Conservation Techniques for Modern Agriculture

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Conservation Techniques for Modern Agriculture

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ABSTRACT

Shrinking of natural resources and deterioration of soil health and fertility due to practice of input-intensive conventional agriculture for meeting the need of ever increasing population has become a great concern in the present century. To combat against this detrimental fate inclusion of conservation technologies in modern agriculture is a promising alternative strategy encompassing three broad principle-minimum soil disturbance, diversified crop rotation and adequate soil cover through residue retention or by growing green manuring crops. This review article deals with the principle, processes and advantages of conservation agriculture (CA) over conventional agriculture based on existing case studies. The CA aims to conserve, improve and make more efficient use of natural resources along with reduction in cost and securing better cop production. The CA was found effective in betterment of nutrient cycling, soil fertility, aggregation; maintenance of soil moisture, aeration and reduction of risk of soil erosion and disease-pest infestation. On an overall basis inclusion of conservation techniques in modern agriculture is a win-win strategy as it capable to meet the necessary demands as well as provides future sustainability. Although adoption of CA is increasing globally, in some regions it is either slow or non-existent. Therefore, for overcoming knowledge gaps more research in the different parts of the world is of utmost importance. On-farm participatory research, demonstration trials, sustained governmental policies and institutional support may play a key role in the augmentation of practice of CA through the provision of required services for farming communities and certain incentives.

Key words : Conservation Agriculture, Zero/No Tillage, Residue Retention, Crop Rotation, Sustainability

Introduction

Despite of using improved varieties, adequate supply of fertilisers and plant protection chemicals modern agriculture is facing a serious problem of the decline in crop yield and degradation of natural resources particularly soil quality (Montgomery, 2007). Hence, to meet the food demand of the ever-growing population employment of an alternative production system is highly needed which could maintain high yields coupled with the maintenance of ecological sustainability. Food security is a multidimensional theme, which directly governs the quality of life of poor and needy

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people as well as economy of a country. The agriculture sector is the most important and effective sector able to provide sustainable solution to overcome the food crisis. In this regard management of critical inputs is crucial for a higher food production but mitigation of natural resource degradation is also important for long run. The conservation agriculture (CA) is a promising new paradigm in 21st century to achieve a base for sustainable agricultural production (Friedrich et al., 2012). The CA aims to conserve, improve and make more efficient use of natural resources through integrated management of soil, water and biological resources combined with external inputs (Meena et al., 2013,2015a,b; Singh et al., 2014; Kumar et al., 2015). The CA is basically a concept of resource-saving agricultural crop production also capable of enhancement of natural and biological processes below and above the ground, contributing towards environmental conservation as well as enhancement and sustenance of agricultural production. CA encompasses three broad principles, viz.(i) minimum mechanical soil disturbance involving reduced tillage (RT) or zero till/ no tillage (NT) and direct seeding; (ii)diversified rotation of efficient and economically viable crops that significantly contribute to soil biodiversity maintenance, improvement of soil fertility, nutrient cycling and suppression of disease pests also; and (iii)providing effective soil cover through residue retention or growing green manures to mitigate soil erosion and to improve soil fertility and soil functions (Kassam et al., 2009). Overall improvement of agriculture through improving water infiltration, groundwater storage, soil aggregation and reducing soil compaction as well as soil erosion could be achieved through CA as it is found efficient in promotion of soil biological activities, enriching in soil organic carbon (SOC), moderating soil temperature and weed suppression. Apart from these advantages it also helps to reduce production cost, saves time, increases yield through suitable rotation.

Why to practise Conservation Agriculture?

