



Potential of conservation agriculture for ecosystem services: A review

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ABSTRACT

Conservation agriculture (CA) has emerged as a promising technology for efficient rational use of available resources and sustained productivity in the long run. By saving inputs, reducing energy usage and greenhouse gases emissions, CA-based management practices are quite viable for bringing sustenance in agricultural crop production. The CA system can provide multiple ecosystem services such as provisioning, regulating and supporting services. The regulating services include improving carbon status, and physical, chemical and biological properties of soil, which further lead to provisioning services in terms of sustained crop and water productivity. Increased soil carbon sequestration improves supporting services, namely, soil aggregation that increases available soil moisture and can be helpful for better plant growth and development. It also improves soil biodiversity both above-and below-ground. Here we focus on the potential ecosystem service benefits accrued from CA. Conservation agriculture in the long run can be a strategy for sustainable crop intensification and a climate resilient crop management system.

Key words: Carbon sequestration, Conservation agriculture, Ecosystem services, Food security, Residue Management

Greater need for food security has led to large scale agricultural intensification and conversion of natural ecosystems to agro-ecosystems. Increased use of external inputs and converting marginal land for cropping could compromise ecosystem services obtained from agriculture, especially natural resource conservation, soil health and biodiversity (Sanderson *et al.* 2013). Increasing food production at the expense of ecosystem services (ESs) can undermine agro-ecosystem sustainability including crop production (Palm *et al.* 2014). With increasing food and nutritional security, there is a need to strengthen ecosystem services by implementing resource conservation strategies on farms. 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 agriculture (CA) is a concept for resource-saving agricultural crop production, which is based on enhancing natural and biological processes above and below the ground. The concerns for soil erosion, soil quality deterioration and chemical hazards loom large in recent years and have compelled the researchers to look back to the past towards evolving conservation agriculture-based practices, which aim at higher productivity and

profitability through rational and sustainable use of available resources on a long-term basis (Das *et al.* 2016). CA is described by three interlinked principles, along with other good agricultural practices, namely: (i) continuous no or minimal mechanical soil disturbance (implemented by the practice of no-till seeding or broadcasting of crop seeds, 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 soil mulch cover on the ground surface (implemented by retaining crop biomass, root stocks and stubbles and cover crops and other sources of *ex situ* biomass); and (iii) diversification of crop species; implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops (Kassam *et al.* 2018). Controlled traffic that lessens soil compaction could be another principle being pondered upon in the recent years. CA is a promising technology for efficient rational use of available resources and sustained productivity in the long-run (Das *et al.* 2014, Nath *et al.* 2017, Oyeogbe *et al.* 2018). Conservation agriculture based management practices are viable options for sustainable agriculture and effective tools to check land degradation (Bhattacharyya *et al.* 2013, Das *et al.* 2013). In 2015–16, CA was practised globally on about 180 Mha of cropland, corresponding to about 12.5% of the total global cropland; a significant increase of 74 Mha from 2008–09 (Kassam *et al.* 2018). There are many potential ecosystem services associated

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with the benefits of conservation agriculture. Ecosystem services are natural processes through which the environment produces natural resources that humans and other living species require for life (Dillaha *et al.* 2010). These include the benefits that human derive directly or indirectly from ecosystem functions (Costanza *et al.* 1997). Millennium Ecosystem Assessment (2005) has grouped ecosystem services into four broad categories: provisioning, supporting, regulating and cultural services with specific services mentioned in each category. These are presented in Fig 1 with some modifications/additions of specific services. Although CA was originally introduced to regulate wind and water erosion (Baveye *et al.* 2011), is now considered to deliver multiple ecosystem services (Oyeogbe *et al.* 2017, 2018). Moreover, CA can meet seven to eight of the United Nations' Sustainable Development Goals (UNDP 2015). Several prominent resource-conserving technologies (RCTs), which could also be CA-based are being popularized among the farmers. They include conservation tillage (zero/minimal), bed planting (narrow/broad beds), laser land leveling, brown manuring with *Sesbania*, crop residue management, crop diversification etc (Das *et al.* 2016, Behera *et al.* 2018). Fig 1 indicates the ecosystem services offered by conservation agriculture.

Potential ecosystem services from conservation agriculture

Several (provisioning, supporting, regulating and cultural) ecosystem services are enlisted by Millennium Ecosystem Assessment (2005). They all are not influenced by CA practices. The ecosystem services, which are positively influenced by CA are discussed below.

