Conservation Agriculture: A New Paradigm for Improving Input Use Efficiency and Crop Productivity

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Abstract

Conservation agriculture (CA) refers to a set of agricultural practices encompassing minimum mechanical soil disturbance, diversified crop rotation and permanent soil cover with crop residues to mitigate soil erosion and improve soil fertility besides soil functions. The CA aims to conserve, improve and make more efficient use of resources through CA-based technologies. It has many tangible and intangible benefits in terms of reduced cost of production, saving of time, increased yield through timely planting, improved water productivity, adaptation to climate variability, reduced disease and pest incidence through stimulation of biological diversity, reduced environmental footprints and ultimately improvements in soil health. However, weeds are a major biotic interference in CA, posing big defy towards its success unless all the principles are completely followed. Development of post-emergence herbicide and growing herbicide-tolerant crops and also the retention of crop residues as a mulch help in managing weed problems and also improve soil moisture retention. Furthermore, this practice of agriculture improves soil organic carbon content which ultimately leads to an increase in input use efficiency.

Keywords

Conservation agriculture • Crop rotations • Crop residues • Carbon sequestration • Nutrient dynamics • Weed management

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J.K. Bisht et al. (eds.), *Conservation Agriculture*,
DOI 10.1007/978-981-10-2558-7_2

2.1 Introduction

Modern agriculture is facing a serious problem of the decline in crop yield and deterioration in soil quality (Montgomery 2007) despite the use of improved varieties, adequate fertiliser nutrition and plant protection chemicals. Hence, synchronising the food demand of the ever-growing population can only be achieved through an alternative production system which can maintain high yields in consonance with maintenance of ecological equilibrium. Food security is a multidimensional theme, which directly hits the poor and needy and, in turn, the quality of life. The agriculture sector is the starting point for finding sustainable solution to overcome the food crisis. It is imperative to manage critical inputs and resources for a higher food production. The CA is an obvious new paradigm in the twenty-first century to achieve a base for sustainable agricultural production intensification (Friedrich et al. 2012). The CA aims 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 (Meena et al. 2013, 2015a, b; Singh et al. 2014; Kumar et al. 2015). The CA is described by FAO (www.fao.org.ag/ca) as a concept for resource-saving agricultural crop production, which is based on enhancing the natural and biological processes below and above the ground. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. CA involves three linked principles, viz. (i) providing permanent soil cover to mitigate soil erosion and to improve soil fertility and soil functions; (ii) minimum mechanical soil disturbance, i.e. reduced tillage (RT) or zero till/no tillage (NT) and direct seeding; and (iii) diversified, efficient and economically viable crop rotations and such type of rotations that contribute to maintaining soil biodiversity (Kassam et al. 2009). The CA can improve agriculture through improvement in water infiltration, enhanced ground water storage, reduced soil erosion, improved soil aggregates and reduced soil compaction through promotion of biological tillage, enrichment in soil organic carbon (SOC), moderated soil temperatures and enhanced microbial diversity and weed suppression; it also helps to reduce cost of production, saves time, increases yield through timely planting, reduces diseases and pests through stimulation of biological diversity and reduces greenhouse gas (GHGs) emissions.

2.2 Conservation Agriculture: Why?

Input-intensive conventional production system has led to second-generation problems such as deteriorating soil health, declining soil organic matter and increasing multiple deficiencies of N, P, K, S, Zn, Fe and Mn due to their overmining from soils (Ladha et al. 2000; Tiwari 2002), decline in the groundwater table, deterioration of groundwater quality (Humphreys et al. 2010), sodicity and salinisation problems (Tiwari et al. 2009), herbicide resistance, shift in weed flora and pest populations (Hobbs et al. 1997). The problems encountered due to input-intensive chemical-based conventional agriculture are:

(i) 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
(ii) Continuous monocropping system which led to the degradation of soil fertility
(iii) No recycling of crop biomass after harvesting, resulting in mining of nutrients
(iv) Overexploitation of groundwater resources
(v) Burning of crop residues after harvesting
(vi) Indiscriminate use of chemical fertilisers leading to decreasing factor productivity
(vii) Energy-intensive farming (Sharma et al. 2012)

The current production system management is posing a serious threat to food security and livelihood of farmers, especially the poor and marginal farmers. Land and water are the natural resources that are essential for the existence of life. Now, these precious resources are under tremendous pressure due to increasing demographic pressure and other biotic and abiotic stresses. Among the natural resources, land is a limited, finite, inelastic and a highly valuable natural resource and a base for food, feed, fuel and fibre production, besides providing many critical ecosystem services. A decrease in the per capita availability of agricultural land in India from 0.48 ha in 1950 to 0.15 ha in 2000, and likely a further reduction of 0.08 ha by 2020 due to continuous increasing industrialisation and urbanisation (Pande et al. 2012), is a serious cause of concern. A number of persons per ha of the net-cropped area were three in 1951 and six in 2000 and could rise to eight in 2025 in India. The present population of more than 1.2 billion, accounting ~18 % of world population supported by only ~2.4 % land area, is estimated to become 1.4 billion by 2025 and 1.7 billion by 2050 AD, needing annually ~380 million tonnes and 480 million tonnes of food grain, respectively (Yadav and Singh 2000). Hence, there is an urgent need to reorient the present management production system to a system which can improve the input (land, seed, water, labour, fertiliser and energy) use efficiency of advanced crop management technologies, while maintaining the natural resource base (Meena et al. 2015c, d).

2.3 Principles of Conservation Agriculture

The CA is a concept for resource-saving agricultural crop production system that strives to achieve acceptable profits together with high and sustained production levels while at the same time conserving and improving the environmental quality. CA system is based on enhancing natural biological processes above and below the ground. The key elements of CA include adequate retention of crop residues on the soil surface for mulching, diversified crop rotations and cropping systems coupled

Fig. 2.1 Three linked principles of conservation agriculture

with minimum soil disturbance through controlled traffic (Hobbs et al. 2008), and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin is applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological base. CA is characterised by three core principles (Fig. 2.1) which are linked to each other, viz. minimum soil disturbance, permanent soil cover and diversified crop rotations. These principles are very specific and economically viable in different agroclimatic and socio-economic conditions of the farmers.

2.3.1 Minimum Soil Disturbance

Minimising mechanical soil disturbance is aimed at reducing tillage operations to the minimum necessary for ensuring a fine seedbed, proper germination and satisfactory crop stand. In the past, soil tillage increased the soil fertility due to mineralisation of soil nutrients (Dumanski et al. 2006), but long-term unnecessary tillage operations led to soil erosion and degradation of soil structure (Donovan and Casey 1998). The introduction of ZT or minimum soil disturbance is to curb the negative impact of excessive tillage and also to reduce soil erosion, which ultimately improves soil and water conservation (Li et al. 2007). Minimising soil disturbance also maintains proper aeration in rooting zone, oxidation of organic matter, water movement in soil and also exposing the weed seeds either for germination (Kassam and Friedrich 2009) or as prey to beetles.