Intensive agriculture through conventional way is responsible for emergence of second-generation problems of soil degradation, soil organic matter depletion and deficiencies of several macro and micro nutrients viz. N, P, K, S, Zn, Fe and Mn which might be attributed to over-mining of nutrients from soils (Ladha et al., 2000; Tiwari, 2002), decline in the groundwater table as well as deterioration of groundwater quality (Humphreys et al., 2010), sodicity and salinity (Tiwari et al., 2009), herbicide resistance, shift in weed flora and pest populations (Hobbs et al., 1997). The major problems associated with input intensive conventional agriculture are :

- Intensive tillage operations for the preparation of fine seedbed for sowing to ensure proper seed germination, improved moisture conservation, weed control and other pests and also application of organic and inorganic fertilisers
- Continuous mono cropping system which led to the degradation of soil fertility

- No recycling of crop biomass after harvesting, resulting in mining of nutrients
- Overexploitation of groundwater resources
- Burning of crop residues after harvesting
- Indiscriminate use of chemical fertilisers leading to decreasing factor productivity
- Energy-intensive farming

Thus, disruption of sustainability of soil as well as ecosystem through recent conventional practices of agricultural systems has become a serious threat now a days as problems regarding land and water are becoming prominent are under this systems day by day. Land and water are two vital natural resources essential for the existence of life. Land is a limited, finite, inelastic and a highly valuable natural resource which provides food, feed, fuel and fibre besides providence of other crucial services of the environment. Reduction in per capita land availability for agricultural from 0.48 ha estimated in 1950 to 0.15 ha in 2000, and likely a further reduction of 0.08 ha by 2020 due to rising industrialisation and urbanisation is a serious concern for India (Pande et al., 2012). On the other hand, number of persons per ha of the net-cropped area were three in 1951 and six in 2000 which could rise to eight in 2025 in India. In present days, India having only around 2.4% of global land area acquires more than 1.2 billion population, accounting about 18% of world population which could become 1.4 billion by 2025 and 1.7 billion by 2050 AD and to meet their demand of food the requirement of annual supply of food grains would be of nearly 380 and 480 million tonnes, respectively (Yadav and Singh, 2000). Hence, it is a big deal to meet these necessities through practise of appropriate cultivation systems which can improve the input (land, seed, water, labour, fertiliser and energy) use efficiency of advanced crop management technologies along with the maintenance of environmental sustainability. Thus, to achieve this goal adaptation of CA is of utmost importance in the smart era of the recent world due to the following advantages over the conventional agriculture :

- CA is very economical for farmers which helps in cost reduction of fuel and machinery and saving time for operations which allow development of other farming and non-farming harmonizing activities.
- It is very resilient to technical possibilities for sowing, fertilizer application, and weed control (helping in carrying out of operations within time).
- It is important to increase productivity and greater stabilization of productivity in long-term effect.
- It conserves the soil and water against water and wind erosion.
- It increases the agronomic efficiency (AE) and production efficiency (PE).
- It increases the nutrient use efficiency (NUE).
- It increases water use efficiency (WUE) or water productivity and water

economy in dryland areas where water scarcity is a serious problem.

- CA also able to improve yearly input organic matter (OM), controlling losses of OM through soil erosion, thermal decomposition and mineralization which indicates its potential to sequester carbon in soil.
- The CA also promotes higher biological activity and diversity of microbes and maintains soil resilience.
- It is also found effective in maintenance of soil moisture availability and providing resistance against water and wind erosions of soil.

Difference between Conventional and Conservation Agriculture

Conventional agriculture involves extensive use of various tillage operations and management practices for land for preparation of seedbed and weed control i.e., mould-board or animal drawn plough or harrowing, drilling, cultivator, etc. Repetition of these tillage and inter-culture operations results in break down of soil structure, clogging of pore and disruption of pore network leading to adverse soil conditions susceptible to erosion and degradation which requires heavy cost of time, fuel, and labor. Exposure of soil due to conventional tillage facilitate aeration and microbial activities causing rapid oxidation of OM resulting a lower concentration of soil carbon which also affects aggregation and soil structure. At the same time, OM oxidation contributes in the phenomena of CO_2 addition into atmosphere which is also responsible for global warming or climate change (Grace et al., 2003). The CA involves specific agronomic practices such as minimum soil disturbance or use of zero tillage or no tillage (NT), soil cover with crop residue or green manure (mulching), and diversified crop rotation which are notably profitable and effective in several aspects for farm community as it saves fuel, time, and labor as well as it promotes soil structure, porosity, soil organic matter (SOM) content, soil aggregation, water-holding capacity and nutrient availability. Again, the rate of SOM decomposition is relatively fast in the tropics than that of subtropical and moderate climates because of the higher temperature (Steiner, 2002). Practice of mulching under CA reduces the thermal decomposition of SOM by maintaining soil temperature. Major comparisons between conventional and conservation agriculture are presented in Table 1.