Crop/food production: Conservation tillage, the most important aspect of CA is thought to take care of the soil health, plant growth and environment (Bhattacharyya *et al.* 2013, 2015). Conservation tillage has beneficial effects on crop root growth, water and nutrient use efficiencies and ultimately the agronomic yield (Das *et al.* 2018). It has been observed that under drought and high temperature conditions, no-till wheat is more resilient than conventional wheat crop. Das *et al.* (2018) reported that in CA-based maize-wheat cropping system, maize yields due to permanent broad bed with residue and permanent narrow bed with residue were 28 and 15% higher than that in CT plots (Table 1). Singh *et al.* (2016) reported that 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

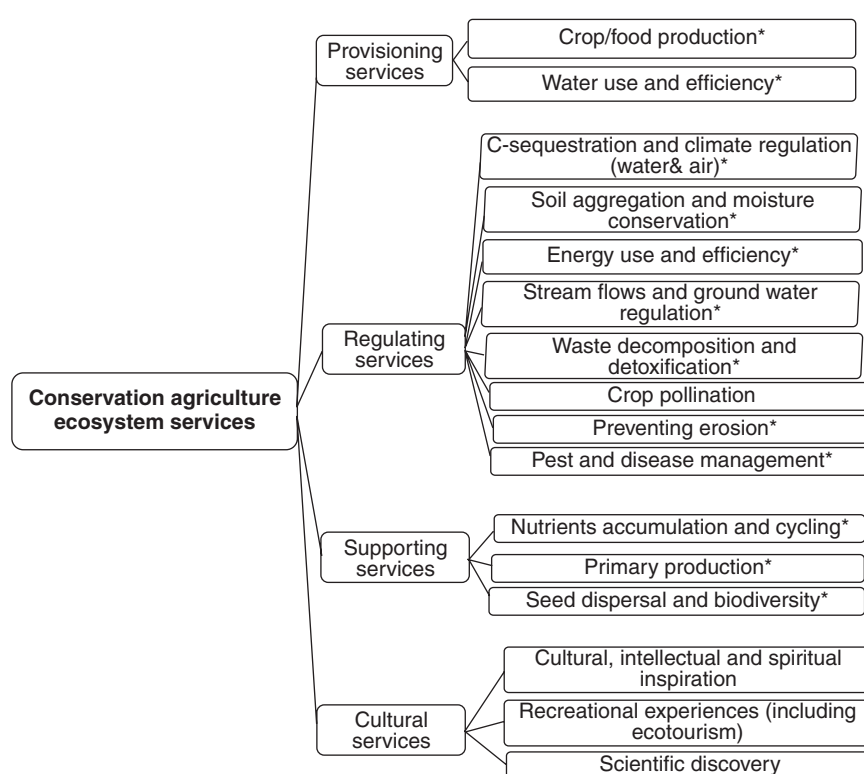


Fig 1 Different ecosystem services provided by conservation agriculture (*services are positively influenced by CA) (Source: Millennium Ecosystem Assessment 2005, Dillaha *et al.* 2010, modified by Authors)

in rice-maize system (RMS). They observed that root mass density was 6 to 49% greater in rice and 21 to 53% in maize under zero-tilled DSR followed by zero-tilled maize with residue retention from both crops compared to conventional RMS in different soil layers to 60 cm depth. Several other studies revealed that zero tillage wheat seeding technology can play an important role in saving inputs, turn around

Table 1 Crop productivity in conservation agriculture (CA) and conventional tillage (CT) treatments

Conservation/ zero tillage	Study duration (Years)	Crop	Increase in crop productivity over CT (%)	Reference
Permanent broad bed with residue	3	Cotton (Cotton-wheat)	51.0 (Cotton)	Das <i>et al.</i> (2014)
Permanent broad bed with residue	3	Maize (Maize-wheat)	28.0 (Maize)	Das <i>et al.</i> (2018)
Zero-till flat bed	4	Pigeon pea Wheat	5.4 2.5	Sepat <i>et al.</i> (2015)
ZT DSR – ZTW+R	7	Rice-wheat	1.3 Mg/ha/ year	Jat <i>et al.</i> (2014)
Zero-till wheat (ZTW)	3	Wheat	9.7	Kumar <i>et al.</i> (2013)
No-till with residue cover	15	Wheat	19.1	Li <i>et al.</i> (2007)

time, reducing energy usage and environmental pollution, enhancing productivity and increasing farmers' income (Kumar *et al.* 2013; Das *et al.* 2014, 2016, 2018).