2.3.2 Permanent Soil Cover

A permanent soil cover is important to protect the soil against the deleterious effects of exposure to rain and sun and also provide micro- and macroorganisms in the soil with a regular supply of food and alter the soil physical environment for optional growth and development of soil organisms. Crop residue is the principal component of soil cover to protect soil and water erosion from top soil and also playing an important role in building soil organic matter, nutrient recycling and improving soil quality (Chauhan et al. 2012). Crop residues are the principal sources of carbon and it has significant effect on soil physical, chemical and biological soil properties (Kumar and Goh 2000).

2.3.3 Diversified Crop Rotations

Diversified crop rotation is of paramount importance in mitigating the biotic and abiotic problems, arising in monoculture particularly in rice–wheat cropping system. It must be suited to different agroclimatic and farmers' socio-economic conditions. Crop rotation involving legumes helps in minimal rates of build-up of population of pest and diseases through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing soil biodiversity (Kassam and Friedrich 2009; Dumanski et al. 2006). Inclusion of legume crops in rotation can also play an important role in conserving groundwater and soil water. Moreover, the quality of these crops (higher protein content) is better than wheat and other cereals in rice–wheat-grown areas. Particularly in wheat, crop rotation addresses the problems of insect, pest and diseases by integrating crop rotations, which help to break the cycle that perpetuates crop diseases such as wheat rust and pest infestations, resulting in higher yield (Witmer et al. 2003).

Nowadays the controlled traffic is loosely taken as the fourth principle (Sims 2011) of CA to ensure less or no soil compaction due to broad wheel tires of tractors. CA systems are not only about the use of one or two principles, although this sort of practice has been very common in adoption of CA in certain crops and locations in India, such as precision planting using a seed drill or planters without tillage or significantly reduced tillage and zero-till sowing without residue in wheat. Rather, it is a holistic set of management practices that can ensure more production in a sustainable manner. The CA is aimed to enhance the input use efficiency through conserving, improving and making more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. CA is now considered the principal path to sustainable agriculture. Thus, it is a way to achieve goals of higher productivity, while soil erosion, water losses from runoff and soil physical degradation may be minimised by reducing soil mechanical disturbance and marinating permanent soil cover (Serraj and Siddique 2012). CA also helps to improve soil biodiversity in the natural agroecosystem base (Friedrich et al. 2012). CA system requires a total paradigm shift from conventional agriculture with respect to integrated

Table 2.1 Some distinguishing features of conventional and CA systems

Conventional agriculture	Conservation agriculture
Cultivating land/ploughing soil/tilling the soil using science and technology to dominate nature	Least interference with natural processes in harmony with nature
Excessive mechanical tillage and soil erosion	ZT or drastically reduced tillage (biological tillage)
High wind and soil erosion	Low wind and soil erosion
Residue burning or removing all organic matter (bare surface)	Surface retention of residues (permanently covered soil surface)
Water infiltration is low	Infiltration rate of water is high
Use of ex situ FYM/composts	Use of in situ organics/composts
Green manuring (incorporated)	Brown manuring/cover crops (surface retention)
Kills established weeds but also stimulates more weed seeds to germinate	Weeds are a problem in the early stages of adoption but decrease with time
Freewheeling of farm machinery, increased soil compaction	Controlled traffic, compaction in tramline, no compaction in cropped area
Monocropping/culture, less efficient rotations	Crop diversification and efficient crop rotations
Heavy reliance on manual labour, uncertainty of operations	Mechanised operations, ensure timeliness of operations
Poor adaptation to stresses, yield losses greater under stress conditions	More resilience to stresses, yield losses are less under stress conditions
Productivity gains in the long run are in declining order	Productivity gains in the long run are in incremental order

Source: Sharma et al. (2012)

management of crops, soil, water, nutrients, weeds and farm machinery (Table 2.1). Farmers are interested in sustainable crop production system to adopt and adapt improved crop management practices, and this may be considered as a new paradigm of the twenty-first century for higher crop productivity and sustainability.

2.4 Spread of Conservation Agriculture in India and World

CA is gaining more attention in both rainfed and irrigated ecosystems of the tropics, subtropics and temperate regions all over the world. At present ~157 M ha area (Fig. 2.2) is practised under the CA system, particularly in the USA, Brazil, Argentina, Canada, Australia, China and Russian Federation, which covers more than 11 % of the world's arable land area (Fig. 2.3) and continues to spread at an annual rate of ~10 M ha (Kassam et al. 2014). In India, CA adoption is still at a nascent stage, but CA-based crop management technologies are being practised in ~43 M ha (Jat et al. 2011) including ~1.5 M ha under the rice–wheat system in the Indo-Gangetic Plains (IGP). In South Asia, it covers almost 3 M ha, and ZT in wheat after rice harvest is the most widely adopted CA technology in the IGP of South Asia particularly in India. ZT technology is being adopted particularly in the

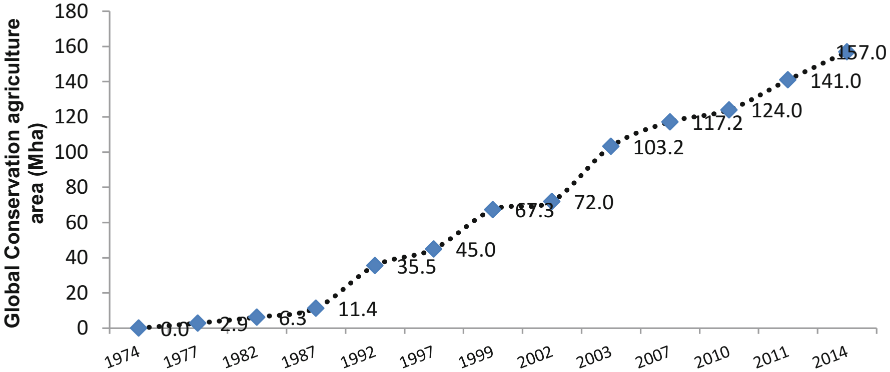

Fig. 2.2 Year-wise adoption of conservation agriculture (Source: FAO 2015)

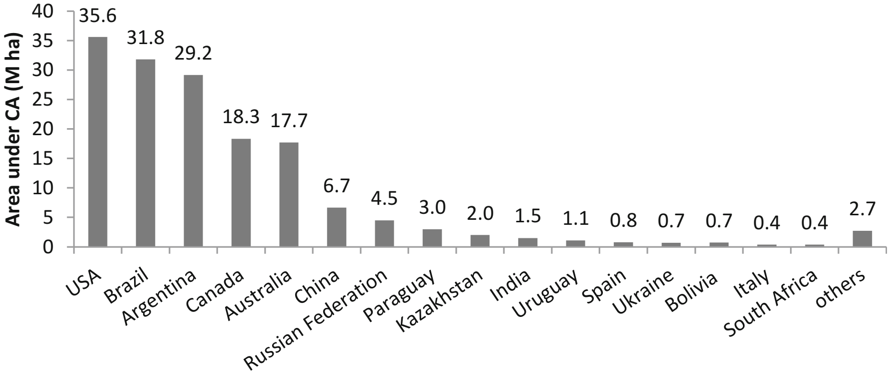

Fig. 2.3 Conservation agriculture system adoption in major countries (Source: FAO 2015)

northwest IGP of India. Although the potential area of this technology is estimated to be 10 M ha, only ~20 % has been achieved till now. CA-based management practices have shown the benefits in enhancing the natural resource base, improving input use efficiency, soil aggregation, soil health, farm productivity and mitigation of climate change.