Table 1. Comparisons of features of conventional and conservation agriculture

Conventional agriculture	Conservation agriculture
Cultivation of land with the help of machinery, using science and technology	Minimal disturbances to nature during crop grown processes
Excessive motorized tillage and leads to deterioration of soil pores or structure	No-tillage or considerably reduced tillage (bio-tillage) increases porosity
Higher wind speed and water erosion	Lower wind speed and water erosion
Removal of crop residue from field or burning or uncovered surface	Soil covered with crop residue permanently covered

Low water infiltration	High rate of infiltration of water
Decrease water-holding capacity	Enhance water-holding capacity
FYM/composts added from outside or green manuring (incorporated)	Use of in situ organics/composts or brown manuring/cover crops (stubble retention)
Due plowing established weeds are kills but also stimulates more weed seeds to germinate	Weeds create problem during early stage of implementation but reduce with time
Soil become very compacted due to more use of heavy traffic or machinery	Control of traffic, there is less compaction

(Adopted from Sharma et al., 2012 ; Choudhary et al., 2016)

History of Conservation Agriculture

The first ploughing or tilling of soil was dated back nearly 3000 BC at Mesopotamia (Hillel, 1998). Tillage is a vital component of agronomic practices which has been modified through the course of time (Table 2).

Table 2. Historical evolution of conservation agriculture

Year	Development	Source
1930	Great dust bowl and start of CA in the USA	Hobbs *et al.* (2008)
1940	Development of direct seeding machinery, first no-tillage sowing	Friedrich *et al.* (2012)
1950	First successful demonstration of no-tillage, crops direct sowing in the USA	Harrington (2008)
1960	No-tillage commercial adopted in the USA	Lindwall and Sonntag (2010)
1962	Registration of paraquat as first herbicide for broad-spectrum control of weed	Lindwall and Sonntag (2010)
1962	Long-term experiment on no-till was started in Ohio, USA	Perszewski (2005)
1964	First no-tillage experiments in Australia	Barret et al. (1972)
1966	Demonstration trails on direct seeding system in Germany	Baumer (1970)
1968	First no-tillage trail in Italy	Sartori and Peruzzi (1994)
1970	First time reported about herbicideresistance resistance development in weeds	Ryan (1970)

1974	First time no-tillage demonstrated in Brazil and Argentina	Friedrich *et al.* (2012)
1975	Book on CA entitled “One straw revolution” by Fukuoka	Fukuoka (1975)
1980	CA introduced and demonstrated on farms in subcontinent	Harrington (2008)
1981	The first national-level conference on no-tillage held in Ponta Grossa, Parana, Brazil	Derpsch (2007)
1990	Development and commercial release of reliable seeding machines.	Lindwall and Sonntag (2010)
1990	CA introduced in India, Pakistan, and Bangladesh	Friedrich *et al.* (2012)
1992	CA research started in China	Derpsch and Friedrich (2009)
1996	Launching of commercial transgenic glyphosate-resistant soybean	Dill (2005)
1998	Identified resistant weed (rigid rye grass) to glyphosate	Powles et *al.* (1998)
2001	First World Congress on Conservation Agriculture, Madrid, Spain	www.ecaf.org
2002	Introduction of no-tillage systems in Kazakhstan	Derpsch and Friedrich (2009)
2003	2nd World Congress on Conservation Agriculture, Iguassu Falls, Brazil	www.febrapdp.org.br
2005	3rd World Congress on Conservation Agriculture, Nairobi, Kenya	www.act.org.zw/congress, Derpsch and Friedrich (2009)
2008	A technical workshop on investing in sustainable crop intensification: the case of improving soil health. FAO, Rome (Italy)	www.fao.org
2009	4th World Congress on Conservation Agriculture, New Delhi, India	www.icar.org.in
2011	5th World Congress on Conservation Agriculture and 3rd Farming Systems Design Conference (WCCA5 and FSD3), Brisbane Australia	www.wcca2011.org
2014	6th World Congress on Conservation Agriculture (WCCA 6), Winnipeg, Canada	www.ctic.org/wcca
2015	The limit lessons learned from long-term conservation agriculture	Thierfelder et al. (2015)
2016	Role of conservation agriculture to mitigate the climate change	Powlson *et al.* (2016)

