The Pharma Innovation Journal 2022; SP-11(7): 2407-2414

www.ThePharmaJournal.com

The Pharma Innovation

**ISSN (E): 2277-7695**
**ISSN (P): 2349-8242**
**NAAS Rating: 5.23**
TPI 2022; SP-11(7): 2407-2414
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www.thepharmajournal.com
Received: 23-04-2022
Accepted: 26-05-2022

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# A review of the needs, challenges and policy implications of the conservation agriculture-based resource conservation technologies

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**Abstract**

Green Revolution has led to an improvement in the yield of crops manifolds but the sustainability in yield and soil quality is still a question. It has been reported since past years that conventional agricultural practices, being intensive are causing a decline in soil organic carbon, increase in cost of production, deterioration of natural resources and thus, affecting the crop yields. Conservation agriculture (CA) based resource conservation technologies (RCTs) being centred on three interrelated principles of no or minimum soil disturbance, permanent soil cover through cover crops or crop residues, and crop species diversification, in combination with good integrated crop and production management practices, provide a good scope for reducing the cost of production, saving water and nutrients, increment in yield of crops and crop diversification, improving the efficient use of natural resources and therefore, benefiting the environment and improved livelihood and food security. This review overviews the CA principles, its grounds, constraints in its adoption by the farmers and what can be done to remove the constraints.

**Keywords:** Conservation agriculture, resource conservation technologies, soil quality, crop diversification, crop residues

## 1. Introduction

Modern agriculture is aimed at achieving long-term yield gains through the use of improved seeds/cultivars, chemical fertilisers, pesticides, irrigation and mechanisation (Foresight 2011) [17] and thus it is an energy-intensive farming system (Khan *et al*. 2010) [28]. However, the continued use of conventional farming practises or modern agriculture, which largely includes conventional tillage (ploughing the land for seed bed preparation and weed control), mixing fertilisers into the soil and burning crop residues, has resulted in the degradation of soil resource base (Hobbs *et al*. 2008; Montgomery 2007) [21, 34] and intensive soil degradation of approximately 67 percent, reducing crop production capacity (World Resources Institute 2000) [43]. Besides this, the major challenges before the developing countries are achieving food security and relieving poverty while having sustainable agricultural systems under the current situations of depleting natural resources, unfavourable impacts of climatic variability, escalating cost of inputs and volatile food prices. The principal indicators of non-sustainable agricultural system include soil erosion, decline in soil organic matter and salinization.

### The main causes of these problems are

a) Intensive tillage induced decline in soil organic matter, degradation of soil structure, wind and water erosion, reduction in water infiltration rates, surface crusting and soil compaction.
b) Unsatisfactory replenishment of organic material.
c) Monocropping (FAO 2012) [15].

The productivity and long-term viability of the rice-wheat system in India's Indo-Gangetic Plains have been jeopardised by:

i) Inefficient current production practices (conventional practices).
ii) Scarcity of resources, particularly water and labour, and associated changes in land usage.
iii) Climate change.
iv) Socio-economic changes (Pathak *et al*. 2011) [37].

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Also, yield growth is getting diminished, which is especially true for rice in Asia (Pandey *et al*. 2010) [36]. In addition to this, global warming also calls for the need to substitute conventional practices to reduce greenhouse gas emissions (You *et al*. 2005) [44] from rice-wheat system. As a result, stronger management approaches are urgently needed to produce more food at high income levels while reducing risks; more efficient use of land, labour, water, nutrients, and pesticides than is currently available; reduction in greenhouse gas emissions (GHGs) and adaptation to climate change. Conservation agriculture (CA) has been evolved as a concept in response to the concerns in sustainability of the agricultural system and has progressively increased worldwide to cover about 11% of the world's cultivable land (157.8 M ha) (FAO 2016) [16]. It is an agricultural production system that saves resources and targets to achieve intensified production and higher yields with the enhancement of natural resource base through its three interrelated principles and good management practices for plant nutrition and pests (Abrol and Sangar 2006) [1]. Hence, CA has been identified as one of the technological options for achieving the global challenges of increasing food production and conserving the environment, thereby improving food and nutritional security and alleviating poverty (Joshi 2011) [26].