Water use and efficiency: The provision of sufficient quantities of clean water is an essential ecological service to agro-ecosystems, and agriculture accounts for about 70% of global water use (WHO 2003). Water availability in agro ecosystems depends not only on infiltration and flow, but also on soil moisture storage, another type of ecosystem service (Power 2010). About 80% of agricultural water use comes from rainfall and stored as soil moisture (~green water). The supply of surface water and groundwater (~blue water) inputs to agriculture through irrigation are indispensable in some parts of the world. With climate change, increased variability of rainfall is predicted to lead to greater risk of drought and flood, while higher temperatures will increase water demand. On-farm management practices that target green water, can significantly alter these predictions of water shortages (Rost *et al.* 2009, Power 2010). Conservation agriculture improves water productivity by enhancing infiltration, reducing soil evaporation and increasing soil water holding capacity for subsequent stomatal transpiration (Dillaha *et al.* 2010). He *et al.* (2009) reported that greater final infiltration rate in the plots under NT was probably owing to residue retention on the surface, less disturbance to the continuity of water conducting pores and increased aggregate stability. Das *et al.* (2018) observed that the permanent broad bed with residue and permanent narrow bed with residue in a CA-based maize-wheat cropping system resulted in higher water-use efficiency and accumulation of more carbon in soil with higher sequestration potential, besides giving sustainable production over the years. In north-western Canada, Arshad *et al.* (1999) demonstrated that steady-state infiltration rate was 60% greater for no-tillage than for conventional tillage after 12 years. Since the early 1970s, there have been steady depletions in ground water table in north-western Indo-Gangetic Plains (IGPs), which has accelerated alarmingly in recent years (Humphreys *et al.* 2010). Sapkota *et al.* (2015) reported that in rice-wheat production system, direct-seeded rice with retention of previous wheat residue led to 55% more water saving than puddled transplanted rice. They observed that increased water productivity in ZT-based production systems was mainly due to requirement of less water to produce same or even more than CT-based production systems and one pre-sowing irrigation for wheat germination could be saved under ZT by utilizing residual moisture after rice harvest. In general, 20-25% savings in irrigation water can be achieved from the ZT practice for wheat in IGP. Bhale and Wanjari (2009) reported an increase in available water content under conservation tillage, particularly in the surface horizon due to improved soil structure and crop residue mulch, which increased consumptive use of water by crops and improved water use efficiency.

Carbon sequestration and climate regulation

Carbon sequestration: Carbon sequestration implies

transforming atmospheric CO₂ into long-lived pools and storing it securely, so it is not immediately re-emitted (Lal 2007). One of the most beneficial aspects of conservation agriculture is its ability to increase soil carbon (Table 2) compared with traditional tillage-based crop production systems (Dillaha *et al.* 2010). In general, soil organic carbon (SOC) content increases with an increase in the quantity of residue returned to soil (Duiker and Lal 1999) and returning residues to soil has converted many soils from sources to sink of atmospheric CO₂ by enhancing soil productivity. Intensive tillage practices in case of conventional agriculture increase the rate of oxidation of organic matter, which leads to release of CO₂ to the atmosphere resulting in greenhouse effect. High carbon sequestration has been given as one of the credits of no-tillage. There are reports (Lal *et al.* 2007, Bhattacharyya *et al.* 2012, Das *et al.* 2013, Bhattacharyya *et al.* 2015, Das *et al.* 2018) that carbon sequestration can be achieved to the tune of 367–3667 kg CO₂/ha/year due to no-tillage. Increased soil C sequestration improves soil aggregation, which results in increasing available soil moisture storage capacity and that in turn can be helpful for better plant growth and development. Several studies (Blanco-Canqui *et al.* 2005, Thomas *et al.* 2007, Malecka *et al.* 2012) have indicated that the introduction of no-tillage systems leads to improved soil nutrient recycling, especially with respect to increased organic C closer to the soil surface. Higher organic C content provides greater aggregate stability as well as improves soil health in case of conservation tillage system (Bhattacharyya *et al.* 2013). According to Hillel and Rosenzweig (2009), conversion to no-till farming increases SOC, which varies from 0.1 to 0.7 Mg/ha/year. Thomas *et al.* (2007) reported that amount of organic C was greater in NT practice than CT in 0-10 cm depth of a Luvisol in a semi-arid, subtropical environment