(Adopted from Choudhary *et al.* 2016)

The term conservation agriculture (CA) was used first time by Edward H. Faulkner in the 1930s in a manuscript called Plowman's Folly (Faulkner, 1943). With time, use of minimum tillage or zero tillage for conserving the soil and soil covering with crop residues gained popularity. Conservation of soil and water through these practices was considered as conservation agriculture (Friedrich *et al.*, 2012).

Introduction of zero tillage (ZT) was made in the early 1970s in Brazil for reducing severe water erosion (Derpsch, 2001). Rise in fuel prices and problems regarding severe erosion were additional reasons during the 1970s that encouraged farmers towards resource-saving agricultural systems. In such condition, adoption of CA by commercial or large farmers was quite natural to reduce the drought-driven soil degradation along with the saving of fuel (Haggblade and Tenbo, 2003).

Conservation Agriculture: Principles and Advantages

According to Food and Agriculture Organization (FAO), "Conservation agriculture (CA) is an approach to managing agricultural ecosystems for enhanced and sustained productivity, improved returns, and food security while preserving and enhancing the resource base and the environment." CA practices include the following features (Figure 1) :

i) Minimum soil disturbance
ii) Diversified crop rotations
iii) Crop residue retention on the soil surface or soil covering with crop organic materials.

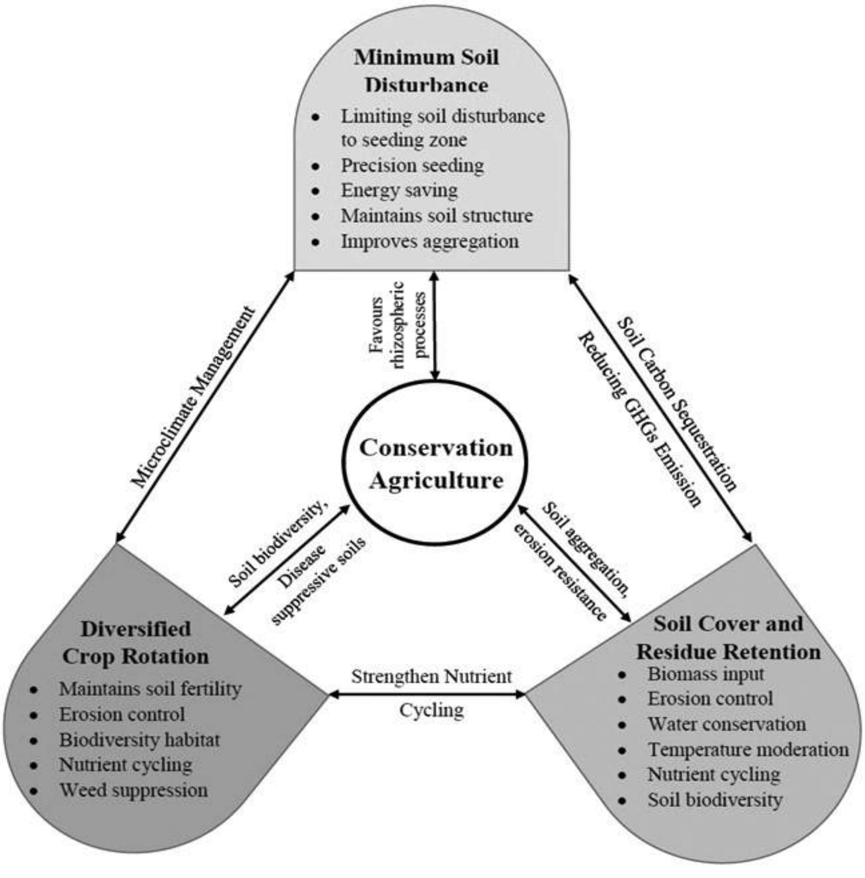

Figure 1. Three broad principles of conservation agriculture and their inter-relations