CA-based resource conservation technologies (RCTs) have been proven energy and input efficient while addressing the emerging environment and soil health problems (Saharawat *et al*. 2010) [39] and is being practised over an estimated 125 M ha (FAO 2012) [15]. The RCTs including no or minimum tillage with direct seeding, bed planting involving residue mulch, innovations in residue management to avoid straw burning, and crop diversification are being considered an alternative to conventional management practices in the rice-wheat system for improving productivity and sustainability (Barclay 2006) [2]. These also provide many possible benefits including a reduction in water and energy use (fossil fuels and electricity), greenhouse gas (GHG) emissions, soil erosion and degradation of the natural resource base, increased yields and farm incomes, and reduction in labour shortages (Pandey *et al*. 2012) [35]. They provide an opportunity to handle agricultural complexity in small-scale farming in the tropics (Hobbs 2007) [22]. RCTs tend to increase the soil organic carbon (SOC) storage and can regulate the rapid decomposition process in soil (Das *et al*. 2013) [7].

## 2. Definition, goals and principles of conservation agriculture

CA as described by FAO (http://www.fao.org.ag/ca) is a concept for resource saving agricultural crop production whose concern is on enhancing the natural and biological processes above and below the ground. It is an array of management practices that maintains a soil cover through surface retention of crop residues with zero/no till and reduced tillage, which minimize effects on composition, structure and natural biodiversity of soil and reduce the occurrence of soil erosion and degradation. CA places a strong emphasis on increasing yields and profitability in order to achieve a balance of agricultural, economic, and environmental benefits. It states that the social and economic benefits of combining production and environmental protection, such as lower labour and input costs, are larger than those of production alone. Farmers may contribute to a healthier living environment by reducing the usage of fossil fuels, pesticides and fertilisers, as well as preserving environmental integrity and services, through CA. It focuses on reversing the deterioration processes associated with conventional agricultural practices, such as intensive agriculture and crop residue burning/removal. As a result, it focuses on preserving, enhancing and making the most efficient use of natural resources through integrated management of available soil, water and biological resources, as well as external inputs. Therefore, it can be called as a resource-efficient or resource-effective agriculture.

RCTs and CA are used sometimes interchangeably. RCTs are techniques that aid in increasing the efficiency of resources or input usage. RCTs refer to the nitrogen (N)-efficient varieties, money-, fuel-, time-and irrigation-efficient approaches, including CA. CA includes RCTs that have the following characteristics:

i) Crop residue retention on the surface soil or covering the soil with green manures.
ii) Rational and profitable crop rotations.
iii) Practices which involve minimal soil disturbance, such as minimum or zero tillage (ZT).

The United Nations Food and Agricultural Organization (FAO) has driven the concept of resource-saving agricultural crop production by integrating farm income and soil health through CA. CA, according to FAO, aims to:

i) Achieve admissible profits.
ii) Maintain and increase production levels,
iii) Conserve the environment (FAO 2009) [13].

CA practises are universally applicable to all crops, including cereals, horticulture, and plantation crops, but are most popular in maize, soybean, rice, and wheat. CA practices provide a tremendous potential for different soils and agro-ecological systems, and are neutral to size holdings of farmers with an urgent requirement for smallholder farmers for a reduced cost of production, increased profit and saving of resources (Derpsch 2008) [10].

CA is based on these four principles given below:

i) Decreasing mechanical soil disturbance and direct seeding onto untilled soil to improve soil organic matter (SOM) content and soil health.
ii) Using cover crops and/or crop residues (mainly residue retention) for enhancing the SOM, which protects the soil surface, conserves water and nutrients, and promotes soil biological activity.
iii) Crop diversification in associations, sequences and rotations for enhancing the system resilience that complements reduced tillage and residue retention by breaking pests and disease cycle (FAO 2010) [14].
iv) Controlled traffic that decreases soil compaction.

CA circumvents straw burning, helps in improving soil organic carbon (SOC) content, enhances input use efficiency and potentially reduces GHGs (Bhattacharyya *et al*. 2012 a, b). However, there is a much-needed wide scale testing of these new technologies under diverse production systems, as the CA practices are site specific and hence, appraisal of CA is important to have significant adoption (Ladha *et al*. 2009) [30].