The ZT has been a success in rice–wheat cropping system due to reduction in cost of production by 2000–3000 per ha, which is the main driver behind its spread (Malik et al. 2005), and improved soil health (Jat et al. 2009; Gathala et al. 2011) too. The potential of C sequestration in C-depleted soils of India is high with the adoption of ZT. Long-term carbon sequestration and build-up of soil organic matter constituted a practical strategy to mitigate GHG emission and impart greater resilience to production systems to climate change (Saharawat et al. 2012) and improved environmental quality (Pathak et al. 2011). Crop residue management provides an opportunity to protect the topsoil, enriched with organic matter, moderate soil temperature, improve soil biological activities (Gathala et al. 2011) and also enhance the water and nutrient use efficiency (Jat et al. 2012; Meena et al. 2015e; Verma et al. 2015a; Ghosh et al. 2016).

Development of non-selective contact and post-emergence herbicide for weed control provided a base for recommendation and allowed for consistent yield and creditable performance, particularly reducing the incidence of the predominant weeds *Phalaris minor* in wheat (Malik et al. 2005).

2.5 Tillage and Crop Establishment: Machinery

Anomalies associated with plough-based farming include deteriorating soil physical environment, declining factor productivity, labour and water shortage, escalating cost of production (Jat et al. 2009; Ladha et al. 2009; Chauhan et al. 2012), emerging new weed biotype and climate change-related challenges. Hence, fundamentally CA requires suitable farm machinery for tillage and crop establishment, fertilisation, weeding, irrigation, crop harvesting and other operations. Crop establishment depends on the external inputs (seed, fertiliser, weedicide, etc.), soil, climatic, machinery and management factors. The first two core principles of CA demand specialised machinery for seeding on unploughed field with crop residue. Direct seeding with ZT machine is one of the best technologies that potentially addresses the issues of labour, energy, water, soil health, etc. (Gathala et al. 2011; Jat et al. 2013) and adaptations to climatic variability (Jat et al. 2009). However, the ZT machinery could not carry out seeding effectively in high quantity of crop stubble, which normally occurs in CA systems. Therefore, the use of the new generation machines like happy seeder, rotary-disc drill, double-disc drill and punch planter may lead to wider adoption of CA (Sidhu et al. 2007). Farmers generally remove the residue or burn prior to wheat sowing, which leads to losses of soil organic matter and nutrients and creates environmental pollution (Singh et al. 2007).

Happy seeder, an improved version of the ZT seed drill machine, developed in Punjab provides an alternate to burning for managing crop residues and allows direct seeding of wheat in high quantity of crop residues (5–9 t/ha of anchored and loose straw). Happy seeder and rotavator are considered to be the efficient equipments for in situ management of rice straw as well as control of weeds (ACIAR 2013; Kang 2013). Qamar et al. (2013) have also noticed a higher growth rate and grain yield in ZT with happy seeder. The advanced version of happy seeder, like turbo seeder, combo happy seeder, post-consumer recycled (PCR) planter and easy seeder, is also being designed for efficient crop establishment and fertiliser placement. Hence, for CA system, the machines need to be more user-friendly to develop the interest of private manufactures for investing in the machine (Akter and Gathala 2014).

2.6 Weed Management in CA Systems

Weed infestations are the major constraints and its control is a major challenge in CA-based systems since weed ecology and management are entirely different in CA systems. Weeds pose serious threat to the companion crop through its competition for nutrients, water, sunlight and space, which cause considerable reduction in yield. Under the tillage system, ploughing and harrowing kill growing weeds mainly by burial, whereas elimination of conventional tillage may cause serious problem regarding weed infestation (Buhler et al. 1994). In CA system, weed seed bank, dispersal mechanism, distribution, growing pattern, weed competition, etc. are more complex than conventional agriculture. Shifts in weed populations from annuals to perennials have been observed in CA systems, and these are known to thrive in CA systems such as Bermuda grass (*Cynodon dactylon*), nutsedge (*Cyperus rotundus*) and Johnson grass (*Sorghum halepense*) which generally reproduce from underground plant storage structure: stolons, tubers or nuts and rhizomes, respectively (Sharma et al. 2012). Similarly, Mukherjee and Debnath (2013) reported higher weed biomass of *Polygonum pensylvanicum*, *Polygonum Persicaria*, *Polygonum orientale*, *Oldenlandia diffusa*, *Cynodon dactylon* and *D. sanguinalis* in Terai region of West Bengal, India. Weed species shifts and losses in crop yield as a result of increased weed density have been cited as major hurdles to the widespread adoption of CA. Hence, it requires special approaches for effective weed management in CA systems such as preventive measures, modified tillage, improved cultural practices (tillage, crop residue, intercropping, cover cropping, competitive crop cultivars, planting geometry, sowing time, nutrient management, etc.), chemical weed control, biological weed control, herbicide-tolerant cultivars and integrated weed management (IWM).

2.6.1 Preventive Measures

Preventive measures are first and the most important steps to be taken to manage weeds in general and especially under a CA system because ‘prevention is better than cure’.

Weeds may tolerate compaction and drainage problems better than many crops. As a result, weeds are more competitive and problems are more severe particularly in CA systems. The best way to control weeds is by keeping them out of your fields:

All weed control encompasses all measures taken to prevent the introduction of weeds (Rao 2000), such as the use of clean seed (certified seed), and prevent the dissemination of weed seeds from one area to another or from one crop to another by using clean equipments (Das 2014);

Controlling weeds in ditches and at the edges of fields or around sloughs is an important practice for limiting the spread of weeds, for example, Canada thistle;

Preventing the weed seeds’ dissemination and dispersal;

Using well-decomposed compost and manure so that it does not contain any viable weed seeds;

Mechanically removing weeds before they have a chance to set seed is an important form of field sanitation.

2.6.2 Modified Tillage Operations

Modified tillage operations provide an opportunity to suitable weed management tools in CA system. It is observed that crop yields can be similar to conventional and CA systems if weeds are properly controlled and crop stands are uniform. Results of on-farm trials at several locations in Haryana, India, revealed that the population of *Phalaris minor* was considerably lower and grain yield of wheat was comparatively higher under ZT as compared to CT (Gupta and Seth 2007). A review of literature indicated that ZT increased as well as the reduced infestation of certain weed species in different crops (Verma and Srivastava 1989; Singh et al. 1998; Chauhan et al. 2003). The infestation of problematic and troublesome weed, *Phalaris minor*, was lesser in ZT wheat due to minimum disturbance of soil (Chauhan et al. 2001; Agarwal and Goswami 2003), and ZT reduced the weed seed bank as compared to disturbed soils, and there was less multiplication of weed seeds in the succeeding years (Singh et al. 2010). Although ZT significantly increased the population of *V. sativa*, it reduced the population of *C. album* in vertisol in Jabalpur, India (Sharma et al. 2013). Thus, ZT with appropriate crop cultivars and herbicide selection provided advantages over conventional tillage (Tubbs and Gallaher 2005; Verma et al. 2015b; Meena et al. 2016).

