Principles, Positives and Limitations of Conservation Agriculture: A Review

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ABSTRACT

Lessons learnt from past experiences push for an alternate way of crop production. One such is Conservation agriculture (CA), which can be seen as a new way forward for conserving resources and enhancing productivity to achieve goals of sustainable agriculture. In recent past, progressive and significant efforts are made to develop, refine and disseminate conservation-based agricultural technologies across globe. Tremendous efforts on zero-till practices and surface management with crop residues for crop production were reviewed. This work was done at Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India. A systematic cum integrative review of research work done in different parts of World, particularly in India was comprehended. Literature search was done during 2020. About 200 review and research papers were screened from various databases like TNAU e-library, ARCC journals, Google Scholar, Research gate and Scopus and 84 papers were used. This review article comprehensively documents major principles of CA along with extent and spread of CA across the globe. It also highlights CA in Indian perspective. Various merits and demerits were also discussed with literature support. This review paper discusses rising concerns of conventional agriculture systems with regard to its adoption, positives and negatives of conservation agriculture in promoting conservation agriculture in tropics.

Key words: Conservation agriculture, Cover crops, Crop rotation, Field traffic, Minimum tillage, Soil cover, Sustainability.

World has faced many challenges and one such is to feed growing and ever increasing population under a changing climate with reduced external inputs (Pittelkow et al., 2015) on a sustainable intensification mode (Tilman et al., 2011; Vanlauwe et al., 2014; Giller et al., 2015) with minimal negative effect on environment (Foley et al., 2011). In recent times, Conservation agriculture (CA) has been highlighted as an alternative and viable option for Sustainable Intensification (Hobbs et al., 2008; Pretty and Bharucha, 2014) of food production. Under conventional agricultural systems, principle indicator of non-sustainability is soil erosion and declining of soil organic matter as mainly caused by: (1) heavy field traffic induced degradation of soil structure, water and wind erosion leading to poor infiltration rate, crusting of soil surface, soil compaction, (2) poor recycling of organic materials and also (3) monocropping (Kavita Bhadu et al., 2018).

Methodology

Review work was carried out at Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India. Almost 10 months during 2020 had been spent in collecting literature which includes 3 months for manuscript writing. About 200 scientific papers were screened, shortlisted and 84 papers used to prepare this manuscript. For searching of research papers, various data bases such as TNAU e library, ARCC journals, Google scholar, Research gate and Scopus were used.

History, development and importance of CA

Repetitive tillage operations in conventional method of field preparation lead to decline in soil organic matter through accelerated oxidation and declining of soil biodiversity and fertility. Further, burning of crop residues causes pollution and loss of valuable plant nutrients. Retention of crop residues on soil surface along with zero-tillage kicks off processes that lead to enhanced soil quality and overall resource augmentation (Das et al., 2013).

The term conservation agriculture (CA) represents a package of agronomic technologies that permit for minimum disturbance of soil, maintenance of soil cover with crop residues and a system approach with crop diversification and rotation both at spatially and temporally (FAO, 2008). Current global estimates indicates that CA has been adopted in 124 m. hectares (Friedrich et al., 2011), 87% of which is concentrated in five countries viz., United States, Brazil, Argentina, Australia and Canada (26.5, 25.5, 25.5, 17.0 and 13.5 m. ha, respectively). Further, a host of supplementary environmental benefits have been theorized and are now
documented (Hobbs et al., 2008) and also in smallholder farming systems in sub-Saharan Africa and South Asia (Pittelkow et al., 2015).

For first time during 1930s, tillage operations in fragile ecosystems were questioned, as dustbowls devastated wide areas of mid-west United States, which led to farm scientists to consider about reducing tillage and keeping ‘soil covered’. This paved way for introduction of conservation tillage aiming at soil protection. Later in 1940s, seeding machinery developments was allowed to seed directly without any soil tillage. Parallely, Faulkner (1945) in his book “Ploughman’s Folly” and Fukuoka (1975) with “One Straw Revolution” explained principles and concepts similar to today’s CA principles. However, it was only in 1960s, no-tillage entered into farming practices in USA (Kassam et al., 2010, 2014). However a Tamil Laureate from India had written ten couplets about farming and plough in his collection on ‘Thirukkural’ and he suggested following measures as early in 50 BCE. English translation of Couplet 1037: (Thiruvalluvar 50 BCE, Tamil Laureate from India).

