New dimensions and options in conservation agriculture

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ABSTRACT : Widespread residue burningcoupled with intensive tillage accelerates oxidation of organic matter resulting in elevated levels CO_2 in theatmosphere thereby contributing to the greenhouse effect and global warming of the planet. Besides, land degradation is serious environmental problem that threatens soil health and food security. Conservation agricultural (CA) practices helps in reversing these trends.CA refers to the system of raising of crops in rotation without tilling or with minimal disturbances to the soil while retaining crop residues on the soil surface. Conversion of conventional practices into conservation agriculture practices helps in sequestration of soil organic carbon (SOC), enhanced soil health and mitigation of climate change effect, besides better soil aggregation, nutrients cycling, and reduction of soil erosion and nutrient losses.CA practices have been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production. Worldwide, CA spreads in about 124 mha, which is aimed to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as economically, ecologically and socially sustainable agricultural production. The location specific CA farm machinerydevelopment and technology generation–dissemination–adoption of CA technologies has to be looked into for broader perspective with interdisciplinary approach. Large scale capacity building at different levels like training farmers, land managers, students, extension faculties and scientistsfor adoption of CA practicesis the need of the hour.

Key words: C sequestration, climate resilience, food security, soil health, tillage

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1. INTRODUCTION

Ever since mankind started practicing agriculture, there was a beginning of awareness about resource conservation. We find evidence of conservation practicesin all ancient cultures. According to Food and Agriculture Organization (FAO) of the United Nations, “Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels, while concurrently conserving the environment” (FAO, 2007). Aspects of conservation that we normally deal are the management of soil, water, crop diversity, animals, storage of produce (seed, fertilizer, etc.) and maintenance of tools, implements, machinery, etc.

Since thousands of years, increasing human needs often changed the natural system from one that is stable and virtually closed to one that is degrading at different scales in various locations of the world. All studies show that land degradation is a real problem affecting livelihoods and the environment. On a global scale the annual loss of soil is 75 billion tons (Lal, 1998; Eswaran *et al.,* 2001). Land degradation is a serious environmental problem that threatens health and food security worldwide. This environmental problem has been a major global issue during the 20th century and will remain high on the international agenda in the 21st century (Eswaran *et al.,* 2001). There is growing concern that degradation of agricultural soil resources is already seriously limiting production and diminishing ecosystem services (Vlek, 2008).Generally, the economic impact of land degradation is severe in densely populated regions of South Asia and sub-Saharan Africa. Unfortunately, many of these regions are facing complex economic problems that prevent them from escaping the trap of land degradation. Then, once land degradationsets in it is likely to result in a vicious cycle of land degradation-productivity decline-land degradation nexus.

Due to the escalating human population and the requirement of ever-increasing food supplies, soil erosion, water scarcity and loss of biodiversity have gained recognition as prime environmental problems throughout the world. The main land degradation processes such as erosion, nutrient mining, carbon loss, etc. are cause of amplified human activities, mainly agriculture. These processes are likely to become more severe as population grows and the demand for more land and food increases. The millennium development goals 1 and 7 of reducing poverty, while ensuring environmental health would point towards systems that conserve resources and maximize efficiencies of resource use. With soil organic matter a key resource to conserve, the agricultural research community has re-assessed the costs and benefits of conservative soil management systems. Food security, ecological integrity and environmental health may be achieved by reducing tillage, leaving residues on the field augmenting nutrient inputs and reducing pest pressures through crop rotation, in short through conservation agriculture (FAO, 2008).

South Asian agriculture is currently facing twine challenges of resource fatigue and decelerating productivity growth of cereal crops. Also, there exit large yield gaps more particularly 'management yield gaps' ranging from 14-47, 18 - 70 and 36-77% in wheat, rice and maize, respectively. In recent years, the challenges are further exacerbated with the sharp rise in the cost of food and energy, depleting water resources, vulnerability of soil to degradation and desertification and loss of biodiversity. Thus, much greater challenges lay ahead as the population of India in 2050 will be 1750 million and the per capita availability of land will be 0.089 ha with projected freshwater supply of merely 1190 $m^3 year^{-1}$. Therefore, the growing threat of food insecurity and rapidly engulfing poor and under-privileged population leading to increased poverty; will be exacerbated further by the projected threats to agriculture due to consequences natural resource degradation and projected climate change effects.Conservation agriculture based management technologies has proved to produce more at less costs, reduce environmental footprints, promote conjunctive use of organics (avoids residue burning), improve soil health and promotes timely planting of winter crops to address issues of terminal heat stresses in the region. Like any other tillage and crop establishment technology, it may not be a panacea for all present day ills, but has proven to bring out south American agriculture out of its stagnant state almost 20 years ago, skyrocketing the cereals and oilseed production system. Thus, for addressing the issues of resource fatigue and bridge 'management yield gaps', Conservation Agriculture based management solutions are cornerstone.