2.6.3 Improved Cultural Practices

Cultural practices are aimed to ensure better soil and crop management (Nazir 1994). Successful weed management is not to merely control weeds in a crop field, rather to create a system that reduces weed establishment and minimises weed competition with crops. There are different ways to handle weeds by improved cultural management practices. Effective water management plays a vital role in weed control under the CA System. Soil cover with dead or live mulch and crop cover also one of the pillars of CA. The crop/cover crop residue may also release some toxic substances, which may also suppress weed seed germination process (Ramesh 2015). Crop rotation in CA is a successful approach to reduce the weed pressure. Laser land levelling is an integral part of CA as it provides uniform moisture distribution to the entire field and allows uniform crop stand and growth, leading to lesser weed infestation. Reduction in weed population in wheat after 30 days was recorded under precisely levelled fields in comparison to traditional levelled fields (Jat et al. 2009). Row crop cultivation is also a good approach to accomplish the management of weeds under reduced tillage. It is very effective to combine the chemical approach and row crop cultivation maintaining high residues in the field. Mulch tillage is specially designed to retain more than 30 % crop residues on the surface, suppressing different weeds due to shading or covering effect. Moreover, different types of organic compounds released from mulches through leaching cause inhibition of weed seed emergence (Ball 1992).

2.6.4 Chemical Weed Management

Herbicides are another weed control option, but greater attention must be given to alternative control methods and to ensuring that chemicals are used properly to reduce health risks and environmental damage. Herbicides are less effective, if improperly applied, for instance, at the incorrect time and dose, or without appropriate adjuvants. Most commonly used burn-down herbicides are glyphosate, paraquat, glufosinate, 2,4-D and dicamba. The rate and time of application is very critical in CA systems as the weed control under ZT systems based on vegetation cover is present in the field (Vargas and Wright 2005). Several low-dose, high-potency, selective, post-emergence herbicides and mixtures are available for effectively managing weeds in crops like rice and wheat grown in sequence under CA system. However, the recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in CA system.

In fact, many farmers in India apply isoproturon, a good broad-spectrum herbicide, by broadcasting it with sand or urea. Improper herbicide use has probably contributed to the herbicide resistance in *P. minor* in India and *A. fatua* in Mexico (Malik and Singh 1995). The use of new herbicides or a mixture of herbicides is another alternative and will remain a part of the weed control strategy. In CA systems the presence of residue on the soil surface may influence soil temperature and moisture regimes that affect weed seed germination and emergence patterns over the growing season. This shows that under CA system, farmers have to change the timing of weed control measures in order to ensure their effectiveness. Soil surface residues can interfere with the application of herbicides, so there is a greater likelihood of weed escape if residue is not managed properly or herbicide application timings or rates are not adjusted. Some herbicides intercepted by crop residues in CA systems are prone to volatilisation, photodegradation and other losses. The extent of loss, however, may vary depending upon their chemical properties and formulations. Herbicides with high vapour pressure, e.g. dinitroaniline herbicides, are susceptible to volatilisation loss from the soil surface.

2.6.5 Herbicide-Tolerant Crops

Herbicide-tolerant crops are designed to tolerate specific broad-spectrum herbicides, which kill the surrounding weeds, but leave the cultivated crop intact. Several crops have been genetically modified to be resistant to non-selective herbicides; particularly glyphosate-resistant soybean has been adopted principally because it simplifies weed control to the use of a single herbicide and with a more flexible timing than that required for conventional herbicides. However, it is very difficult to isolate the effects of the adoption of GM crops from other factors which may affect pesticide use (Heimlich et al. 2000). Almost 90 % of all transgenic crops grown worldwide are glufosinate and glyphosate resistant (GR) (Duke and Powles 2008). GR crops offer farmers a vital tool in fighting weeds and are compatible with NT agriculture (Duke and Cerdeira 2005). They give farmers the flexibility to apply herbicides only when needed, to control total input of herbicides and to use herbicides with preferred environmental characteristics. Aulakh et al. (2010) reported that glyphosate-tolerant cotton increased 13–29 % higher yields than the glufosinate-tolerant cotton and conventional cotton.

2.6.6 Integrated Weed Management in CA System

Integrated weed management (IWM) is a holistic approach under CA system. This also includes the biological weed control methods. Biological weed control offers a huge, largely untapped resource for weed control method (Kennedy 1999); it includes a large number of available living entities such as predators, pathogens and other plant competitors of weeds that are exploited to kill or suppress the weeds. Microorganisms that suppress growth of many common agricultural weeds have been identified and commercial development is underway (Stubbs and Kennedy 2012). In short, it is an effective method of weed control in CA systems. IWM is basically a long-term approach which aims to manage weeds rather than controlling weeds. IWM has the potential to restrict weed populations to manageable levels; reduce the economic losses, risk to human health and potential damage to the ecosystem; increase cropping system sustainability; and reduce selection pressure for weed resistance to herbicides. A combination of different weed management strategies such as herbicide rotation, green manures (Kirkegaard et al. 2014), selection of suitable crop cultivars and cropping systems coupled with CA principles may help in weed management (Ramesh 2015).

2.7 Nutrient and Water Management

Tillage practices favourably modify the soil physical and biological environment facilitating root proliferation. These actively growing roots can take up nutrients from a greater soil volume and could improve the nutrient use efficiency. Conservation tillage (CT) and deep tillage increased NPK uptake compared to minimum tillage (MT). Tillage practices along with organic matter (OM) further affected the moisture and nutrient availability to crops. The availability of nutrients at different growth stages of *Sorghum* was increased by deep tillage (Patil and Sheelavantar 2006). In general, crop yields under ZT practices are more stable than under tilled systems with greater efficiency in the use of nutrients (Martin 2006). The retention of crop residues on the soil surface, along with fertilisation with organic manure and involvement of legumes in crop rotation coupled with MT and ZT practices, plays an important role in sustaining soil fertility, improving fertiliser/water use efficiency (WUE) and physical conditions of soils and enhancing crop productivity and agricultural sustainability (Dalal and Chan 2001; Lampurlanes et al. 2001). The chemical, physical and biological fertility of soil is depending on soil organic carbon (Chan et al. 2008).

