Savings of irrigation water, applied to different cropping systems (cotton-wheat, pigeon pea-wheat, maize-wheat and DSR-wheat-mung bean) under CA on an Inceptisol at IARI, New Delhi were compared to transplanted rice-wheat cropping system. Results showed that irrigation water savings ranged from 34.8% to 67.9% under different best treatments in respective cropping system. Concomitantly, system water productivity increased by 90.8% to 215.4% under various best treatments in different cropping systems compared to transplanted rice-wheat system; the highest increase being in cotton-wheat system due to reduction in water use. Also, there were 20% and 50% savings in wheat and rice seeds under CA. A 25% N saving in cotton-wheat (~67.5 kg N/ha) and 25%N in maize-wheat and rice-wheat (~60 kg N/ha) was also achieved. Mean water productivity of the system in the permanent broad bed with residue retention (12.58 kg wheat grain $ha^{-1}mm^{-1}$) was 12-48% greater compared with CT, narrow bed with and without residues, broad bed, and ZT plots. Net return of the permanent broad bed plots with residue retention was 36% and 13% greater compared with CT and narrow bed plots, but was similar to other treatments. (Das *et al.*, 2014).

In another experiment on an Inceptisol, treatment of permanent bed maize-wheat/ system (PBMW) +/ mung bean (MB)/ + residue retention (R)/ +/ precise irrigation (PI) recorded 38% higher system productivity, saved 1660/ mm of irrigation water, increased irrigation/ +/ rainfall water productivity (WPI+R,) by 270% and increased net returns by 84% compared to Conventional till rice-wheat system (CTRW). Zero till rice-wheat system (ZTRW)/ +/ MB/ +/ R/ +/ PI recorded 24, 41 and 37% (3 yrs' mean) higher system productivity, WPI+R and net returns, respectively, compared to Conventional till rice-wheat system (CTRW). System productivity was increased by 19 and 33%, WPI+R by 223 and 29% and net returns by 84 and 57% with ZTRW and PBMW compared to CTRW, respectively irrespective of MB integration and residue management. On average, inclusion of MB in cereal systems (RW/ MW) contributed an 18% increase in system productivity and a 15% increase in net returns. CA based sustainable intensification of MW systems (PBMW/ +/ MB/ +/ R/ +/ PI) is a better alternative to RW system (ZTRW/ +/ MB/ +/ R/ +/ PI) as it provides opportunities for saving 79% of precious water, enhancing crop and water productivity by 12 and 145%, respectively along with high (34%) economic benefits thereby helping to arrest decline in ground water table in the North-West IGP of India (Chaudhary *et al.*, 2018a).

In another system of rice-mustard for five years, mean irrigation water productivities of rice and mustard crops differed significantly across the treatments. Generally, the CA-based practices had higher irrigation water productivities than the TPR-CTM /ZTM systems ($P<0.05$). The ZTDSR-ZTM-ZTSMB (+R) practice resulted in highest

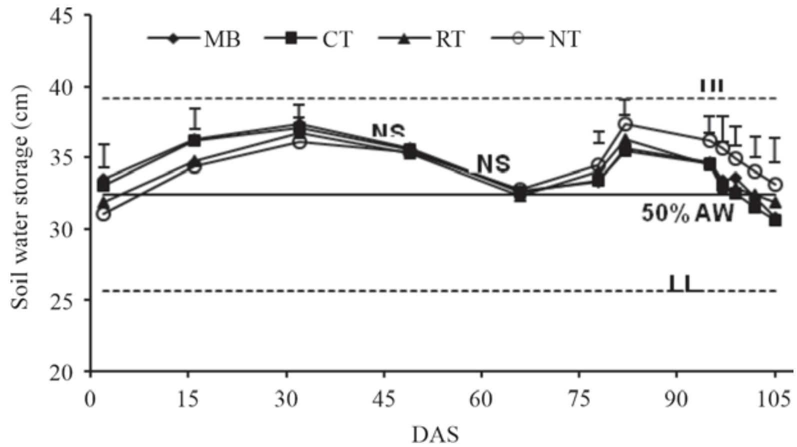

Fig. 4. Temporal variation of soil water storage at 0-90 cm depth during soybean growing season as affected by tillage treatments; UL - upper limit of available water (AW), LL - lower limit of available water, vertical lines represent LSD ($P < 0.05$) between the treatments in each date of sampling, NS - not significant; MB, CT, RT and NT are mould board, conventional, reduced and no tillage, respectively. (Source: Hati *et al.*, 2015a)