Table 2 Carbon sequestration/accumulation in conservation agriculture (CA) and conventional tillage (CT) treatments

Conservation/ zero tillage	Crop	Study duration (Years)	Depth (cm)	Increase in C sequestration/ accumulation over CT (%)	Reference
ZT	Rice- wheat	4	0-5	11.0	Bhattach- aryya <i>et al.</i> (2012)
PBB+R	Maize- wheat	3	0-30	19.4 [with C- sequestration potential (CSP) of 5.59 Mg/ha]	Das <i>et al.</i> (2018)
ZTDSR/ZTM	Rice- maize	5	0-30	25.8	Singh <i>et al.</i> (2016)
ZT	Wheat	12	0-10	17.7	Thomas <i>et al.</i> (2007)
ZT	Barley	7	0-5	26.1	Malecka <i>et al.</i> (2012)

in southern Queensland, Australia. They also opined that greater organic matter application close to the soil surface under NT practice is beneficial to soil chemical and physical status and crop production in the long run. Das *et al.* (2018) reported that in a CA-based maize-wheat cropping system, the practice which involved permanent broad bed with residue (PBB + R), resulted in highest SOC pool at 0–30 cm soil layer, which was considerably higher than that in CT. This system showed maximum carbon sequestration potential. Bhattacharyya *et al.* (2012) reported that zero tilled (ZT) soils stored about 11% higher total soil organic carbon (SOC) than conventionally tilled (CT) plots (12 g/kg bulk soil) after 4 years of rice-wheat cropping in the 0 to 5 cm soil layer. Conservation practices and management decisions, such as no-tillage, minimum tillage, maintaining a high-residue surface cover, use of cover crops, implementing a more permanent cover such as grasslands, or introducing a forage crop such as alfalfa into the rotation, can contribute to the mitigation of climate change by accelerating atmospheric carbon sequestration. Soil C sequestration is a building block of soil productivity that contributes to higher water holding capacity, better drainage, higher cation exchange capacity, and better storage of nutrients, which are key factors of soil productivity and long-term sustainability (Delgado *et al.* 2013).

Climate regulation: Agricultural activities and land use changes contribute to about one-third of total greenhouse gases (GHG) emissions and are the largest source of N₂O 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 N₂O 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. Intensive soil tillage accelerates the oxidation of organic matter and converts crop residues into CO₂, which is liberated to the atmosphere contributing to the greenhouse effect and global warming. Increased carbon sequestration through residue retention can be a key practice for climate change adaptation. Conservation tillage practices decrease the exposure of un-mineralized organic substances to the microbial processes, thus reducing SOM decomposition and CO₂ emission. Flooded rice production contributes to nearly 15% of total global CH₄ emissions. Due to continuous flooding in rice field, anoxic condition arises, which leads to release of CH₄ gas known as methanogenesis. Yan *et al.* (2003) reported that alternate wetting and drying can effectively reduce CH₄ emission from rice field. This, however, can increase N₂O emission concurrently (Palm *et al.* 2014), which may serve as an offset partially for its wider recommendation. Direct seeded rice (DSR) has an enormous potential to reduce CH₄ 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

potential (GWP) per unit of grain yield (GHG intensity) compared to TPR, while in wheat, the same was observed in ZTW + neem oil coated urea treatment. Among different rice-wheat treatments, DSR-ZTW and DSR-RR+ZTW had significantly lower GHG intensity, indicating adoption of DSR followed by ZTW could significantly reduce GWP per unit of crop yield. Sapkota *et al.* (2015) reported higher CH₄ emission from rice in puddle transplanted field with continuous flooding compared to direct seeded production system (50–250 mg CH₄/m²/d in puddle transplanted vs. <50 mg CH₄/m²/d in direct seeded rice). There is no clear response on the effects of NT or RT compared to CT on N₂O emissions (Snyder *et al.* 2009). With NT, residues are returned to the soil resulting in surface mulches which may lower evaporation rates and hence increase soil moisture and increase labile organic C (Galbally *et al.* 2005) and consequently increase N₂O emissions compared to CT (Palm *et al.* 2014). Rochette (2008) concluded that N₂O emissions only increased in poorly-drained and fine textured agricultural soils under zero tillage located in regions with a humid climate, but not in well-drained aerated soils. The conservation agriculture technologies such as ZT with residues, laser land leveling, direct drilling into the residues, direct-seeded rice, brown manuring with *Sesbania*, un-puddled mechanical transplantation of rice, raised bed planting, crop diversification, and associated component technologies like site specific nutrient management provide opportunities for saving on inputs, improving resource-use efficiency and mitigating GHG emissions and climate change adaptation.