Crop residues enhanced the soil organic matter and total soil N levels in the long term (Cassman et al. 1996). Mohammad et al. (2012) found that N yield and fertiliser N utilisation by wheat were increased significantly by crop residues under NT compared to the tillage. Higher nutrient use efficiency (i.e. PFP) of applied N under NT than in conventional tillage was probably due to better moisture conservation under NT which might have facilitated plant nutrient uptake. Formation of a layer of crop residues on the soil surface under NT system improved the crop growth rate and nutrient uptake (Sapkota 2012). Sapkota et al. (2014) conducted on-farm trials in seven districts of Haryana, India, for two consecutive years (2010–2011 and 2011–2012) to evaluate three different approaches to SSNM based on recommendations from the Nutrient Expert® (NE) decision support system in NT and CT-based wheat production systems; as a result NT with site-specific approaches for nutrient management can increase yield, nutrient use efficiency and profitability while decreasing GHG in wheat.

Nutrient management in CA is a significant concern of agriculture today. Intensive cropping pattern over the years have mined soil nutrients due to improper replenishment. Increasing the awareness and close monitoring of nutrient budgeting will promote the researchers and farmers to compute the soil nutrient input–output balance sheet in rational ways. In the conventional system of crop cultivation, the tillage operation is higher which promote higher level of soil disturbance and affected the nutrient dynamics in soil. The soil surface, covered with crop residue also modified the soil properties in many ways, especially nutrient availability to crops (Dotaniya 2012). Nutrient management in CA system mainly follows some basis aspects like:

(i) Enhance the soil biological process to protect the soil microorganism population and diversity, so that the SOM is either build-up or maintained.
(ii) Maintain the adequate biomass production and biological N fixation in relation to soil biota activities in terms of soil energy and nutrient stocks.
(iii) Provide adequate access to all plant nutrients by plant root from soil solution, from natural and also from synthetic sources, to fulfil the crop demand.
(iv) Keep soil pH within the acceptable range.

Reduced tillage practices in CA reduced the rate of soil organic C burning, preserved C, enhanced the soil aggregation or reduced the soil bulk density. The soil residue cover directly increased the soil C on the soil surface (Dotaniya et al. 2013). The nutrient management approaches like integrated soil fertility management (ISFM) and integrated natural resources management (INRM) are having more attention on meeting crop nutrient requirement rather than managing soil health and land productivity. In the CA system, the use of both organic and inorganic plant nutrient sources is listed in ISFM and INRM process as per the requirement of crop and soil with respect to temporal and special variability.

The CA is widely affected by the tillage and cropping system, and the soil health improvement, enhancement of crop productivity and wide support to livelihood and the environment are interlinked with them. The old agricultural practices clearly described that healthy agricultural soils constitute biologically active soil system and having wide range of soil microbial diversity and plant nutrient process are in equilibrium with various existing phases and the adequate nutrient supply to plants in combination of ecosystem services. In the present context, CA emerged as a new breakthrough system approach for crop production and soil health. It represents biologically and bio-geo-physically integrated system of nutrient management during crop production and maintaining soil health in the long perspective (Friedrich and Kassam 2009). It could reduce the requirement of external inputs due to generation of high level of internal ecosystem services, which enhanced the crop production factor response in higher magnitude.

The CA practice depends on the climate and resources availability, i.e. in dry tropical and subtropical ecologies with small number of farmers with poor resources, the establishment of CA will take a longer period. The long-term applications of conservation practices improve the soil organic carbon and soil properties, mostly in ~10 cm upper soil layer. Increasing levels of C improved the soil aggregates, water holding capacity, microbial growth and plant nutrient transformation and reduced soil erosion. Application of crop residue on the soil surface conserved the soil moisture and mediated the plant nutrient dynamics. India produces a larger amount of crop residues approximately 500–550 MT annually (IARI 2012); these residues are used through the major practices like burning, incorporation and removal. It affected the N availability in soil solution due to immobilisation with wider C/N ratio of incorporated crop residues and the crop productivity (Bradford and Paterson 2000). Some researchers suggested that temporary immobilisation of N in the ZT system caused the leaching and denitrification losses of mineral N, but in longer way, it reduced the N application rate; and initial N fertiliser requirement during the crop production is high (Dotaniya et al. 2014). In case of P availability, it was more reported in ZT compared to conventional tillage practices. Accumulation of higher P concentration in the surface layer in ZT compared to CT is due to more availability of residue. According to Ismail et al. (1994), after 20 years of ZT practice, availability of P was increased ~42 % in upper 0–5 cm and lower (8–18 %) in 5–30 cm as compared to CT in a silt loam soil.

Increasing the crop residues in CA practice increased the availability of K in surface soil solution and declined with increasing soil depth (Du Preez et al. 2001). According to Govaerts et al. (2007), permanent raised bed enhanced the extractable K concentration 1.65 times in 0–5 cm and 1.43 times higher in 5–20 cm soil under ZT over conventional practice under crop residue retention plots. Micronutrient role in crop production is also important, and the use efficiency of these fertilisers is lower than macronutrient fertilisers, but the role in crop production is vital. Addition of organic residue in CA enhanced the micronutrient concentration, especially cations (Zn, Fe, Cu and Mn), than conventional tillage practices. Zn and Mn concentration are more found under ZT, due to surface placement (0–5 cm) of organic residue compared to conventional tillage (Franzluebbers and Hons 1996). However, CA improved the soil properties, i.e. chemical, biological and physical, and plant nutrient concentration influences the soil biological activities and nutrient transforming process.

An intensive soil tillage and mismanagement of irrigation water and fertilisers under current agricultural practices have accelerated the pace of degradation of irrigated dry lands in India. Increasing water scarcity and concerns of irrigation water quality have further raised serious doubts about the sustainability of current conventional agricultural systems. WUE of crops can be improved by the selection of crops and cropping system based on the availability of irrigation water resources. The latter can be achieved by the selection of irrigation methods, irrigation scheduling, tillage, mulching and fertilisation. Puddling rice paddies reduces percolation of water and leaching of fertilisers, especially N, besides helping in weed control. ZT machines have become particularly relevant in rice–wheat cropping system, where wheat sowing is generally delayed if the conventional methods of pre-sowing irrigation and land preparation are adopted (Mehla et al. 2000). It is now possible to sow wheat soon after rice harvest without primary cultivation, which permits timely sowing (Yadav et al. 2005) and saving irrigation water for field preparation. The advantage of ZT has also been reported for maize after rice in Telangana region of Andhra Pradesh (Reddy and Veeranna 2008). Reducing tillage and optimising N fertilisation are important strategies for soil and water conservation and N use efficiency for sustainable agriculture. Incorporation of crop residues on the soil surface under ZT system minimises water loss through evaporation which enhances higher growth rate of crop leading to higher water productivity (Sapkota 2012).