irrigation water productivities of rice and mustard, which were significantly higher than that of all other treatments, except the ZTDSR+BM – ZTM (+R). It increased irrigation water productivity by 27.8% in rice and 35.1% in mustard, and total water productivity (irrigation + rainfall) by 35.7% in mustard crop compared to the TPR-CTM system ($P<0.05$). Averaged over the residue management treatments, the residue retention was found to be superior, which increased total water productivity by 11-15% in rice and mustard over the residue removal treatments.

A study conducted on a Vertisol at ICAR-IISS, Bhopal showed that during the four years of experimentation conservation tillage system increased the profile water storage during the late crop season. During the early crop growth period of soybean (up to 30 DAS), soil water storage in the 0-90 cm depth was more in MB and CT than NT (Fig. 4). This might be due to higher infiltration of rainwater in MB and CT as the soil was relatively loose owing to ploughing during summer before the onset of rainfall. But in the later phase (78 DAS onwards) NT retained more water in the profile than other three tillage treatments. This might be attributed to reduction of initially high infiltration rate in MB and CT treatments with time due to detachment of soil particles by the impact of raindrops. Besides this better aggregation could have favoured stability of pore space and higher water retention together with less evaporation due to the presence of plant residues might have helped in maintaining greater soil water content under NT.

Another experiment conducted on a Vertisol showed that the water productivity increased from 1.2 kg/m^3 under conventional tillage system to 1.8 kg/m^3 maize equivalent yield under conservation agriculture with 90% residue retention in case of maize–chickpea cropping system (Fig. 5), while it increased from 0.9 kg/m^3 under conventional tillage system to 1.36 kg/m^3 wheat equivalent yield under conservation agriculture with 90% residue retention in soybean –wheat cropping system.

Nutrients accumulation and cycling

Soil organic matter is an integrator of several soil functions and as such is a key component of soil quality and the delivery of many ecosystem services (Palm *et al.*, 2014). The CA practices of zero tillage and residue retention increases SOM in the top soil which, in turn, provides energy and substrate for soil biota which encourage formation of stable soil structure and nutrient cycling, as well as many other soil processes and ES (Brussaard,2012). Residue retention in CA promotes nutrients recycling and nutrient use

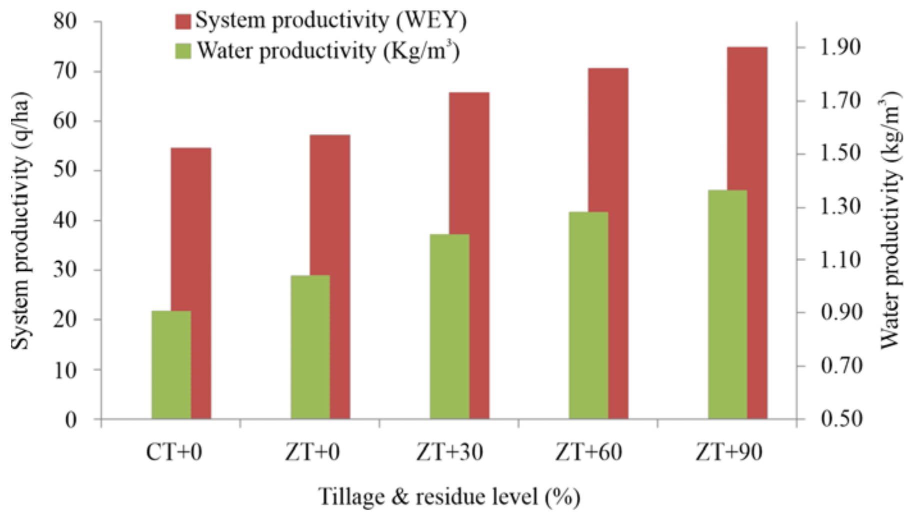

Fig. 5. Effect of different residue levels on system productivity and water productivity of maize- chickpea cropping system under conservation agriculture in central India