Therefore, CA could be considered as an agronomic practice that comprises reduced tillage (RT) or no-tillage (NT) or minimum tillage, diversified rotation of crops along with stable cover to soil with organic materials or by retaining residue of crops or growing green manure crops as cover crop. The above mentioned principles are said to be common to systems of CA. However, components which are specific in nature such as selection of implements for farm, methods of establishment, rotation of crops with pulses or legumes, management of fertility in soil, management of mulch and residue of crops, etc., are varied according to environment. Hence, the CA principles are globally applicable to all agricultural landscapes and land uses with locally adapted practices. The CA is potent enough to be applied in various types of agro-ecological zones and helpful enough to maintain food security for a considerable number of smallholder residents of developing countries (Sayre, 2000; Derpsch and Friedrich, 2009). The sustainability of natural resources such as soil, water, vegetation, and biodiversity could also be managed effectively by CA practices in future prospects. Apart from these, CA have potential to mitigate the detrimental effects of climate change by optimizing crop productivity, reducing greenhouse gas (GHGs) emissions and maintaining a coordination among agricultural, monetary, and ecological benefits (Giller *et al.*, 2009; FAO, 2011a; FAO, 2014a).

i. Minimum Soil Disturbance

Seeding with minimal disturbance along with sufficient residue retention facilitates soil and water conservation by controlling erosion of soil, improving soil aggregation which results in better soil biological activity, improved soil biodiversity, soil C sequestration also. No tillage (NT) system is also found effective in betterment of water infiltration, soil–water-use efficiency and resilience against drought stress. Minimum soil disturbance helps in maintenance of optimum aeration in root-zone, organic matter oxidation as well as porosity for water movement, retention, and release (Kassam and Friedrich, 2009).

Seeding with minimum soil disturbance refers to opening the slot with the help of khurpi or other equipment and putting the seed in it or direct seeding or broadcasting of seed. The disturbed area must be less than 15 cm wide or less than 25% of the cropped area (whichever is lower) (FAO, 2014b).Direct seeding deals with farming systems in which seeds and fertilizer are put directly into undisturbed soil in a single field operation or two separate operations of fertilizing and seeding. Fertilizers and seeds are generally placed through strips or slots of small width that are opened by suitable equipment. After seeding these slots should be well covered by mulch or green manure crops and no loose soil should be visible on the surface (Figure 2). Inclusion of precise land levelling with laser land leveller; slashing or rolling the weeds, previous crop residues, or cover crops; or spraying herbicides for weed control could be made during land preparation for seeding or planting under no-tillage. Crop residues could be either retained entirely or to a suitable amount to guarantee the complete soil cover, and application of fertilizers and amendments are made either through broadcasting on the soil surface or during seeding (Roper *et al.*, 2013).

Fig. 2. Minimum soil disturbance along with soil cover under conservation agriculture (Source:http://agritech.tnau.ac.in/agriculture/agri_tillage_modernconcepts.html)

No-tillage (NT) or minimum tillage is notable agronomic practice following such criteria of minimum soil disturbance through which seed and fertilizer could be put into the soil without hampering various soil physical properties such as soil structure, aggregation, aggregate stability, and porosity. In the past, mineralisation of nutrients facilitated by soil tillage raised the soil fertility to a little extent (Dumanski *et al.*, 2006), but intensive tillage for long-term basis results in soil erosion and degradation (Donovan and Casey, 1998). Therefore, ZT or minimum soil disturbance was found effective to alleviate the negative impact of excessive tillage as well as soil erosion (Li *et al.*, 2007).Thus, minimum or no-tillage associated with CA not only improves water permeability and aeration of soil by reducing subsurface compaction

(Sayre and Hobbs, 2004) but also provides niche of diverse microbial populations.

ii. Diversified Crop Rotation

The objective of diversified rotation of crops is to complement natural soil biodiversity and create a healthy soil which is naturally aerated, retains and supplies plant-available water, augments nutrient cycling, and denatures and filters pollutants. Crop rotations and associations can be implemented as cropping sequences. Inclusion of minimum three different agricultural crops is needed in effective rotation. However, cyclical cropping of wheat, maize, or rice is not suitable in this purpose, but rotation is recorded where practiced (Kassam *et al.*, 2015).