On a sandy loam (Typic Haplustept) soil in semiarid climate of New Delhi, Saha et al. (2010) evaluated the effect of tillage (ZT and CT) and residue management (incorporation, retention and removal) on soil physical properties after 3 years of continuous maize (*Zea mays*)–Indian mustard (*Brassica juncea*) sequence and reported that ZT optimised water use by ~14 % and 12 % in maize and mustard, respectively, as compared to conventional tillage. Maximum WUE was obtained in conventional tillage with residue incorporation, mainly because of maximum yield in maize (2.93 t/ha) and mustard (1.83 t/ha) obtained under the treatment (Fig. 2.4). Continuous rice–wheat cropping with intensive tillage in the IGP of South Asia has resulted in land degradation and inefficient use of water. Hence replacement of rice with less water-requiring crops such as soybean in RW system and identification of effective strategies for tillage management are prime need to sustain the productivity in the IGP of India. An experiment conducted in the IGP of India by Ram et al. (2013) revealed that soybean and wheat planted on raised beds recorded ~17 % and 23 % higher WUE, respectively, than in flat-bed planting. Similarly, Das et al. (2016) also reported that CA had significantly higher WUE as compared to conventional tillage in second and third year experiments despite the similar water use in pigeon pea (*Cajanus cajan* L.)–wheat (*Triticum aestivum*) system in the IGP region.

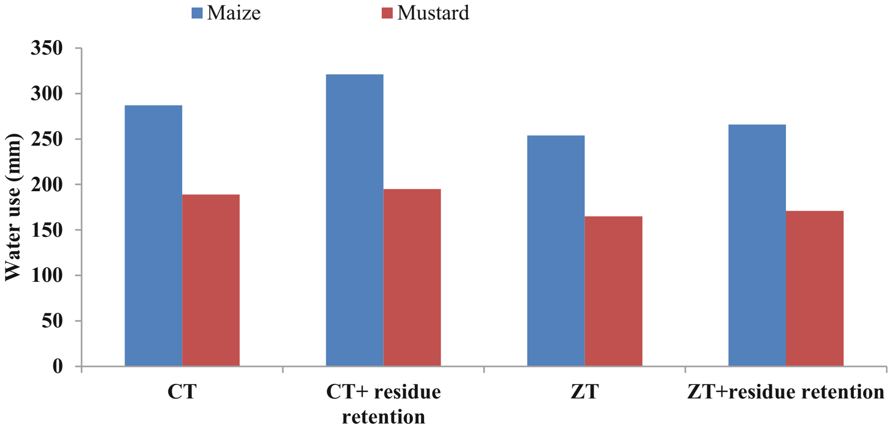

Fig. 2.4 Water use under different CA practices (Source: Saha et al. 2010)

2.8 Crop Productivity Levels in CA

The crop yield can be variable in the CA system (Farooq et al. 2011), for example, a CA may increase crop yield through improving soil fertility by conserving soil, water and sequestering organic carbon in farmland soils (Holland 2004; Goverts et al. 2007; Liu et al. 2010). The real effects of CA on crop yield may depend largely on specific CA practices, regional climate characteristics and cropping systems (Hobbs et al. 2008; Giller et al. 2009). CA systems also include improved efficient cultivars, less inputs and improved production and income and address the emerging problems (Gupta and Seth 2007; Saharawat et al. 2009). The CA technologies involve ZT or minimum-till farming with direct seeding, bed planting and crop residue retention for higher input use efficiency (Abrol and Sanger 2006) , crop productivity and stability (Bhushan et al. 2007), and also CA includes crop diversification and laser land levelling for increasing input use efficiency and higher farm profitability. Sen et al. (2002) recorded significantly higher grain yield of wheat under ZT as compared to conventional system, while Yadav et al. (2005) reported higher yield attributes of wheat, viz. effective tillers, grain per spike and 1000-grain weight. ZT resulted in better aggregate stability, more earthworms, a more open and continuous network of soil pores, more roots in the top 100 mm of soil and the same yield at lower cost. Guo et al. (1995), who studied ZT and minimum tillage in wheat for 25 years in an area where soils are heavy and plant stands are poor, reported that CT helped to preserve surface soil moisture and improved plant stands, soil structure and weed control.

The MT along with crop residue management has been found to be beneficial for improving crop productivity (Sharma et al. 2005; Saharawat et al. 2009; Jat et al. 2012). In similar, CT to wheat with crop residue retention on surface produced grain yield either equivalent to or greater than residue incorporation at sowing in conventional tillage in hills of north-west India (Achrya et al. 1998). Tillage with the incorporation of wheat residue in the cotton–wheat system increases seed cotton yield by 23–39 % (Jalota et al. 2008), and the reduced tillage in cotton and minimum tillage in wheat were also found to be effective with respect to soil disturbance to sustain yield and apparent crop productivity in the cotton–wheat system (Blaise 2014). In China, Zhang et al. (2007) reported relay cropping of cotton in wheat row had land use advantages than monocultures. Zheng et al. (2014) performed a meta-analysis to quantify the actual impacts of different CA practices such as NT/RT only, CT with straw retention (CTSR) and NT with straw retention (NTSR) on crop yields as compared to CT without straw retention and found that each CA practice, CTSR and NTSR significantly increased crop yield by ~4.9 % and 6.3 %, respectively, as compared to CT. Similarly, Ghosh et al. (2015) reported that the mean wheat equivalent yield was 47 % higher with CA as compared to conventional agriculture in maize–wheat crop rotation. The results across IGP in India suggested that double ZT with retention of crop residues produced higher system productivity over conventional and ZT without residues (Jat et al. 2011). A comparison of different CT practices that include ZT drilling, strip till drilling, rotary till drilling, bed planting and conventional sowing and crop residue management practices (retrieval, burning and recycling) in rice–wheat cropping system on crop productivity by Singh and Sharma (2005) over 6 years revealed that the rotary, strip and zero-till drilling and bed planting of rice and wheat provided higher yields (2–8 %) and are cost-effective (9–27 %) and energy efficient (21–32 %).

The in situ recycling of wheat straw provided rice yields of 6.3 t/ha that was 11 % and 7 % higher than residue retrieval and burning, respectively. In another study at New Delhi, direct-seeded rice (DSR) alone gave ~0.5 t/ha lower yield than transplanted rice in rice–wheat cropping system. However, the loss was compensated when brown manuring with *Sesbania* was done or green gram residues were incorporated in the previous summer season, while the highest productivity was recorded under DSR followed by ZT wheat and green gram cropping system (Sharma et al. 2012).

The addition of crop residues in soil before sowing had a positive effect on the restoration of soil fertility, which results in increased yield (Table 2.2). The wheat and rice yield increased with crop residue, left over stubble and fly ash application

Table 2.2 Effect of crop residues on grain yield of rice and wheat

Crop/ treatment	No crop residues	Pre-crop residues at 5 t/ha	Leftover stubbles	Fly ash at 2 t/ha	CD ($P = 0.05$)
Rice					
2001	2.93	3.42	3.12	3.39	NS
2002	3.29	3.68	3.65	3.95	0.31
Wheat					
2001	1.87	2.33	2.25	2.37	0.22
2002	1.96	2.29	2.21	2.42	0.16

Source: Kachroo and Dixit (2005)

(Kachroo and Dixit 2005). Generally, straw retention improved aggregate stability, reduced soil erosion, and increased the infiltration and conservation of soil water, thus enhancing soil productivity (Li et al. 2007; He et al. 2009, 2011). Additionally, straw retention directly increased the input of organic matter and nutrients into soil, in turn improving soil nutrient availability for crop growth (Kaschuk et al. 2010; Qin et al. 2010).