Reduce your soil to that dry state, when ounce is quarter-ounce’s weight;
Without one handful of manure, Abundant crops you thus secure.

English translation of Couplet 1038: (Thiruvalluvar 50 BCE).
To cast manure is better than to plough; Weed well; To guard is more than watering.

In early 1970s no-tillage reached Brazil, as farmers along-with scientists transformed these technologies in to a system, presently known as CA, however it took another 20 years before CA principles reached a significant adoption levels. Simultaneously, impetus on improvements in designing of farm equipment especially seeding implements and zero/minimum tillage focussed agronomic practices was developed to ensure crop production. It still continuing as there is no end for creativity of farm scientists and farmers. From early 1990s CA started growing exponentially, leading to a revolution in agriculture of southern Brazil, Argentina and Paraguay (Kassam et al., 2015).

Derpsch and Friedrich, (2009) listed many practices adopted under rain-dependent marginal soils in different countries, like mulch cover for avoiding soil crusts and surface sealing; adopted (e.g., Australia, Argentina); small land holders (< 0.5 acre) practice No-tillage CA in China, Zambia and Paraguay; and larger holdings in Argentina, Brazil and Kazakhstan.

Lack of technical knowhow, mind rejections due to traditions and prejudice, poor policies and direct farm payments (EU), non-availability of suitable equipment and machineries (many countries of world) and lastly absence of strategies for weed and vegetation management, barred CA from acceptance among farmers (Friedrich and Kassam, 2009; Jat et al, 2014; Farooq and Siddique, 2014).

Many bilateral and multi-lateral donors to come forward to support and spread CA as it is sustainable, but intensive production system through awareness creations that led to growth of zero or No-till/CA organizations worldwide and also framing of national and regional policy support across world (Kassam et al., 2015).

Definition and description of conservation agriculture

According to (Hubbard et al., 1994; Karlen et al., 1994) CA is a common title for a set of agricultural practices intended to enhance sustainable food production by conserving and protecting existing and available soil, water and biological resources thereby keeping external inputs at minimum (Garcia-Torres et al., 2003). This term is usually applied to no-tillage, direct drilling, or minimum tillage practice when it is coupled with crop residue cover of 30% of soil surface and associated with conservation of time, fuel, earthworms, soil water and nutrients (Baker et al., 2002). Stagnari et al. (2009) observed that, conservation tillage can be a transition step towards CA agriculture which still depends on tillage as structure-forming element in soil.

CA is not a routine and usual business as observed by Dumanski et al. (2006). FAO (2014a) describes it as a resource saving crop production concept, which is based on enhancing above and below ground natural and biological processes. CA is to 1) achieve adequate profits 2) sustained production levels and 3) conserve environment. It aims at reversing degradation process which is inherent to conventional agricultural practices besides ensuring efficient utilisation of natural resources in an integrated way, combined with external inputs. Hence, CA is a resource efficient/ effective agriculture Suraj Bhan and Behera (2014).

Carbon sequestration at about 0.2 to 1.0 t/ha/year or more depending on location and management practices (Gonzalez-Sanchez et al., 2012; Sa et al., 2013 and Corsi et al., 2014) is added benefit of CA. Reduction in labour requirements by 50% helps farmers to save on time, energy and machinery costs (Saturnino and Landers, 2002; Baker et al., 2007; Lindwall and Sonntag, 2010; Baig and Gamache, 2009; Crabtree, 2010). More than 60 percent energy savings was reported by Sorrenson and Montoya (1991).

Need for conservation agriculture

As conventional intensive tillage-based production systems has many deleterious effects on natural resources such as soil, water, terrain, biodiversity and associated ecosystem services providers (Montgomery, 2007; Kassam et al., 2013 and Dumanski et al., 2014) which leads to degradation of land resources and declining of factor productivities thereby affecting crop yields (Goddard et al., 2006; Jat et al., 2014 and Farooq and Siddique, 2014) and 30 percent of greenhouse gas emissions (IPCC, 2014), there is a need for sustainable yet intensified production system that ensures remunerative agriculture and natural resource conservation and harnessing environmental services (FAO, 2011a). Further, it should mitigate factors that cause climate change and also enhance soil biodiversity to improve
ecosystem services for better productivity and environment. (Kassam et al., 2015).