2. CONSERVATION AGRICULTURE

Conservation agriculture (CA) is a farming approach that fosters natural ecological processes to increase agricultural yields and sustainability through key principles namely minimizing soil disturbance, maintaining permanent soil cover, and diversifying crop rotations.According to the Food and Agriculture Organization, tillage methods used by most farmers today are a major cause of soil erosion and desertification on many agricultural lands. As a result, farmers and scientists have been working to find alternatives to conventional tillage. Conservation agriculture (CA) has emerged as an alternative to conventional tillage that attempts to reverse the process of soil degradation. Over the past 2-3 decades, globally, CA has emerged as a way for transition to the sustainability of intensive production systems (Hobbs, 2007). CA permits management of water and soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to its degradation. It has assumed importance in view of the widespread natural resource degradation leading to increased production costs, unsustainable resource use, environmental pollution and deterioration of health of ecosystems. CA provides direct benefits to environmental issues of global importance, including control and mitigation of land degradation, mitigation of climate change, improved air quality, enhanced biodiversity including agrobiodiversity, and improved water quality. Besides this for a country like India where most of the farmers are small and marginal farm holders, adoption of CA can increase their ability to adapt to climate change by reducing vulnerability to drought and enriching the local natural resource base on which farm productivity depends. The CA aims at increasing the annual input of fresh organic matter, controlling soil organic material losses through soil erosion, and reducing the rate of soil organic material mineralization.

CA is conventionally viewed and defined as a set of field-level agronomic practices encompassed by three basic principles viz. i) minimizing soil disturbance through direct seeding, minimal or no tillage by machinery, draft animals, or humans; ii) maintaining permanent soil cover through the use of cover crops, intercrops, and/or mulching provided by crop residues or other organic matter sources; and iii) diversifying crop rotations to plant context-appropriate sequences of crops—often including nitrogen-fixing species-that help maintain soil health, while reducing pest and disease problems.

2.1 Benefits of conservation agriculture

Benefits to farmers: The benefits to farmers are i) reduced cultivation cost through savings in labour, time and farm power; ii) timeliness of sowing of crops helps in improving the use efficiency of residual moisture present in the soil and also will help the crops to be more resilient in future climate change scenario when the growing season of crops will be shorter or season may shift; iii) enhanced and sustainable yield with reduced use of inputs like fertilizers, pesticides, etc.; and iv) in case of mechanized farming, there will be a longer life and minimum repair of tractors and lower fuel consumption due to reduction in primary tillage operations. However, the benefits of CA come about over a period of time and in some cases, it may appear less profitable in the initial years.

Benefits to natural resources: Natural resources are benefitted by i) reduced soil degradation through reduced impact of rainfall causing structural breakdown, reduced erosion and runoff; ii) gradual decomposition of surface residues leading to increased organic matter and biological activity resulting in improved capacity of soils to retain and regulate water and nutrient availability and supply; iii) addition of organic matter and less disturbance of the soil through reduced tillage operations improves soil physical and biological properties resulting in better soil quality; iv) improved biological activity and diversity in the soil including natural predators and competitors; v) reduced pollution of surface and ground water from chemicals and pesticides, resulting from improved inputs use efficiency; vi) savings in non-renewable energy use and increased carbon sequestration; and vii) retention of crop residues through CA help in suppression of weed population

3. CONSERVATION AGRICULTURE: INDIAN SCENARIO

In India, CA based crop management technologies have been developed and deployed in several production systems and ecologies. But until recent past, the major focus of the technology development has remained on tillage, crop establishment and to some extent on residue management with primary domains of IGP. In India, efforts to adopt and promote resource conservation technologies have been underway for more than a decade (Abrol and Sangar, 2006). Concerns about stagnating productivity, increasing production costs, declining resource quality, declining water tables and increasing environmental problems are the major forcing factors to look for alternative technologies, particularly in the northwest region encompassing Punjab, Haryana and western Uttar Pradesh (UP). In the eastern region covering eastern UP, Bihar and West Bengal, developing and promoting strategies to overcome constraints for continued low cropping system productivity have been the chief concern. The primary focus of developing and promoting CA practices in India has been the development and adoption of zero tillage cum fertilizer drill for timely sowing of wheat crop in rice–wheat system, so as to escape terminal heat at maturity stage. Other interventions being tested and promoted in the Indo-Gangetic plains include raised-bed planting system, laser-aided land-leveling equipment, residue management alternatives, and alternatives to rice–wheat cropping system in relation to CA technologies. The area planted with wheat adopting zero-tillage drill has been rapidly increasing in last few years. It is estimated that over the past few years, adoption of zero-tillage has expanded to cover about 1.0 m ha. The rapid adoption and spread of zero tillage was attributed to benefits resulting from timely sowing of crop, reduction in cost of production, reduced incidence of weeds and therefore savings on account of herbicide costs, savings in water and nutrients and environmental benefits. Adopting CA systems further offers opportunities for achieving greater crop diversification. Crop sequences/rotations and agroforestry systems, when adopted in appropriate spatial and temporal patterns, can further enhance natural ecological processes which contribute to system resilience and reduced vulnerability to climatic extremes. Zero-tillage when combined with appropriate surface-managed crop residues sets in processes, whereby slow decomposition of residues results in structural improvement of soil and increased recycling and availability of plant nutrients. Surface residues are also expected to improve soil moisture regime, improve biological activity and provide a more favourable environment for growth. These processes, however are slow and results are expected only with time.