efficiency, and increases stratification of nutrients. A field experiment conducted with different CA practices at IARI, New Delhi found that the amount of total N taking into account use of input (through fertilisers, residue, irrigation, rain and seed uptake) is maximum (371 kg/ha) in double ZT rice-wheat system with residue and brown manuring resulting in more input of nitrogen. The triple ZT rice-wheat system with residue retention also showed high nitrogen at 354 kg/ha. This treatment also had higher removal, as a result of which the N balance was the lowest. Similarly, the highest amount of P input was observed to the tune of 81.2 kg/ha in triple ZT system with residue and the triple ZT system (without residue) at 74.1 kg/ha was comparable to it. This was closely followed by double ZT system with residue and brown manuring at 68.9 kg/ha. It is clear that CA based practices of residue retention and zero tillage, aided by means like brown manuring enrich the soil by enhancing the phosphorus pool. All CA-based systems except ZTDSR-ZTW (without residue) had high P balance compared to TPR-ZTW/CTW. The highest amount of K input of 256 kg/ha was observed in triple ZT system with residues at followed by the double ZT system with residue and brown manuring (240 kg/ha). The lowest K input was observed in double zero till without residue, and CT systems were comparable to it. Moreover, the balance tipped towards the negative side across all treatments, with less input but more removal.

Efficient nutrient management in conservation tillage is one of the major concerns in vertisols, as residue retention on soil surface and reduction in tillage operation can have a major impact on nutrient dynamics and stratification. The available phosphorus concentration at 0-5 and 5-15-cm soil layers under no-tillage and reduced tillage system increased compared to conventional tillage due to retention of residues and minimum soil disturbance. The no-tillage system showed a trend to accumulate available P near the soil surface layer causing higher P stratification than the conventional system (Kushwa *et al.*, 2016).

Erosion prevention

Soil erosion control is one of the most important goals of CA, contributing to both on-, and off-site ecosystem services. Reduced or NT and surface applied residues directly reduce erosion by minimizing the time that the soil is bare and exposed to direct impact of wind, rainfall and runoff. CA can reduce wind erosion due to the larger proportion of dry aggregates, less wind erodible fraction and greater crop residue cover of the soil surface (Verhulst *et al.*, 2010). CA also indirectly reduces erosion by water through the effects on soil properties and processes that increase water infiltration and reduce runoff. Soil physical properties such as aggregation and macroporosity are important for determining rates of water infiltration, runoff, plant available soil water, erosion, and others. These factors are usually greater with CA and are related to reduced erosion and runoff. Though there are fewer studies on water quality, in general, less sediment load and reduced N are observed with CA. Thus, CA helps in physical protection of the soil surface against direct impact of rain drops and maintaining or improving soil physical properties which are related to the ES of water regulation and provision on different soil types and agro-ecosystems.

Ghosh *et al.* (2015) while working in Indian Himalayan region reported that mean runoff coefficients and soil loss with conservation agriculture were 45% and 54% less than conventional agriculture plots. Mean data over five years of soil loss were 7.2 t/ha under conventional agriculture, whereas in CA plots, the soil loss was 3.5 t/ ha, a reduction of 51%. Over the five consecutive years, the CA treatment reduced runoff significantly compared to conventional agriculture. Crop rotation in conservation agriculture also significantly reduced soil erosion. They also reported that the mean wheat equivalent yield was ~47% higher in the plots under CA compared with conventional agriculture in a maize-wheat crop rotation. Kurothe *et al.* (2014) also reported that average soil loss in NT was 37.2% less than CT. Comparing runoff under different tillage analyzed across cropping system, shows highest mean annual runoff under CT. The highest and lowest sediment concentration maxima were observed under CT (22.9 g l^{-1}) and NT (10.2 g l^{-1}), a net reduction in sediment concentration by 55%. Runoff and soil loss are invariably tightly linked quantitatively. Therefore, any interventions which effectively restrict runoff should also reduce soil loss. Soil loss under NT was nevertheless less than CT due to less sediment concentration in similar volumes of runoff, because disturbed soil is more easily eroded.