Another set of scientists (Kassam et al., 2013; Jat et al., 2014; and Siddique and Farooq, 2014) said CA is a combination of soil-crop-nutrient-water-landscape system management practices which saves on energy and mineral nitrogen use; enhances soil biological activity. However, CA should be incorporated with integrated pest management, plant nutrient management, weed and water management (FAO, 2011).

Accusation of conventional agriculture for soil erosion problems, surface and underground water pollution, water consumption (Wolff and Stein, 1998) and also for land resource degradation, wildlife and biodiversity reduction, low energy efficiency and contribution to global warming problems (Boatmann et al., 1999), pushed farming community to seek alternative in form of CA, which offers a permanent soil cover, natural increase of organic matter content and also stresses conservative way of cultivation soil, air, water and biodiversity (Derpsch et al., 2010; Derpsch et al., 2011).

**Extent and adoption of CA in World and India**

**At World level**

A steady increase in adoption and spread of Conservation agriculture practices worldwide has been evident as about ~8% of world arable land (124.8 M ha) is now under CA (FAO, 2012; FAO, 2014b) as it is a resource-saving but intensified agricultural production system that aims to achieve good plant nutrition and pest management practices besides, high yields while enhancing natural resource base Abrol and Sangar (2006) were.

CA has now emerged as an effective alternative agricultural strategy to achieve sustainable agriculture goals as it is able to address increasing concerns of grave and extensive problems of natural resource degradation and environmental pollution. According to latest estimates, CA has been followed in 80 M. ha, largely under rainfed conditions and area is expanding rapidly (Harrington and Olaf, 2005). USA took a lead in adopting CA with 18 M. ha and other leading countries following CA include Australia, Argentina, Brazil and Canada. In Latin America, it is rapidly accepted by farmers with policy decision to promote it. In Europe, France and Spain, CA has been adopted in about 1.0 M. ha area under annual crops. Further, a regional group uniting associations in UK, France, Germany, Italy, Portugal and Spain has been formed under banner of European Conservation Agriculture Federation. In Southeast Asia (Japan, Malaysia, Indonesia, Philippines and Thailand) CA is becoming popular under Community-led initiative strongly supported by Research and development organizations (Sangar et al., 2005).

**India**

In India, though efforts were made to spread resource conservation technologies for years (Negi and Rana, 2016) but it is recently only technologies are accepted and adopted by farmers. This effort has been spearheaded by Rice-Wheat Consortium for Indo-Gangetic Plains, a CGIAR eco regional initiative involving several CG centres and National Agricultural Research System of India, Pakistan, Bangladesh and Nepal. In northwest regions of India, concerns about stagnating productivity, high production costs, deteriorating resource quality, decreasing water tables and escalating environmental problems push farm scientists to look for alternative technologies, particularly, in states of Punjab, Haryana and western Uttar Pradesh (UP) (Akhter et al., 2004). But in eastern regions, low cropping system productivity is chief concern to seek alternatives, particularly in states of UP, Bihar and West Bengal. In these regions, primary focus was on development and adoption of zero-till cum fertilizer drill for sowing, raised-bed planting system, alternatives for residue management and to rice–wheat cropping system in relation to CA technologies, etc and it resulted in rapid adoption of zero-till drill sowing (Hobbs and Gupta, 2003) in an area of 1.0 M ha. plausible reasons for rapid adoption are less cost production, lowering incidence of weeds and minimised weedicide costs and, savings in water and nutrients management. Abrol and Sangar, (2006) were of opinion that zero-tillage combined with residue management favoured improvements in of availability of soil nutrients and moisture, recycling and soil biological activity and thus provided a more favourable environment for crop growth. Though, CA is being well thought-out as a road to sustainable agriculture, yet, in India, CA is a new concept and its roots are only now beginning to find grounds.

In India, Erenstein and Pandey (2006) and Piyush et al. (2018) conducted experiments to measure benefits of CA in Indo-Gangetic plains and found a few ground reality benefits harvested by farmers under CA was illustrated in Fig 3. Crops grown by adopting CA is climate resilient, ensures food security and soil nutrition besides reducing energy consumption as presently farmers are facing problem of labour shortage and drudgery of farming these are all can be reduced by conservation tillage practice.