## 3. What is the need for CA-based RCTs?

Present challenge for agricultural fraternities is to meet the food security needs of the ever-growing population by increasing food production. Such production needs must be accomplished sustainably, through minimizing negative environmental effects, conserving, improving and making more efficient use of natural resources and also providing increased income for those employed in agricultural production. Many of the sources of productivity growth like improved cultivars, fertilizers and water, are being exploited from the last 40 Green Revolution years. Sources of productivity growth in the future will become more complex and harder to be found. There will be competition for surface and groundwater resources as domestic and industrial needs will strive for it. Agricultural land is shrinking because of increasing urbanization and its use in other purposes. Fossil fuels cost will escalate, thereby affecting the production costs directly and indirectly. There will be an increase in GHG emissions, having subsequent effects on climate resulting in an increase in severe climatic events like drought, floods, etc. which will make the challenge much more complicated. Therefore, more efficient use of the natural resources is the need of the hour to produce food and for maintaining the ecological balance to support life and making the resources available for present and future generations, which can be made possible by adopting CA based RCT practices. CA is 20 to 50 percent less labour-intensive and contributes to a reduction in GHG emissions through lower energy inputs and improved nutrient use efficiency. Furthermore, it helps in stabilizing and protecting the soil from breaking down and releasing carbon into the atmosphere (www.fao.org).

## 4. Status and extent of CA adoption worldwide

In 2015-16, the global extent of CA cropland increased from 157 M ha. in 2013-14 to 180 M ha. (12.5 percent of global cropland), representing an increase of approximately 74 M ha. (69 percent) in seven years since 2008-09 (106 M ha.) and 23 M ha. over two years since 2013-14 (15 percent) (Table 1) (Kassam *et al*. 2018) [27]. Since 2008-09, the rate of change has increased to approximately 10.5 M ha., indicating an increase in farmers interest in CA management practises for sustainable production and good management. Mainly, this expansion was in North America, South America, Australia and New Zealand. But recently, it is also expanding in Asia, particularly with large farms in Kazakhstan and China and with small farms in India and Pakistan. Wheat-rice cropping systems in India and Pakistan's Indo-Gangetic Plains are being transformed into CA systems known as "double no-till" rice–wheat systems, with a short season legume crop added in some cases. CA cropping systems are expected to be widely adopted across Asia in the coming decades. Table 1. shows that the number of countries where CA adoption and uptake is occurring has increased from 36 to 55 in 2013-14 to 78 in 2015-16 since 2008-09. CA is getting adopted globally due to its benefits in fast-growing production system, like increased factor productivity and farm output, reduction in the cost of production and improved profitability, increased resilience to biotic and abiotic stresses, decrease in soil erosion and degradation, improvement in soil health and mitigating climate change. According to Kassam *et al.* (2018) [27], approximately 69.9 M ha (38.7 percent) of the total global area under CA is in South America, corresponding to approximately 63.2 percent of cropland in the region, and approximately 63.2 M ha (35.0 percent) is in North America, particularly in the United States and Canada, corresponding to approximately 28.1 percent of cropland in the region, as shown in Table 2. Furthermore, 22.7 million hectares (12.6 percent) are in Australia and New Zealand, accounting for 45.4 percent of cropland, while 13.9 million hectares (7.7%) are in Asia, accounting for 4.1 percent of cropland in the region.