Energy use and efficiency: Reduction of energy requirement is possible by reducing number of tillage operations by adoption of conservation tillage (Table 3). According to Kour *et al.* (2011), conservation tillage could offset as much as 16% of world-wide fossil fuel emissions and can slow or prevent the loss of organic C in soil. On an average, by adopting ZT for land preparation and crop establishment in rice-wheat system of the IGP, farmers could save 36 l diesel/ha (Erenstein and Laxmi 2008). Saad *et al.* (2016) studied the energy auditing in CA-based maize-wheat-mungbean system and found that ZT bed planting with wheat and maize residue retention could be a substitute of the conventional agricultural system for adoption in maize-wheat-green gram cropping system in the irrigated north western Indo-Gangetic Plains. Kumar *et al.* (2013) showed that ZT improved the operational field capacity by 81%, specific energy by 17% and the energy usage efficiency by 13% as compared to CT. A study conducted by Parihar *et al.* (2018) showed that ZT and PB plots consumed lower energy (7 years average) in land preparation (49.7–51.5%) and irrigation (16.8–22.9%) compared to CT. They also reported that CA practices with diversified maize-based rotation (Maize-wheat-mungbean) could be a feasible alternative to attain high energy-use efficiency, biomass productivity and bio-energetics in north-western India and other similar agro-ecologies of South Asia.

Preventing erosion: It is well established that soil

Table 3 Energy use comparison between conservation agriculture (CA) and conventional tillage (CT)

Conservation/zero tillage	Use efficiency/ saving of energy in CA over CT		Reference
	Parameters	Increase or saving (%)	
Zero tillage (ZT)	Fuel saving	75.0	Erenstein and Laxmi (2008)
	Saving in tractor operational time	81.0	
ZT	Saving in input energy	12.6	Mishra and Singh (2012)
	Output energy	27.9	
ZT	Operational field capacity	81.0	Kumar <i>et al.</i> (2013)
	Specific energy	17.0	
	Energy-use efficiency	13.0	
ZT- raised bed (40 cm bed and 30 cm furrow)	Saving in input energy	8.0	Saad <i>et al.</i> (2016)
	Energy saving in land preparation	91.0	
	Energy saving in irrigation	38.0	
ZT permanent bed (40 cm bed and 30 cm furrow)	Energy saving in land preparation	49.7-51.5	Parihar <i>et al.</i> (2018)
	Energy saving in irrigation	16.8-22.9	
	Energy-use efficiency	13.4-17.1	

erosion can negatively impact many factors, such as soil fertility, nutrients, soil organic matter, soil quality, and water holding capacity, which can lead to decreased soil productivity (Bakker *et al.* 2004). Conservation agriculture owing to its principle of residue retention, protect soil from the abrasive action of water and wind. Lal *et al.* (2007) opined that NT technologies are very effective in reducing soil and crop residue disturbance, moderating soil evaporation and minimizing erosion losses. More stable aggregates in the upper surface of soil result in higher total porosity. Conservation tillage practices such as NT and minimum tillage (MT) can protect the soil from wind and water erosion. Comparison of plots after 16 years of continuous tilled and no-till treatments on the Loess Plateau of China have provided evidence that reduced soil disturbance and increased residue retention under no-till have improved soil physical structure, structural stability and water infiltration (He *et al.* 2009). Similarly, Delgado *et al.* (2013) reported that good management and implementation of sound conservation practices, such as return of crop residue to the soil, minimum tillage and cover crops, provide the key benefit of contributing to the maintenance of soil cover and reduction of soil erosion. Dabney *et al.* (2004) observed that no-till management reduces soil erosion relative to chisel/disk-tillage in a silt loam soil (Glossic Fragiudalf) used for corn production in

northern Mississippi for five to ten years. The surface water contamination is very less under ZT because of drastic reduction in erosion and quick break down of herbicides into harmless compounds by soil organisms.