Soil quality and biodiversity

Soil quality is the key to crop production and several ES. Some soil quality indicators relate fairly directly to an ES, such as soil aggregation and macro-porosity to soil water movement. Integrated studies and assessments are needed in CA to identify the key soil properties (and related processes) that contribute to crop production as well as to regulate the ES that are related to resource use efficiency and reduced losses to the environment. Regular addition of crop residues leads to an increase in the organic matter content of the soil. In the beginning this is limited to the top layer of the soil, but with time this will extend to deeper soil layers. Organic matter plays an important role in the soil: fertilizer use efficiency, water holding capacity, soil aggregation, rooting environment and nutrient retention, all depend on organic matter. Further, residues on the soil surface reduce the splash-effect of the raindrops, and once the energy of the raindrops is dissipated the rain water proceed to the soil without any harmful effect. This results in higher infiltration and reduced runoff, leading to less erosion. The residues also form a physical barrier that reduces the speed of water and wind over the surface. Systems, based on high crop residue addition and no tillage, accumulate more carbon in the soil, compared to the loss into the atmosphere resulting from plough-based tillage. It also generally hosted the highest soil microbial diversity and activity in diversified cropping systems under no-till.

The meta-analysis of West and Post (2002) showed that NT can increase SOC rapidly, especially at the soil surface. Given that the increase in SOC observed in these systems is largely due to physical protection, maintaining the NT regime is important to ensure that the SOC remains sequestered. Thus, soils managed with NT not only increase SOC, but they also have improved microbial functioning and availability of nutrients (Thomas *et al.*, 2007). Conservation agriculture in general shows positive effect in improving soil quality and health.

Soil microbial communities perform critical functions in ecosystem processes. These functions can be used to assess the impact of agricultural practices on sustainable crop production. Chaudhary *et al*. (2018b) studied soil bacterial diversity under conservation agriculture-based cereal systems in Indo-Gangetic Plains. They evaluated four different scenarios *viz*. Sc.I CT-based rice–wheat system (farmers' practice); Sc.II, partial conservation agriculture (CA) based in which rice is under CT–wheat and mungbean under zero-tillage (ZT); Sc.III, full CA-based in which rice–wheat–mungbean are under ZT and Sc.IV, where maize–wheat–mungbean are under ZT using Illumina MiSeq sequencing technology., The variable regions V3–V4 of 16S rRNA were sequenced and the obtained reads were analyzed to study the diversity patterns in the scenarios. They reported that predominant phyla in all scenarios were Proteobacteria, Acidobacteria, Actinobacteria, and Bacteroidetes which accounted for more than 70% of the identified phyla. However, the rice-based systems (Sc.I, Sc.II, and Sc.III) were dominated by phylum Proteobacteria; however, maize-based system (Sc.IV) was dominated by Acidobacteria. The class DA052 and Acidobacteriia of Acidobacteria and Bacteroidetes of Bacteroidia were exceptionally higher in Sc.IV. Shannon diversity index was 8.8% higher in Sc.I, 7.5% in Sc.II, and 2.7% in Sc.III compared to Sc. IV.

Vesicular Arbuscular Mycorrhiza (VAM) colonization as affected by 5 years of residue retention was studied during wheat growing season at ICAR-IISS, Bhopal. It was observed the VAM colonization in wheat root was significantly higher in 90% of residue retained plot in comparison to no residue retained plot. It was recorded that in 90% of residue retained plot VAM colonization was 46% whereas it was only 26% in 0% of residue retained plot. Easily extractable glmomalin related soil protein (EEGRSP), an index of organic N supplying capacity of soil found significantly improved with the retention of residue. Retention of residue resulted in 80% improvement in EEGRSP concentration in comparison to no residue retained plot. This clearly indicates that retention of residue under no till system helps in improvement in nitrogen supplying capacity of soil.

Tillage and residue management influence soil quality via its effects on soil physical, chemical, and biological properties, which in turn affect crop productivity. A study conducted at ICAR-IISS, Bhopal evaluated the effects of different levels of residue retention (0 and 90%) under no-till (NT) system. It was observed that retention of residue (6 years) to the tune of 90% significantly improved total soil organic carbon (1.54%) in 0-10 cm of soil depth in comparison to 0% of residue retained plot (1.24%). Retention of residue under NT system resulted in 38% improvement in Walkley and Black Carbon (WBC) in comparison to no residue retained plot. They also recorded 64% improvement in particulate organic carbon (POC) concentration in residue retained plot as compared to no residue retention treatment. In comparison to conventional agriculture system, there was a two fold increase in POC concentration in 90% residue retained treatment in comparison to conventional agriculture system. Six years of residue retention under no till plot resulted in 17% improvement in water soluble carbon in soil.