**Table 1:** Worldwide extent of adoption of CA in 2008-09, 2013-14 and 2015-16

| No. | Country | CA area 2008-09 | CA area 2013-14 | CA area 2015-16 |
|---|---|---|---|---|
| 1. | USA | 26,500.00 | 35,613.00 | 43,204.00 |
| 2. | Brazil | 25,502.00 | 31,811.00 | 32,000.00 |
| 3. | Argentina | 19,719.00 | 29,181.00 | 31,028.00 |
| 4. | Canada | 13,481.00 | 18,313.00 | 19,936.00 |
| 5. | Australia | 12,000.00 | 17,695.00 | 22,299.00 |
| 6. | Paraguay | 2400.00 | 3000.00 | 3000.00 |
| 7. | Kazakhstan | 1300.00 | 2000.00 | 2500.00 |
| 8. | China | 1330.00 | 6670.00 | 9000.00 |
| 9. | Bolivia | 706.00 | 706.00* | 2000.00 |
| 10. | Uruguay | 655.10 | 1072.00 | 1260.00 |
| 11. | Spain | 650.00 | 792.00 | 900.00 |
| 12. | South Africa | 368.00 | 368.00* | 439.00 |
| 13. | Germany | 354.00 | 200.00 | 146.00 |
| 14. | Venezuela | 300.00 | 300.00* | 300.00# |
| 15. | France | 200.00 | 200.00* | 300.00 |
| 16. | Finland | 200.00 | 200.00 | 200.00 |
| 17. | Chile | 180.00 | 180.00 | 180.00# |
| 18. | New Zealand | 162.00 | 162.00 | 366.00 |
| 19. | Colombia | 102.00 | 127.00 | 127.00# |
| 20. | Ukraine | 100.00 | 700.00 | 700.00# |
| 21. | Italy | 80.00 | 380.00 | 283.92 |
| 22. | Zambia | 40.00 | 200.00 | 316.00 |
| 23. | Kenya | 33.10 | 33.10* | 33.10# |
| 24. | United Kingdom | 24.00 | 150.00 | 362.00 |
| 25. | Portugal | 25.00 | 32.00 | 32.00# |
| 26. | Mexico | 22.80 | 41.00 | 41.00# |
| 27. | Zimbabwe | 15.00 | 90.00 | 100.00 |
| 28. | Slovakia | 10.00 | 35.00 | 35.00# |

| | | | | |
|---|---|---|---|---|
| 29. | Sudan | 10.00 | 10.00* | 10.00# |
| 30. | Mozambique | 9.00 | 152.00 | 289.00 |
| 31. | Switzerland | 9.00 | 17.00 | 17.00# |
| 32. | Hungary | 8.00 | 5.00 | 5.00# |
| 33. | Tunisia | 6.00 | 8.00 | 12.00 |
| 34. | Morocco | 4.00 | 4.00 | 10.50 |
| 35. | Lesotho | 0.13 | 2.00 | 2.00 |
| 36. | Ireland | 0.10 | 0.20 | 0.20 |
| 37. | Russia | - | 4500.00 | 5000.00 |
| 38. | India | - | 1500.00 | 1500.00# |
| 39. | Malawi | - | 65.00 | 211.00 |
| 40. | Turkey | - | 45.00 | 45.00 |
| 41. | Moldova | - | 40.00 | 60.00 |
| 42. | Ghana | - | 30.00 | 30.00# |
| 43. | Syria | - | 30.00 | 30.00# |
| 44. | Tanazania | - | 25.00 | 32.60 |
| 45. | Greece | - | 24.00 | 24.00# |
| 46. | Korea, DPR | - | 23.00 | 23.00# |
| 47. | Iraq | - | 15.00 | 15.00# |
| 48. | Madagascar | - | 6.00 | 9.00 |
| 49. | Uzbekistan | - | 2.45 | 10.00 |
| 50. | Azerbaijan | - | 1.30 | 1.30# |
| 51. | Lebanon | - | 1.20 | 1.20# |
| 52. | Kyrgyzstan | - | 0.70 | 50.00 |
| 53. | Netherlands | - | 0.50 | 7.35 |
| 54. | Namibia | - | 0.34 | 0.34# |
| 55. | Belgium | - | 0.27 | 0.27 |
| 56. | Pakistan | - | - | 600.00 |
| 57. | Romania | - | - | 583.82 |
| 58. | Poland | - | - | 403.18 |
| 59. | Iran | - | - | 150.00 |
| 60. | Estonia | - | - | 42.14 |
| 61. | Czech Republic | - | - | 40.82 |
| 62. | Austria | - | - | 28.33 |
| 63. | Lithuania | - | - | 19.28 |
| 64. | Croatia | - | - | 18.54 |
| 65 | Bulgaria | - | - | 16.50 |
| 66. | Sweden | - | - | 15.82 |
| 67. | Latvia | - | - | 11.34 |
| 68. | Uganda | - | - | 7.80 |
| 69. | Algeria | - | - | 5.60 |
| 70 | Denmark | - | - | 2.50 |
| 71. | Slovenia | - | - | 2.48 |
| 72. | Bangladesh | - | - | 1.50 |
| 73. | Swaziland | - | - | 1.30 |
| 74. | Tajikistan | - | - | 1.20 |
| 75. | Vietnam | - | - | 1.00 |
| 76. | Cambodia | - | - | 0.50 |
| 77. | Laos | - | - | 0.50 |
| 78. | Luxemburg | - | - | 0.44 |
| 79. | Cyprus | - | - | 0.27 |
| | Total | 106,505.23 | 156,738.96 | 180,438.64 |
| | % difference | | 47.17 since 2008/09 | 69.42 since 2008/09<br>15.12 since 2013/14 |