4. CONSERVATION AGRICULTURE: IN RAINFED AREAS

Unlike, in rest of the world, spread of CA technologies in India is taking place in the irrigated regions in the Indo-Gangetic plains where rice-wheat cropping system dominates. CA systems have not been tried or promoted in other major agro-eco-regions like rainfed semi-arid tropics, the arid regions or the mountain hilly-ecosystems on a large scale, though in some of the rainfed areas, CA in different forms have been tested. Considering the severe problems of land degradation due to runoff induced soil erosion, rainfed areas particularly in arid and semi-arid regions require the practice of CA more than the irrigated areas in order to ensure a sustainable production (Venkateswarlu *et al.,* 2009).

Unlike the homogenous growing environment of the IGP, the production systems in arid and semi-arid regions are quite heterogeneous with contrasting land and water management and cropping systems. These include the core rainfed areas, which cover up to 60-70% of the net sown area and the irrigated production systems in the remaining 30-40% area. The rainfed cropping systems are mostly single cropped in the red soil areas, while in the black soil regions; a second crop is taken on the residual moisture. In black soils, farmers keep lands fallow during *kharif* and grow *rabi* crop on conserved moisture. The rainfall ranges from >500 mm in arid to 1000 mm in dry sub-humid. Alfisols, Vertisols, Inceptisols and Entisols are the major soil orders. Soils are sloppy and highly degraded due to continued erosion by water and wind. Sealing, crusting, sub-surface hard pans and cracking are the key constraints, which cause high erosion and impede infiltration of rainfall. The choice and type of tillage largely depend on the soil type and rainfall. Leaving crop residue on the surface is an important component of CA, but in rainfed areas due to its competing uses as fodder, little or no residues are available for surface application. Experience from several experiments in the country showed that minimum or reduced tillage does not offer any advantage over conventional tillage in terms of grain yield without incorporation of surface residue. Leaving surface residue is the key to control runoff, soil erosion and hard setting of soil in rainfed areas, which are the key problems of the areas under Alfisols. In view of the shortage of residues in rainfed areas in arid and semi-arid regions, several alternative strategies have emerged for generation of residues either through *in- situ* cultivation and incorporation as a cover crop or harvesting from perennial plants grown on bunds and adding the green leaves as manure cum mulching. Agroforestry and alley cropping systems are other options, where biomass generation can be integrated along with crop production. This indicates that the concept of CA has to be adopted in a broader perspective for the arid and semi-arid areas which includes practices like reduced tillage, land treatments for water conservation, on-farm and off-farm biomass generation and agroforestry. Here, conservation tillage with residue retention on surface is more appropriate than zero tillage, which is emphasized in irrigated agriculture.

In a network project on tillage conducted since 1999 at various centers of the All India Coordinated Research Project for Dryland Agriculture, it was found that rainfall and soil type had a strong influence on the performance of reduced tillage. In arid regions (<500 mm rainfall), low tillage was found on par with conventional tillage and weed problem was controllable in arid inceptisols and aridisols. In semi arid (500-1000 mm) region, conventional tillage was superior. However, low tillage + interculturewas superior in semi-arid Vertisols and low tillage + herbicide was superior in Aridisols. In sub-humid (>1000 mm) regions, weed problem was severe depending on the rainfall distribution. In this zone, there is a possibility of reducing tillage intensity by using herbicide.

Results of a long-term conservation tillage experiment with soybean-wheat cropping system conducted on a Vertisol at the Indian Institute of Soil Science, Bhopal showed that the physical properties of the soil *viz.* mean weight diameter, soil water retention, hydraulic conductivity, infiltration characteristics improved significantly under both the reduced and no tillage systems compared to the conventional tillage system after ten cropping cycles. Soil organic carbon content and macro-aggregate associated carbon content of the conservation tillage treatments were also higher than the conventional tillage treatment, while the conservation tillage system maintained yield level on par with the conventional tillage system. Other conservation agriculture study also reveals that there was a relative improvement of some soil properties like moisture content, organic carbon and pools, and microbial biomass carbon under reduced tillage than conventional tillage after three years of crop cycle; however tillage had no effect on yield.