CA practices such as ZT and permanent raised beds (PB) accelerated deposition of soil organic matter and augmented associated biological properties of soil through enhanced inputs of organic carbon (Parihar *et al.*, 2018). They reported significantly larger contributions (8.5–25.5%) of labile SOC pools to TOC at various soil depths in permanent bed (PB) and ZT. They further observed significant positive effect of CA practices and diversified crop rotations on MBC and DHA (dehydrogenase activity) at all the soil depths and sampling times. The combination of CA (PB and ZT) practices and appropriate choice of rotations (MCS and MWMb) were found to be the most appropriate option for restoration and improvement of the soil health of light textured Inceptisols through the accumulation of soil organic matter (SOM) and improvement in soil biological properties.

Monetizing Ecosystem Services of Conservation Agriculture

The conservation agriculture improves overall micro economic condition in the practiced area and ensures better economic returns to the individual practitioner which are evidenced from different studies. The immediate benefit to the practitioner is accrued through reduction in input costs thereby reducing the overall cost of production and reducing demand on critical inputs during peak farming season. The wider scale practice of conservation agriculture induces development of social capital in terms of improving collective action and strengthening group dynamism. The benefits from conservation agriculture have a pyramidal cascading effect with local, regional, national and global impact thereby improving macroeconomic environment. The overall improvement in soil edaphic regime, water availability scenario, and improved climate conditions leads to overall improvement of quality of life of population locally, regionally, nationally and globally due to tangible and intangible benefits. However, some times the potential benefits are not visible to the individual practitioners unlike the traditional practices which disincentivize the farmers to adopt conservation agriculture. Under conservation agriculture, farmer field demonstrations of SRI, (Annual Report, AICRP on IWM), that conserves water and other inputs in paddy recorded water use efficiency of 92.3 kg/ha-cm vis a vis 62.3 kg/ha-cm and benefit cost ratio of 2.23 against 2.07 (Table 6) in conservation agriculture against traditional practices with improved income to the farmer practitioner of conservation agriculture. Similarly another experiment at Powerkheda, Madhya Pradesh, India under AICRP on Irrigation Water Management revealed that highest net return of INR 49480/ha was obtained under zero tillage with water productivity of 1.25/ kg-/grain /m^3 (Table 7) vis a vis INR 38330 with water productivity of 1.11 kg grain /m^3 in conventional tillage under wheat-pearlmillet crop sequence. Similarly under ridge and furrow method of water conservation technology under conservation agriculture (Table 8) at Powerkheda, a net profit of Rs. 39780/- was recorded against Rs. 23680/- under traditional practice in pearlmillet crop in the tail reach of canal command. The individual benefit to the farmers if aggregated at regional scale, the contribution of conservation agriculture in improving overall micro economic condition will be immense. There are number of economic principles which are applied for measuring the ecosystem services of conservation agriculture. The formation of social capital through collective action would influence the adoption of conservation agriculture technologies fast. The impact of conservation agriculture on national income is sometimes reflected through green accounting process under National Income Accounting framework in different countries. In the absence of direct valuation methods for eco system services, non-market valuation techniques (FAO) are sometimes practiced to measure the impact of soil conservation measures on ecosystem services. At the farm level, a whole-farm system approach may be adopted to have financial analysis of conservation agriculture ecosystem services (FAO, 2001). Production function model, transaction cost models, hedonic,

Table 6. Mean seed yield, WUE and economics return at the farmer's field under water conservation demonstration through system rice intensification (SRI) carried out at Powerkheda centre of Madhya Pradesh, India under All India Coordinated Research Project on Irrigation Water Management of ICAR (pooled of 5 years)

Treatments	Seed yield (kg/ha)						WUE	NMR	B:C
	2011	2012	2013	2014	2015	Mean	(kg/ha-cm)	(₹/ha)	ratio
Irri. @ 1 DADPW + SRI	4555	5353	4880	4930	4520	4847	92.3	80447	2.23
Irri. @ 1 DADPW + Transplanting	4087	4713	4450	4462	4346	4411	84.0	67367	2.03
Submergence + traditional practice	4555	4475	3810	3997	4198	4207	62.3	65247	2.07

- Based on 5 years data, seed yield of rice under SRI with irrigation at 1 DADPW = 4847 kg/ha.
- WUE = 92.3 kg/ha-cm
- Net returns = Rs. 80447 /ha)
- B:C ratio = 2.23)