2.9 Energy Conservation and Climate Change

Modern agricultural production system is energy and input intensive and also depends on the external use of fossil fuels for excessive use tillage, overuse of fertilisers, pesticides and other farm operations. Paddy field contributes to 5–20 % of total methane emission throughout the world under the conventional system (Scheehle and Kruger 2006; IPCC2007; Xu et al. 2007). However, CA-based technology may mitigate the risk of methane emission through direct seeding of rice crop into the field by ZT machine without standing water such as upland wheat. Similarly, the extensive tillage operations prior to wheat crop sown can be the source of atmospheric CO_2 when octane-rich fuel is used (H-ur-Rehman et al. 2015). ZT improves the operation field capacity by 81 % and grain yield by ~6 % in the CA system due to reduced tillage, or ZT ensures more timely sowing, precision and quality of field operations; saves labour and irrigation water cost; reduces weather risk in these changing climatic scenarios with improved crop productivity; and generates employment (Barclay 2006; Ladha et al. 2009; Saharawat et al. 2010). Mishra and Singh (2012) reported that the rice–wheat system require maximum energy (38,187 MJ/ha) under the conventional tilled system due to intensive field operations, whereas CA-based ZT system requires less energy and a has high energy output to input ratio as well as higher system productivity. Ram et al. (2010) also reported least cost of production, minimum energy usage, higher water productivity, higher net returns and higher energy use efficiency in CA-based (ZT) maize–wheat cropping system.

ZT reduces the cost of energy by lowering the tractor-operated costs with conventional tillage and lessening the irrigation requirement in ZT wheat than conventional methods, thus reducing the energy costs associated with pumping underground water (Hobbs and Gupta 2003). Crop residue is also an integral part of CA, which can serve as a continuous energy source for soil microorganism and provide ideal conditions for increase microbial abundance (Carter and Male 1992; Salinas-Garcia et al. 2002). The use of CT reduces the energy consumption and emission of carbon oxide emission (Holland 2004). In similar, using the best nutrient management techniques, the negative consequences of extreme climatic situations can be minimised (Subash et al. 2014). Therefore, adoption of CA-based practices can save the environment through a reduction in GHG emissions by decreasing the tillage operations (Erenstein and Laxmi 2008) particularly in IGP regions.

2.10 Carbon Sequestration and GHG Emission

Increasing the GHG emission in the atmosphere enhanced the atmospheric temperature; affected the soil process, crop production and productivity and emergence of new insect pest and caused sudden changes in climatic events. The effects of climate change are assumed to have reached to that level where the irreversible change in the functioning of the earth planet is feared. Today we need to reduce the GHG emission or capture from the atmosphere in a long-lived pool, so that it cannot re-emit to the atmosphere (Kundu et al. 2013). Among the GHGs, CO_2 plays a crucial role, due to its larger concentration and wide sources of emissions. Intensive tillage practices reduced the soil C emitted into the atmosphere. It reduced the soil fertility and productivity adversely. The CA is one of the options in the agricultural system to reduce the GHG emission and also C sequestration through agricultural crops. The reduced burning of crop residue and incorporation of surface cover enhanced the soil C and reduced the rate of C emission into the atmosphere. Minimum tillage practices also improved the plant nutrient efficiency and cut off the volatilisation or denitrification losses during the crop production.

The CA practice can contribute to making the agricultural system more resilient to climate change. It has a powerful mechanism to adopt climate change by increasing resilience to drought, increasing water use efficiency and thermal stress to agricultural crops and also increasing moisture content in soil. The CA aims to increase the annual C rate into the soil through reducing the C losses through erosion and mineralisation. When the crop residues are retained on the soil surface in combination with no tillage, it improved the soil quality and overall resource enhancement. It leads to sustainable improvement in the nutrient use efficiency, nutrient balance and availability and reduced soil moisture loss, which all enhanced the productivity of system in terms of carbon sequestration. In general the adoption of best management practices in CA sequestered the soil C 1.8 ton CO_2 per hectare per year (FAO 2008). Lal (1998) computed the adoption of best management practices of CT on 400 M ha of crop land by the year of 2020 can sequester average total C of 1500–4900 Mg. This figure can be more intensive in agricultural areas. Across the global world, average production of crop residues is ~3.4 billion Mg, its 15 % of C can be converted to passive SOC fractions, and it can promote C sequestration rate 0.2×10^{15} g/year Lal (1987). The carbon sequestration is dependent on C input and output rate; it follows three stages:

i. Steady state: in which *C* input is equal to *C* output of the system.

$$\text{Steady state} \quad \ldots \quad C_{\text{input}} = C_{\text{output}} \cdots \tag{2.1}$$

ii. Soil C depletion: *C* output rate is greater than the input. In this case C sequestration rate is low and the system promotes the emission of GHGs and climate change activities.

$$\text{C depletion} \quad \ldots \quad C_{\text{input}} < C_{\text{output}} \cdots \tag{2.2}$$

iii. Carbon sequestration: this stage is associated with CA; in which system prominently act as sequester rather than C emission. This stage is beneficial for mitigating climate change effect and reduction of GHGs.

$$\text{C sequestration} \quad \ldots \quad C_{\text{input}} > C_{\text{output}} \ldots \tag{2.3}$$

Some soils are poorly managed and the C loss (50–75 %) is higher from the ecosystem. These estimates can be more in high erosion areas in lower input or poor management by the farmers. This loss is more in coarse-textured compared to fine-textured soil. The terrestrial C sequestration C cycle is governed by the climate, soil, crop and management factors and also their complex interlinking effects. The estimates of both GHG emissions and C sequestration are also affected by soil microorganisms; poorly managed soil evolution has greater amount of CO_2 than well-managed soil.

The C sequestration under CA can be more under the situation of maximising the C input factors and reducing the C loss from soils (Table 2.3). The primary cautions are minimising the GHGs from the source points during the crop production, i.e. fertiliser application, volatilisation rate, denitrification in high pH soil, soil erosion, crop residue burning, etc., and in secondary use the best management practices in combination with the C can sequester at an optimum level (Kushwah et al. 2014). The crop diversification is also important for CA, in which N is taken up by various depths with C/N ratios of various root residues.