*2013/14 values taken from 2008/09; #2025/16 values taken from 2013/14; Source: 2008/09 and 2013/14 estimates, FAO-AQUATSTAT; 2015/16 estimates, Kassam *et al*. 2018.

**Table 2:** Cropland area region-wise under CA (M ha) in 2015/16; CA area as percent of global total cropland, and CA area as percent of cropland of each region

| Region | CA Cropland area | Percent of global CA Cropland area | Percent of Cropland area in the region |
|---|---|---|---|
| South America | 69.90 | 38.7 | 63.2 |
| North America | 63.18 | 35.0 | 28.1 |
| Australia and New zealand | 22.67 | 12.6 | 45.5 |
| Asia | 13.93 | 7.7 | 4.1 |
| Russia and Ukraine | 5.70 | 3.2 | 3.6 |
| Europe | 3.56 | 2.0 | 5.0 |
| Africa | 1.51 | 0.8 | 1.1 |
| Global Total | 180.44 | 100 | 12.5 |

**Source:** Kassam *et al*. (2018).

## 5. Constraints or challenges for the adoption of CA

i) The basic mindset that restricts the adoption of CA is that soil tillage is essential for agricultural production. A change in behaviour of farmers, technicians, extensionists and researchers from soil degrading tillage operations towards sustainable production systems like no tillage is required (Derpsch 2001) [9]. Hobbs and Govaerts (2010) [20] also emphasized that probably the most important factor in the adoption of CA is overcoming the bias or mindset about tillage. In many cases, it becomes difficult to convince the farmers about the potential benefits of CA beyond its potential to reduce production costs, mainly by tillage reductions. Therefore, an extensive educational programme demonstrating the benefits ensued by CA is needed to make a complete shift from intensive tillage operations to zero or minimum tillage.

ii) Another challenge for CA is the high cost of machinery and implements. Agriculture, together with its allied sectors, is India's most important source of income. 70% of the rural households still rely on agriculture as their primary source of income, with 82 percent of the farmers being small and marginal (www.fao.org). Therefore, there cannot be an immediate shift from the existing or available machinery to the conservation agriculture machinery.

iii) A major constraint in promoting CA, especially under rainfed conditions is the large-scale use of crop residues for livestock feed and fuel. In rainfed areas, farmers face a paucity of crop residues because of low biomass production by different crops and hence, there will be competition for CA practice and livestock feeding and fuel for crop residues.

iv) CA systems management asks for ample scientists to address the problems from a systems perspective and to be able to work in close partnerships with the farmers and other stakeholders. Therefore, this will be crucial for developing and promoting new technologies.

v) Another challenge is related to skill development. New machinery and cultivation practices require skill development of the farmers. Agroecological-based CA practices are available, which demands the farmers to adopt and implement those in their production environment. Since most of the farmers lack skill in using zero-till machines and cultivation practices, it prevents the adoption of CA practices.

vi) Technological challenges include development, standardization and adoption of farm machinery for seeding with minimum soil disturbance, developing crop harvesting and management systems. The basic principles of CA practices, that is, no tillage and surface managed crop residues although understood; their adoption under different farming conditions is the key challenge.

vii) Research in CA must have long-term perspectives as the advantages of resource improvement come progressively and take time. Therefore, a basic understanding of the dynamics of changes and interactions among soil physical, chemical and biological processes will help in developing improved soil-water and nutrient management practices (Abrol and Sangar 2006) [1].