Growing of various crops in a particular area in sequenced season is referred to as crop rotation. Monocropping or growing of same crop in same place for many years deteriorates the soil health which could be recovered by the practice of effective crop rotation as it reduces allelopathic effect of crops and improves crop productivity, soil fertility and quality. Balanced crop rotation such as incorporation of legumes or pulse crops in rotation curbs the infestation of various pest and disease caused by proliferation of harmful bacteria, viruses, and fungi as well as allelopathic effect of various crops which is harmful for beneficial crops. It also favours abundance of beneficial soil microorganism that can help keep pest and disease problems in check. Rotation of crops could also help in interruption of the life cycles of different weeds resulting in a depletion in overall weed population. Hence, along with providing greater biodiversity crop rotations also reduce the need as well as cost of pesticides and herbicides to some extent. Crop rotations not only offer a diverse "diet" to the soil microorganisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients and water. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop can be used by the deep rooted crops included in the rotation. Thus rotation of crops functions as biological pumps. A typical increase in yield of about 10% under crop rotations over monoculture might be due to these factors (Vanlauwe *et al.*, 2014). On the other hand, diversified rotation of crops also results in a diverse soil flora and fauna, as the roots of diverse flora excrete various organic substances that attract several types of bacteria and fungi, which in turn play an important role in the transformation of these compounds into available plant nutrients (FAO, 2015).

Effects of Crop Rotation

- Higher diversity in plant production and thus in human and livestock nutrition.
- It reduces the risk of pest, diseases, and weed infestations.
- Diversified crops are grown which enhance root penetration, porosity, moisture, and nutrient recycling equal transformation in soil profile.
- Enhance biological N_2 fixation through certain plant–soil biota symbionts and improved balance of N/P/K from both organic and mineral sources.
- Increased humus formation.

iii. Maintaining Soil Cover and Residue Retention

Maintaining soil cover permanently or semi-permanently with crop residue is essential to conserve the soil and moisture, to provide enough moisture during adverse or drought conditions. Soil cover with crop residue (Figure 3) protects the soil from erosion and run off by preventing the physical impact on soil from wind and rain. There are three types of soil cover (i) 30–60 %, (ii) > 60–90 %, and (iii) > 90 % cover of ground, without delay following the direct seeding process. CA does not include area <30% soil cover. Soil cover should ideally be above 100% measured immediately after planting operation; ground cover of less than 30% is not considered as CA practice (Friedrich *et al.*, 2009; Kassam *et al.*, 2015). The residue cover can be improved by including a cover crop in the rotation cycle. Crop residues on the soil surface protect the soil by lowering erosion (Boulal *et al.*, 2011; Brouder and Gomez-Macpherson, 2014) and runoff (Thomas *et al.*, 2007). Soil cover moderates soil temperature, improves water infiltration and reduces evaporation from soil surface. Retaining crop residue and eliminating tillage improved infiltration and soil moisture content where potential evapotranspiration was high and water-holding capacity was low (TerAvest *et al.*, 2015).

Fig. 3. Soil cover through residue retention in maize field (Nickel, 2018)

Along with protecting organic matter-enriched topsoil against chemical and physical weathering crop residues undergoes decomposition themselves in situ and act as a source of biomass input too. Hence, generally a slow but gradual rise in soil carbon content could be observed under residue retention or incorporation (Das *et al.*, 2014).Crop residues provide a steady source of food in the form of organic matter from which the micro- and macro-organisms derive their energy. It also maintains and alters the microclimate of the soil that governs optimal growth and development of soil organisms as well as plant roots (FAO, 2014a,b). In an overall basis, maintaining soil cover by residue retention improves soil aggregation, soil biological activity and soil biodiversity and carbon sequestration (Ghosh *et al.*, 2010).

Advantage of Soil Cover

- Ease of infiltration in the soil and soil moisture retention during adverse or harsh conditions increase availability of plant nutrients.
- It provides energy and habitat for diverse soil biota, creation of channels for air and water, biological tillage and substrate for biological activity through the recycling of organic matter, and plant nutrients.
- Increases humus formation.
- Reduces the direct impacts of raindrops which causes soil crusting and splash erosion.
- Resultant reduction of runoff and erosion.
- Soil regeneration is higher than soil degradation.
- It provides better penetration, development of roots, and seedling growth.