Nutrients accumulation and cycling: Efficient utilization of nutrients plays a vital role for increasing agricultural production. Proven is that the soil chemical properties of the surface layer are generally more favourable under no-till than tilled soils. Delgado *et al.* (2007) reported that conservation rotations (e.g. cover crops, leguminous crops, deep-rooted crops) could increase system nitrogen-use efficiency, subsequent crop yields, and recover nitrate from the lower soil profile that had been leached from the previous shallow-rooted crops. Jacobs *et al.* (2009) observed that minimum tillage (MT) improved aggregate stability and increased the concentrations of soil organic carbon (SOC) and N within the aggregates in the upper 5–8 cm soil depth after 37–40 years of tillage treatments. Bhattacharyya *et al.* (2013, 2019) and Das *et al.* (2013) reported similar improvement in SOC and N status from a CA-based maize-wheat system in IGP of India. A study conducted in Poland showed that a total of 7 years of tillage resulted in higher contents of soil organic C (SOC), total N, available K and Mg under reduced tillage (RT) and NT conditions than under CT in the 0–5 cm soil layer (Malecka *et al.* 2012). Thomas *et al.* (2007) found higher organic matter (organic C and total N) and exchangeable K under NT than CT and RT in Luvisol in southern Queensland, Australia. The NT could lead to accumulation of higher $\text{NO}_3\text{-N}$ in soil when stubble was burnt or removed (Radford *et al.* 1992). Therefore, suggestion was made that stubble retention should be practised with NT to reduce potential leaching of $\text{NO}_3\text{-N}$ in soil.

Biodiversity: Biodiversity is often considered fundamental to the delivery of ecosystem services and especially the stability of delivery of these ecosystem services (Naeem *et al.* 2012). The CA practices of NT and residue retention are key to maintaining or increasing soil organic matter in the topsoil which in turn provides energy and substrate for soil biota activities and their contributions to soil structure and nutrient cycling, as well as many other soil processes and ecosystem services. Soil microbial biomass, composed primarily of bacteria and fungi, is an indicator of soil quality due to its role in decomposition, nutrient cycling rates and patterns, formation of soil organic matter (SOM), and soil aggregation (Palm *et al.* 2014). There are several reports of improvement in microbial biomass C (MBC) and associated microbial activities in soil under CA due to improved microclimate and greater availability of C resulting from less disturbance of the soil, and retention of crop residues on the soil surface (Liu *et al.* 2014, Singh *et al.* 2018). Larger SOM reflects better soil aeration and greater dehydrogenase (DHA) activity because of less tilling and the addition of more root exudates in CA-based crop management and rotations than under CT (Madejon *et al.* 2007). Usually higher populations of bacteria, actinomycetes and fungi are observed in zero till

sowing with happy seeder. Earthworms carry out important roles in soil-forming process and provide ecosystem services (Wright and Jones 2003). They improve soil structure, porosity, nutrient cycling by their movements through soil, breaking down litter and binding soil particles with their excretions and enhance plant growth. They are known as 'nature's plough' and 'ecosystem engineers' (Hale *et al.* 2008). Intensive cultural practices are often associated with decrease in their populations. Karlen *et al.* (2013) observed that intensive deep ploughing with a mouldboard plough had a significant negative effect on soil health and quality. Briones and Schmidt (2017) conducted global meta-analysis and found that minimum soil disturbance (e.g. no-tillage and conservation agriculture) significantly increased earthworm abundance (mean increase of 137% and 127%, respectively) and biomass (196% and 101%, respectively) compared to conventional ploughing. Earthworms are reported to bioaccumulate high concentrations of heavy metals like Cd, Hg, Pb, Cu, Mn, Ca, Fe and Zn in their tissues by ingesting them with soil and thus they may be regarded as bio-indicators for evaluation of soil health.

Several cultural ecosystem services such as cultural, intellectual and spiritual inspiration; recreational experiences (including ecotourism); scientific discovery (Fig 1) are enlisted by Millennium Ecosystem Assessment (2005). Conservation agriculture has hardly or little specific and direct relevance to these ecosystem services.

Conclusion

Conservation agriculture (CA)-based systems play a vital 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 in accordance with UNDP Sustainable Development Goals. They 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. Studies should be focused on CA-based agricultural practices specific to location, cropping system and cropping season and how the ecosystem services are modified by them. Also, there should be clear comparisons on ecosystem services generated by conservation and conventional agriculture over a wide range of soil and climatic conditions so that assessment of CA can be done better. Doing this can help CA to be adopted widely and sustain the natural resources and productivity on a long-term basis.

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