## 6. Policy implications

CA reduces resource degradation, diminishes factor productivity and lowers cultivation costs, making agriculture more resource-efficient, competitive and sustainable. Adoption of CA can be spontaneous, but it needs the support of policy, public and private sector institutions. Policy and institutional support are required for the implementation and rapid adoption of CA on the assumption that all stakeholders work together toward a common goal. Since CA requires an absolute shift from conventional agriculture, policy analysis is the need of the hour for understanding how CA technologies interact with other technologies and how instruments in policy and agreements in institutions can bolster or dissuade CA (Raina *et al*. 2005) [38]. Below are some of the important points for considering policy implications for fostering CA.

i) As identified by Uri (1998) [42] for the furtherance of CA, should begin with regional policy makers who will identify whether CA adoption is providing a net negative or a positive return to its probable adopters. After this apprehension is resolved, he suggests:

i) Educational and technical assistance to the farmers who are not aware of the technology or profitability or who does not have the required skills to implement it, in areas where CA is profitable.

ii) Financial assistance to the individual farmer where conservation is not profitable, with provision of substantial public benefits.

iii) Regulation and taxes for the farmers involved in conservation behaviour or for those who are involved in related income support programmes (e.g. a cross-compliance measure).

ii) McNairn and Mitchell (1992) [33] were of the view that for encouraging the adoption of CA, it requires assurance of long-term multiple (i.e., economic and non-economic) benefits from adoption, unambiguous and accurate information, and active promotion. Education plays a key role in motivating adoption and requires tailored, credible, and appropriate information and experience that is communicated through the proper channels. Extension services to provide information and assistance can be highly effective, especially in the case of new or emerging technologies, although public agents need not be the exclusive providers of such services.

iii) For facilitating the expansion of CA and for the farmers to reap more benefits from the CA practices, a greater support is essential from the stakeholders involving the policy and decision makers at the local, national and regional levels. A farmer's participatory on-farm research is required to have an evaluation/refinement of the technology in the initial years of its implementation followed by large scale demonstration in the subsequent years. Efforts for on-farm evaluation and demonstration of CA technology for its promotion are being initiated in India through a network research project.

iv) The focus should shift from "food security" to "soil, environmental and livelihood security". About 13.5 million hectares (Mha) is occupied by rice-wheat cropping systems in the Indo-Gangetic Plains, of which 10 Mha are in India (Mahajan *et al*. 2009) [31], causing a decline in factor productivity, stagnation in yields and degradation of natural resource base (Gill *et al*. 2014; Sharma and Singh 2014) [19, 41] and thus, calling for crop diversification. Crop diversification helps in risk minimization, improvement in biodiversity, diversifying income sources through generating employment and in enhancing resource sustainability. Policy interventions influence the nature of cropping patterns and the extent of crop diversification. Pricing policy, tax and tariff policies, trade policies and policies on public expenditure and agrarian reforms are certain government policies that directly or indirectly influence crop diversification (Behera *et al*. 2007) [3].

v) CA provides a good scope for diversified cropping systems in several agro-ecoregions. Developing, improving, standardizing equipment for seeding, fertilizer placement and harvesting with assurance of minimum soil disturbance in residue management for different edaphic conditions will be a good accomplishment for the success of CA. Incentivizing the quality and availability of equipment will be important, requiring the subsidy support from national or local government to the firms for developing low-cost machines, thus helping in the promotion of CA technologies.

vi) Availability of trained personnel at the base level is one the major drawback in the adoption of CA. Hence, trainings must be organized on CA for capacity building through policy support. This training must be supported at every level and should be exercised for all new and existing extension personnel in the respective departments. To alleviate extension shortages at the local level, certain approaches of extension such as the ‘Lead Farmer Approach’ should be made. Conservation and sustainability concepts should be included in course curricula at the university levels along with biophysical and social sciences for achieving sustainable resource management.

vii) CA should be prevalent in respective ministries, departments or institutions and should get adequate material, human and financial resources assuring that farmers receive effective and timely support from well trained and motivated extension personnel. Institutionalizing CA into relevant government ministries and departments and regional institutions is essential for sustainability of the technology. It should be supported and spearheaded by local, national and regional policy and decision makers for formulating and developing strategies and mechanisms for scaling up the technology. For furtherance in productivity of CA, it can be integrated into interventions such as seed, fertilizer, and tillage and draft power support programmes.