Means and Practices for Effective Soil Cover

- Use of high-quality seeds for high yields as well as high residue production and good root development.
- Integrated management and reduced competition with livestock or other uses, e.g., grow cover crops as green manure which also serves as feed for animals and fodder crops in the rotation.
- Use of various cover crops, especially multipurpose crops, like biological N_2 fixing, soil porosity restoring, pest repellent, etc.
- Optimization of crop rotations in spatial, timing, and economic terms.
- “Targeted” use of herbicides for controlling cover crop and weed development.

Other Features of Conservation Agriculture

Integrated Nutrient Management (INM)

Inclusion of integrated nutrient management i.e. application of inorganic fertilizers along with organic manures, crop residue, and various composts in CA would be significantly effective for maintaining sustainability of soil health for the longer period of time. The main principle behind it should be to feed the soil rather than fertilizing the crop which ultimately reduce chemical pollution, improve water quality, and maintain the natural ecological health of the soil while along with optimizing crop productivity and economic returns (Vanlauwe *et al.*, 2014).

Integrated Disease and Pest Management

CA greatly depends on enhanced biological activity for controlling insect pests and other disease-causing soil microorganisms. Involvement of suitable crop rotations and other beneficial plant substances as well as chemical pesticides, herbicides, and fungicides in integrated pest management (IPM) under CA not only make it effective to control insect pest and disease problems but also reduce the use of agro-chemicals over time.

No Burning of Crop Residues

Crop residues which are the principal element of permanent soil cover should never be burnt or removed from the soil surface. Rather, plant residues should be left on the soil surface to protect organic matter-enriched topsoil from erosion which also helps in addition of fresh organic matter upon decomposition to. Burning not only contributes towards significant air pollution but also drastically augments soil carbon mineralization rates ultimately resulting in rapid depletion of soil organic matter and nutrients from the soil (Kumar *et al.*, 2015) (Figure 4).

Farmers in NW India and many parts of Eastern and Southern India often prefer to burn surplus CRs to establish next crops. Out of 89 MT of surplus cereal residues, rice and wheat constitute ~85%, which are burned on farm annually. Of total CRs burned globally, India contributes ~33.6%. In Punjab alone, ~20 MT of paddy and wheat residues out of whole 37 MT of residues are burned in situ every year, which leads to loss of ~8 MT of C equivalents to CO_2 load of ~29 MT/year and also loss of ~1×10^5 ton of N, besides thrashing of S and annihilation of favorable soil microflora (Choudhary *et al.*, 2013; Singh *et al.*, 2015; Kumar and Deka, 2017). Due to the burning of CRs, there is incidence of harmful effect on human/animals' health and road accident because of invisibility in NW India (Singh *et al.*, 2010). 1.0 ton of CRs on burning liberates 1515 kg CO_2, 92 kg CO, 3.83 kg NOx, 0.4 kg SO_2, 2.7 kg CH_4, and 15.7 kg non-methanogenic compound (Andreae and Merlet, 2001). These gases and aerosols consist of carbonic matters that have adverse impact on human health and act as the main source of climatic change. Estimated open field burning of CRs is ~25% of available residues. It is estimated that the emissions from field flaming of paddy/wheat straw in India were 110 Gg CH_4, 2306 Gg CO, 2.3 Gg N_2O, and 84 Gg NOx during 2000 (Gupta *et al.*, 2004). Besides, burning of CRs leads to loss of organic matter and 80% of N and S, 10–20% of other nutrients.

However, in some situations farmers need to think of the trade-off between removing residues to feed their animals and leaving them to feed the soil.

Fig. 4. Residue (stalks and stubble) burning after harvesting in the Indo-Gangetic plains responsible for GHGs emission. (Singh, 2019)

(source : https://www.downtoearth.org.in/news/agriculture/here-is-a-solution-for-crop-residue-burning-problem-66149)

Controlled Traffic of Heavy Machineries over Land

Principle of minimum soil disturbance of CA also involves significant reduction in number of tractor that passes over a given field as compared to conventional tillage systems. However, rise in bulk densities have been recorded under CA in several cases which could be corrected by limiting the use of heavy farm machinery when soils are wet and most prone to compaction. Thus, lower magnitude of soil compaction could be achieved through controlled traffic over land under CA.