Table 7. Residue Management & Irrigation Level on Wheat in Wheat-Pearlmillet Crop Sequence at Powerkheda centre of AICRP on Irrigation Water Management

Treatments	Grain yield (t/ha)	Stover yield (t/ha)	Gross income ($\times 10^3$ Rs. /ha)	Net return ($\times 10^3$ Rs. /ha)	Total water use (m^{-3} litre/ha)	Water productivity (kg /grain-m^3)
Sowing Methods						
CT	4.12	4.70	76.48	38.33	3712	1.11
ZT	4.37	5.03	81.73	49.48	3501	1.25
50% RRSHS	4.54	5.38	85.38	44.63	3401	1.34
100% RRSHS	4.60	5.44	86.47	37.62	3315	1.39
Irrigation Level						
3 Irrigations	4.12	4.86	77.41	40.72	2945	1.40
4 Irrigations	4.52	5.12	84.29	45.00	3444	1.31
5 Irrigations	4.64	5.46	87.14	45.25	4035	1.15

CT-Conventional Tillage, ZT-Zero Tillage, RRSHS-Residue Retention Sowing through Happy Seeder

Table 8. Effect of Ridge Furrow (Intercultural Operation & Water Conservation Practices) in Pearl millet - Tail Reach

S. No.	Particulars	Farmers Practice	Improved Practice
1.	Name of variety	Hybrid	Hybrid
2.	Nutrient applied (N:P:S kg/ha)	80:40:20	80:40:20
3.	Sources of irrigation	Canal + tubewell	Canal + tubewell
4.	Effective rainfall (mm)	171	171
5.	Total water applied (mm)	140	105
6.	Method of irrigation	Flooding	Ridge furrow
7.	Grain yield (t/ha)	2.85	3.97
8.	Straw yield (t/ha)	7.27	9.83
9.	Total cost of production (× 000 /ha)	19.92	20.77
10.	Net profit (× 000 ₹/ha)	23.68	39.78
11.	Water productivity (kg grain/m^3)	0.793	1.223

travel- cost approaches are some of the methods used in estimation of the economic benefit cost of the ecosystem services. At the macroeconomic level, the system of national accounts has integrated soil degradation through formal green accounting initiatives such as the United Nations System of Integrated Environmental and Economic Accounting (FAO, 2001). Thus the ecosystem service accounting under conservation agriculture would require both monetary and non-monetary approaches for estimation of benefit and cost for its wider impact.

Conclusion

Maximization of the provisioning services from agro-ecosystems can result in tradeoffs with other ecosystem services, but thoughtful management of agro-ecosystem can substantially reduce or even eliminate these tradeoffs. Efficient agricultural management practices are keys to realizing the benefits of ecosystem services and reducing disservices from agricultural activities. Conservation agriculture (CA)-based systems play a pivotal role in sustainable agricultural production. These systems provide a wide range of provisioning, regulating and supporting ecosystem services that are essential to increase use efficiency of natural resources (soil, water, air, fuel) and to meet environmental and food security goals. CA can potentially influence multiple ecosystem services in multiple environments and improve agricultural sustainability through increasing food production, improving soil health through carbon sequestration, mitigating GHGs emissions and conserving biodiversity. Studying the differential impact of CA management practices on soil process and ES is necessary to develop a predictive understanding that can be used for improved, site specific CA management guidelines. To better assess, manage and target CA, it is necessary to know the relative importance of tillage, residue management, crop rotations and their combination on different ES and also how those ES relate to crop production. The types of experiments installed for testing CA and comparing with conventional practices (tillage, residue removal or incorporation and monocultures) may not necessarily have the design and controls that are required to separate the individual and combined effects of different CA practices. Establishing a set of strategically located experimental sites that compare CA with conventional agriculture on a range of soil-climate types would facilitate establishing a predictive understanding of these relative controls of higher order factors (soil and climate) and management (tillage, residues, crop rotations) and ES outcomes, and ultimately in assessing the feasibility of CA or CA practices in different sites and socioeconomic situations. Agricultural systems focused solely on production to meet the need for human food may achieve the goal of global food security but to sustain, and not just meet, food production needs, however, requires the conservation of natural resources that support agricultural systems.

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Received: January 17, 2021; Accepted: April 09, 2021