viii) The focus of the country should shift from heavy-traffic causing machinery to CA machinery or equipment which cause less traffic or minimum soil disturbance and must ensure its development and availability to the small and marginal farmers, especially. This needs policy support to manufacture these machines at the local level, so it can be made available to the small and marginal farmers of the country.

ix) CA adoption has multiple benefits to the environment and to the farmers as well and hence, the farmers practising it must be encouraged and rewarded. Likewise, those involved in practices of stubble burning or any such practices which cause a harm to the ecosystem and livelihood must be imposed with a fine. All these can be possible through policy interventions.

x) As reported by FAO (2005) [12], the challenging task for the personnel involved would be to develop a good partnership with the farmers, involving with them in discerning and resolving problems rather than just expecting them to participate in the implementing projects from an outer core. This calls for a systems perspective to build a relationship with the farmers and thus, make a healthy partnership and better understand this system because CA systems are complex and their efficiency depends upon better understanding of the basic processes and component interactions which happen to determine the system performance. This will need the support of policy makers, extension personnel, scientists, farmers, and other stakeholders of private sector to work together in partnership mode for the development and promotion of CA technologies. Therefore, a more participatory action is required where farmers are provided and trained for the equipment to experiment with the CA practices on themselves whether it works and what is needed to make it productive on their hands rather than demonstrating the practices on farmer’s fields and expecting them to adopt.

xi) The respective government should provide credit loans to the farmers for the purchase of CA equipment, machinery and inputs through the responsible banks and credit agencies with reasonable interest rates. The government, at the same time, should subsidize the purchase of equipment by the farmers.

## 7. Benefits of CA adoption

i) CA practice-based sustainable intensification improves soil quality, biota, and system productivity over conventional rice-wheat system (Choudhary *et al*. 2018) [6].

ii) It helps save water, labour use, improvement in soil health and gives higher yields in cereal-based systems (Gathala *et al*. 2013; Jat *et al*. 2015) [18, 24].

iii) It provides an opportunity to increase the farmer’s profit under CA-based system intensification by integrating short-duration mungbean (Vigna radiata) (Kumar *et al*. 2018) [29].

iv) CA based RCTs regulate the rapid decomposition process of organic matter in soil and thus increase the soil organic carbon storage (Das *et al*. 2013) [7].

v) Malik *et al*. (2005) [32] reported a reduction in the incidence of weeds like Phalaris minor, in wheat.

vi) Das *et al*. (2017) [8] conveyed that resource conservation techniques having zero tillage and real-time nitrogen management in transplanted rice could offer a low carbon technology in long run in one hand as these minimize greenhouse gas (GHGs) emissions and increase soil carbon stock and also sustain yield in tropical lowland rice.

vii) It helps in the enhancement of water and nutrient use efficiency (Jat *et al*. 2012; Saharawat *et al*. 2012) [23, 40].

viii) Adopting CA practices help in the reduction in greenhouse gas emissions and improvement of environmental sustainability (Pathak *et al*. 2011) [37].

ix) As reported by Jat *et al*. (2009a) [25], CA practices improve resource use efficiency through crop residue decomposition, improve soil structure, increase recycling and availability of plant nutrients.

x) Cost reduction by about Rs. 5760 per hectare (roughly by 5 to 10 per cent), as reported by Erenstein and Pandey (2006) [11] in the Indo-Gangetic Plain in India.

## 8. Conclusion

Conservation agriculture-based resource conservation technologies can be the future of sustainable agriculture, as it helps in saving water, is less labour-intensive, energy and input efficient, reduces greenhouse gas emissions and provides sustainable yields to the farmers without degrading the soil and natural resource base. In the recent years its adoption has shown an increment with certain constraints specific to the region, in its implementation in the farmer's field and in making available of the CA machineries to the small and marginal farmers of the country. The challenges and constraints for CA adoption needs government integrated policy interventions and financial support and widespread awareness among the farmers through effective communication by the stakeholders about the CA-based RCTs.

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