**Principles of conservation agriculture**

CA practices followed in many parts of world are built on sustainable ecological principles (Wassmann et al., 2009; Behera et al., 2010 and Lal, 2013). Balancing Resource use efficiency (RUE) and crop productivity is utmost essential for managing natural resources and to accomplish agriculture sustainability. Conservation agriculture fundamentally relies on following principles:

**Minimal mechanical soil disturbance**

Concept of ‘biological tillage’ is a natural phenomenon promoted by soil microorganisms through biological activity that produces stable soil aggregates and a range of sizes of pores thus allowing air and water entry and infiltration in soil. This process is comparable to mechanical tillage but mechanical tillage spoils soil biological structuring processes.

This facilitates gaseous exchange in root-zone, moderate oxidation of organic matter, soil pores assisted water movement, retention and release and restricts re-exposure
of weed seeds and their germination (Kassam and Friedrich, 2009).

**Permanent soil organic cover**

Maintenance of permanent soil organic cover (at least 30 percent) with crop residues or cover crops ensures formation of a protective layer on soil surface which suppresses weeds; protects soil from impact of extreme weather patterns; helps to preserve soil moisture and avoids compaction of soil.

Besides, it protects soil from exposure to rain and sun, ensures continuous supply of food to soil organisms and alters soil microclimate for growth and development of soil organisms. In turn it improves biological activity in soil aggregation of soil particles and carbon sequestration (Ghosh et al., 2010).

**Rotation of crops**

Rotation of crops ensures a diverse “diet” to soil microorganisms and favours recycling of nutrients from deeper soil layers to surface through diverse rooting pattern of crops grown in rotation. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna.

Inclusion of legumes in cropping sequence and rotations negatively influences pest species through life cycle disruption and builds up biological nitrogen fixation (Kassam and Friedrich, 2009; Dumanski et al., 2006). CA components and their positive interaction in soil and crop yield influencing factor are illustrated in Fig 1.

**Controlling field traffic**

Controlled traffic that lessens soil compaction could be another principle being pondered upon in recent years. In a long-run, CA practices are promising in terms of efficient rational use of resources and sustained productivity (Das et al., 2014, Nath et al., 2017; and Oyeogbe et al., 2018).

**Advantages of Conservation Agriculture**

Multifaceted benefits of CA are depicted in Fig 2. CA ensures (i) physical protection against weather (raindrops, wind, dry or wet periods), (ii) better soil structure and cohesion, (iii) helps in erosion control and nutrient transport and (iv) saves money, time and energy. CA promise great potential for different soils and agro-ecological systems. It is a farm-holding size neutral but CA adoption is most urgently required by smallholder farmers to reduce their cost of production, increase profit and save resources (Derpsch, 2008). Often conservation agriculture is misunderstood as organic farming. There are little differences between these two concepts. Though both have common ideology of improving soil health through natural resources; organic farming prohibits application of chemical inputs while CA permits.

CA is being promoted as a solution to increase crop productivity and food security (Hobbs, 2007) and has potential to reduce labour needs for land preparation and improve soil fertility while also reducing water stress in crops (IIRR, 2005). The Main objectives of conservation agriculture is reducing tillage, year round cropping, crop rotation, mulching may be live or residue. Due to reduced mechanical tillage, activity of micro flora and macro flora get increases that improves biological tillage of soil, that in turn improves soil structure and enhances the plant growth (Selvakumar and Sivakumar, 2021).

**Constraints for adoption of conservation agriculture**

Kavita Bhadu and her team in 2018 identified problems associated with conservation agriculture while adopting it and found that mind set of farmers is the major deterrent as they were educated extensively on conventional intensive
agriculture and use of external inputs. A few other constraints are:

**In adoption of reduced tillage**

- In absence of fertilizer minimum tillage may lead to nutrient immobility causing farmers to experience reduced yields (Giller et al., 2009).
- Decomposition of crop residues can lead to short term nitrogen immobilization because of increased activity of soil organisms that lock up nitrogen in their bodies (Verhulst et al., 2010).
- Even though tilling allows incorporation of residues and thereby, hastening decomposition process, it allows nutrients to be available for next season only.
- Weed control is primary motivations for tillage (Wall, 2007) as reduced tillage greatly increases weed pressure and it push for use of more labourers for weed control, but in CA, this constraint can be overcome with herbicides (Baudron et al., 2007).
- Minimum tillage without herbicides faces challenge of controlling perennial weeds (Vogel, 1995).