5. CHALLENGES IN ADOPTION OF CONSERVATION AGRICULTURE

Technological challenges: The CA system constitutes a major departure from the past ways of doing things. This implies that the whole range of practices, including planting and harvesting, water and nutrient management, disease and pest control, etc. need to be evolved, evaluated and matched in the context of new systems.

The key challenge relates to i) development, standardization and adoption of farm machinery for seeding and fertilizer placement in the midst of higher residue retained field with minimum soil disturbance; ii) evaluation and development of suitable weed management strategies like identification of appropriate herbicide molecules, integrated weed management through crop rotation and breaking weed life cycles etc. for various cropping systems and agro-ecoregions; iii) developing and continuously improving site specific crops, soil nutrient and pest management strategies that will optimize benefits from the new systems as well as accelerated adoption of CA; iv) stratification of nutrients especially build-up of phosphorus and potassium in the surface layer and difficulty in application of N fertilizer under residue retained plots; v) developing machinery like high clearance for standing crop as well as management of higher quantity of residues on the soil surface; and vi) training of man power for adoption of the new techniques, which needs new skills and management strategies.

Ways to overcome the challenges for the adoption of conservation agriculture in India are i) development of effective and specific herbicides to control weeds (such herbicides should not harm succeeding crops); ii) development of low-cost alternative methods of weed control, especially for resource poor farmers who cannot afford costly herbicide; iii) development of suitable crop rotations including cover crops and improved cropping sequences that result in more effective storage of rainfall and efficient utilization of soil available water, and control of weed population; iv) provision of appropriate equipment for differential placement of seeds/planting and fertilizer, proper nitrogen management through site specific nutrient management using greenseeker and leaf colour chart (LCC) coupled with soil test crop response value; v) identifying existing crop cultivars orbreedingnew lines that are adaptable to conservation tillage systems and also have characteristics that aid in erosion control as well as improve soil fertility; vi) development of custom hiring system for new CA equipments for better utilization and economics; and vii) capacity building for new skills and management strategies at different levels like training farmers/stakeholders, students, extension faculty and scientists for adoption of the new techniques.

6. RESEARCHABLE ISSUES

- Location specific CA package of practices for a range of farming situations in rainfed and irrigated areas need to be developed.
- There is an urgent need for developing strategies to achieve enhanced soil health, improved input use efficiency and carbon sequestration. Stratification of C, N, P, K and other nutrients in topsoil under CA need be studied.
- There is also a need for understanding the long-term impact of adopting CA practices on soil-water-plant continuum/relationship and ecosystem services like clean air and water.
- Enhanced capabilities and skills of scientific and stakeholders in the realm of CA need to be developed
- Well defined knowledge network for CA and better mechanism for information flow between farmers-researchers-extension staff-manufacturers for energy efficient and cost efficient technologies for different situations of the country is the need of the hour.

7. CONCLUSION

Many of the CA related soil processes, *e.g.* increased soil organic matter content and soil porosity, or increased biological nitrogen fixation by legumes in rotation, or exploitation of the deeper soil layers through crops with deep and dense root systems, have a significant bearing on nutrient management. Evidence shows that in CA systems, nutrient requirements are lower, nutrient efficiencies are higher and risks of polluting water systems with mineral nutrients lower. However, systematic research into CA systems and their nutrient management requirements are of relatively recent origin. In CA systems, the focus is on managing soil health and productive capacity simultaneously and which depends on many complex cropping system relationships in space and time and on biodiversity and organic matter within soil systems when they are enlisted on behalf of agricultural production. Ultimately, the management of nutrient input-output relationships in CA systems must balance the nutrient accounts, which means that the levels of outputs of biological products that are aimed at, will dictate the levels of inputs, and ongoing nutrient balances must remain positive. The major difference with CA systems is that the management of the multiple sources of nutrients and the processes by which they are acquired, stored and made available to crops are more biologically mediated. Much more research needs to be done on the different aspects of soil health and nutrient management in CA-system as is now beginning to occur as more countries begin to adopt and integrate CA concepts and practices into commercial production activities at both small and large scale as a basis for future sustainable production intensification strategies.CA is definitely a sustainable production system which not only conserves natural resources but also enhances productivity and soil quality. Location specific CA technology generation–dissemination–adoption of CA technologies has to be looked into for broader perspective with interdisciplinary approach and it must go hand in hand with close partnership of farmers.

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