Limitations for adaptation of CA

Despite of having several advantages there are numerous constraints to adoption of CA due to the following reasons:

- Initially high investment is required for purchasing of specialized sowing and/or planting implements, and requirement of technical knowledge for better management is short-term drawback of the conservation agriculture.
- Reduction in yield during initial years of adoption, higher cost of inputs,

higher labor for weeding, competition for crop residue between animal feed and mulching and its promotion as universal system without considering agroecological and socioeconomic conditions (Baudron *et al.*, 2012; Brouder and Gomez-Macpherson, 2013; Corbeels *et al.*, 2014; Giller et al., 2009; Valbuena *et al.*, 2012).

- A particularly important gap is the lack of knowledge on locally adapted cover crops that produce good biomass under the prevailing conditions.
- The success or failure of CA depends greatly on the flexibility and creativity of the farmer and extension and researchers of a particular location.

Future lines of work

To promote adoption of CA in India and other developing countries the following points should be kept in mind:

- Knowledge gap and lack of information are the main constraints to adoption of CA in most countries. Relevant, factual, locally appropriate, credible, and useful information are needed to create awareness and interest among farmers for which clear conceptions among farmers, researchers, technicians, and extension specialists regarding CA is the primary requisite.
- Conservation tillage has been found superior over conventional tillage under diverse conditions worldwide. Therefore, development and adaptation of the system locally is highly needed based on the specific environmental and socioeconomic conditions of each specific site. Knowledge regarding the soils not suitable for adoption of CA, specific constraints to applying the system and how to overcome these constraints are also crucial for better and successful implementation of CA.
- The socioeconomic factors and human dimensions should be kept in mind in its adoption. Apart from that additional constraints such as machineries, herbicides, adequate crop rotations, adequate green manure cover crops should also be considered.
- Assessment of profitability along with assessing agronomic yield is also important. Study of machinery costs; labour and tractor hours; timelines; economic returns; and other benefits are associated with this.
- Close interaction between government agencies, farmers, private sector, technology generators and disseminators and nongovernment organizations is needed in policy reform for broader acceptance and circulation of CA.
- Government endorsement must be involved for adoption of CA in the development of national and international policies for provision of numerous ecosystem services.
- Adoption of CA technologies could be appropriately promoted through payments for ecosystem services such as soil carbon sequestration and improvement of water use efficiency.

Conclusions

Degradation of natural resources particularly soil along with decline in crop yield is the most alarming issue as a result of long-term practice of conventional agriculture involving intensive tillage and higher inputs. In this smart era of agriculture in recent world, inclusion of conservation technologies would be a promising step towards achieving food security through higher productivity along with maintenance of sustainability of soil as well as environment for future days. Three broad principles of conservation agriculture (CA) are minimum disturbance of soil, diversified crop rotation and maintaining soil cover through residue retention or growing green manuring crops. Minimum soil disturbance was found effective in promotions of soil aggregation, infiltration, soil carbon stocks and microbial activity; maintenance of soil air and moisture and reduces soil erosion. Apart from these issues, zero, minimum or no tillage operations followed under CA lower the costs of fuel and labour to a significant extent. Suitable crop rotation of a concerned area would offer the provision of better planning of growing crops in sequence which helps in betterment of productivity, nutrient cycling and rejuvenation of soil fertility along with suppression of disease and pest attack. On the other hand, effective soil cover reduces risk of soil erosion as well as acts as a source of organic matter and nutrient addition into the soil. It also moderates the temperature of soil and improves soil biological activity. Hence, on an overall basis inclusion of conservation techniques in modern agriculture is a win-win strategy as it capable to meet the necessary demands along with the nourishment of natural resources. For exploring avenues of further opportunities and curbing down the knowledge gaps more research in the different parts of the world is highly needed. On-farm participatory research and demonstration trials are also crucial to accelerate the dissemination and adoption of CA. Favourable governmental policies and institutional support may play pivotal role in the promotion of CA through the provision of required services for farming communities and certain incentives.

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