**In mulching**

- Limited reliable markets and shortage of improved legume seeds is a peril for inclusion of legumes in crop rotation (Baudron et al., 2007; Haggblade and Tembo, 2003).
- Greatest profits were earned from growing maize only when compared to cotton and sunnhemp in rotation despite yield increases from rotation.
- Inclusion of livestock challenges maintenance of mulch (Baudron et al., 2007; Nyathi et al., 2011) and mulch sometimes favours crop pests infestation, especially termites (Nyathi et al., 2011). Furthermore, maintaining mulch may lock up nitrogen, requiring increased fertilization in short term (IIRR, 2005).

**In crop rotation**

- Crop geometry pushes farmers not to choose plant legumes in permanent planting basins (Baudron et al., 2007).
- Key challenges for crop rotation are dearth of reliable markets for many leguminous crops and shortage of improved legume seeds (Baudron et al., 2007; Haggblade and Tembo, 2003).

### Difference between conventional and conservation agriculture.

| Practices                      | Conventional agriculture                                                                 | Conservation agriculture                                                                 |
|--------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Land cultivation               | Dominate nature                                                                          | Least interference with natural processes.                                                |
| Tillage                        | Excessive mechanical tillage and soil erosion                                            | No-till or drastically reduced tillage (biological tillage).                             |
| Soil conservation              | Low wind and soil erosion                                                                  | High.                                                                                    |
| Residue management             | Burning or removal (barren surface)                                                       | Retention (permanently covered).                                                         |
| Infiltration of water          | Low                                                                                      | High.                                                                                    |
| Weed management                | Killing weeds simultaneously stimulating more weeds to germinate                          | Problem of early stages but decrease with course of time.                               |
| Field traffic and soil compaction | Free-wheeling and high soil compaction                                                    | Controlled traffic and no compaction in crop area.                                       |
| Cropping system                | Mono cropping or monoculture                                                             | Diversified and crops rotated often.                                                     |
| Labour and time                | Heavy reliance on manual labour and delayed often                                         | Minimum mechanized operations and timely operations.                                     |
| Adaptations                    | Poor adaptation to stresses                                                              | More resilience to stresses.                                                            |

Source: (Sharma et al., 2012; Kavita Bhadu et al., 2018)
Prospects of conservation agriculture in tropical regions

Indian farmers (70-75 percent) have only small and holdings and pay little attention to long term management of natural resources and can rarely afford input such as quality seeds, fertilizer, heavy machines and herbicides for chemical weed management (Piyush et al., 2018).

Minimising cost of production

Zero-till technology for wheat saved $33 to 50/ha (Malik et al., 2005; RWC-CIMMYT, 2005; Poddar et al., 2017) due to savings in energy, labour and inputs.

Minimal weed infestation

A low incidence of invasive weed species Phalaris minor in wheat field was observed due to zero-till.

Water saving

Water saving (20-30 percent) and also nutrients savings were achieved with zero-till planting under laser levelled and bed planted crops (De Vita et al., 2007) stated that no-till planting had higher (>20%) soil water content under than under conventional tillage.

Yield enhancement

About 200 – 500 kg ha⁻¹ increased yield was found with no-till wheat compared to conventional wheat in Indo-Gangetic plains, it is due to avoidance of soil degradation, improved soil fertility, moisture and crop rotational benefits. (Hobbs and Gupta, 2004). A few studies claimed that CA results in higher and more stable crop yields (African Conservation Tillage Network, 2011), on contrary, there are also numerous examples of no yield benefits, yield reductions during initial years.

Environmental benefits

Insisting on a permanent soil cover under CA eliminated in situ burning of residue, which avoids loss of plant nutrients.

Crop diversification opportunities

Ample scope for crop diversification and cropping sequences/rotations.

Resource improvement

Zero-till coupled with crop residues management helps in soil structural improvement and efficient recycling and mulching moderates soil temperatures, reduces evaporation and improves biological activity (Suraj Bhan and Behera, 2014)

CONCLUSION

A paradigm shift from conventional system to Conservation agriculture is a necessity across tropical regions of world as it has wider scope for reversing downward gradient of resource degradation. Further, CA policies for regional/ country wise basis has to formulated first and networking all these has to done so as to have a global platform for CA. Adequate funding support has to be provided worldwide to intensify research as well as create awareness in tropical regions among small holding farmers to make CA, a mass movement.

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