The SOC scenario mainly varies as per the management and tillage practices. A hypothetical graph is showing the three scenarios and each scenario having its own C sequestration potential: scenario A, SOC realistically increased to 0.25 Mg C/ha/year, whereas in scenario B it is C sequestration which is effective in CA, the same as observed in conventional agriculture, because in conventional agriculture SOC

Table 2.3 Strategies to sequester SOC

(1) Maximising C input	(2) Minimising C loss from soil
Plant selection	Reducing soil disturbance
Species, cultivar, variety	Less intensive tillage
Growth habit (perennial/annual)	Controlling soil erosion
Rotation sequence	Utilising available soil water
Biomass energy crops	Promote optimum plant growth
Tillage	Reduces soil microbial activity
Type	Maintaining surface residues cover
Frequency	Increased plant water use and production
Fertilisation	
Rate, timing, placement	More fungal dominance in soil
Organic amendments	

Source: Franzluebbers (2008)

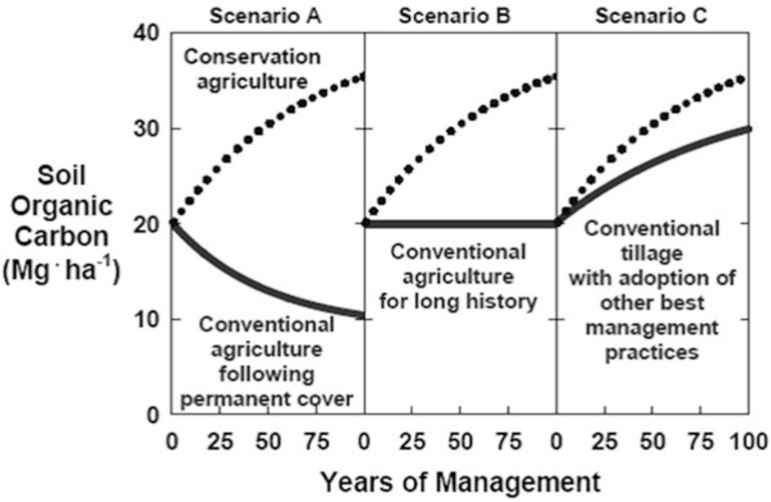

Fig. 2.5 Hypothetical examples of SOC content under CA and three different baseline conditions (Source: Adopted from Franzluebbers (2008))

rate is in a steady-state condition. In scenario C, SOC sequestration in CA would have adjusted to 0.05 Mg C/ha/year, because the conventional agriculture was improved due to CA and the sequestered SOC is at 0.10 Mg C/ha/year (Fig. 2.5).

2.11 Tangible and Intangible Benefits of CA

CA is generally a win–win situation for both farmers and environments, and it has tangible monetary benefits like the reduced labour, irrigation water, fertilisers and more stable yields and improved soil nutrient exchange capacity, thereby resulting in higher overall farm profits. Adoption of ZT wheat reduces the production cost by ₹2000–3000/ha (Malik et al. 2005) due to reduced land preparation costs, early sowing, less seed rate (Piggin et al. 2011) and reduced diesel consumption by 50–60 l/ha (Sharma et al. 2005). Thus it ultimately reduced the cost of production, increased yields and increased net returns (Sidhu et al. 2010). The use of rice residue in ZT wheat may save irrigation water through reducing water losses by evaporation (Chauhan et al. 2012); similarly furrow-irrigated raised-bed system (FIRBS) can help in saving irrigation water from 18 % to 50 % (Jat et al. 2005). In addition to tangible benefits, a large number of intangible benefits can be gained:

- Enhancement of soil quality, i.e. soil's physical, chemical and biological conditions (Jat et al. 2009; Gathala et al. 2011).

- Long-term carbon sequestration, significantly build up in soil organic matter and mitigate GHG emissions and greater resilience to production system to climate change (Saharawat et al. 2012).
- Enhancement of input (water, nutrient and fertilisers) use efficiency (Jat et al. 2012).
- Avoidance of crop residue burning reduces loss of nutrients and environmental pollution, which reduces a serious health hazard (Sidhu et al. 2007).
- Improvement of resource use efficiency through residue decomposition, improvement in soil physical environment and increased recycling and availability of plant nutrients (Jat et al. 2009).
- Residue incorporation or retention as mulch to control weeds, moderate soil temperature, reduce evaporation and improve soil biological activities (Jat et al. 2009; Gathala et al. 2011).

2.12 Constraints in Adoption of CA

Despite several tangible and intangible benefits of CA system, it is very difficult to convince the farmers about the potential benefits of CA beyond its ability to reduce production costs, due to reduction of the mainly tillage operations. The mindset of farmers is a big issue in the adoption of CA technologies particularly about ZT (Hobbs and Govaerts 2010). The major barriers to the adoption and spread of CA practices are as follows:

(i) Lack of trained and skilled human resources.
(ii) Lack of suitable and low-priced machineries (seeding/planting equipment into anchored and loose crop residue conditions) especially for small and marginal land holding farmers.
(iii) Widespread use of crop residues for livestock feed and fuel particularly in rainfed areas.
(iv) Weed management strategies without tillage practices; especially for small and marginal farmers with limited accessibility to purchase costly herbicides, weed infestations are the major obstruction to adoption of CA.
(v) Localised insect pest population densities.
(vi) Biophysical, socio-economic and cultural barriers such as limited access to financial capital, credit opportunities, inability to take risk, short-term priorities and small land farmers.
(vii) Agronomic constraints and lack of CA knowledge among the technicians and extensionist.

2.13 Future Outlook

The CA is not a panacea to arrest all agricultural problems, but it is a new paradigm for raising crops which will offer new opportunity to tackle with diverse agricultural production system and sustain the environmental quality. A lot of research on CA has been conducted, keeping views in the effect of CA on soil health (Baudron et al. 2012), but more research is needed to find the effect of different CA practices on crop yield, weed dynamics and nutrient dynamics, especially in long-term experiments. Future research needs to be identifying best nutrient management strategies with crop residue retention and economically viable crop rotations to boost crop productivity (Vanlauwe et al. 2014). Research should be conducted on weed dynamics to understand weed biotypes development under the CA and weed management research. Development of integrated weed, disease or pest management strategies is paramount for the success of CA systems. Development of low-price CA machineries particularly direct seeders/planters for seed sowing into crop residues (loose and anchored crop residues) especially for small and marginal farmers is also needed. Other research areas include understanding herbicide performance under heavy load of crop residues, nutrient dynamics under residue cover, etc.

2.14 Conclusions and Summary

Continuous shrinking of natural resources, decline in crop yield, deterioration in soil health and rising costs of agricultural inputs in conventional production system pose a threat to food security and livelihood of farmers. In this situation, CA is an obvious new paradigm in achieving higher productivity, improving environmental quality and preserving natural resources. CA systems involve mainly three principles like providing permanent soil cover, minimum mechanical soil disturbance and diversified crop rotations. Several benefits of sustainability have been addressed in ZT wheat in rice–wheat cropping system: reduced costs in fuel and labour, timely planting of crops, higher yield production, reduced weed density, saving of irrigation water and improved input use efficiency because of better crop stands due to good seed and fertiliser nutrient placement. Residue retention or inclusion of cover crops (*Sesbania*, cowpea, mung bean, etc.) on the soil surface is also one of the main CA principles which provide beneficial effects on soil moisture, temperature moderation and weed control. It also minimises water loss through evaporation which enhances higher growth rate of crop leading to higher water productivity. The combination of tillage and crop residue enhanced the SOC in the upper layer of soil. The best crop management practices improved the soil microbial diversity and population, which mediated the nutrient transformation and availability to crop plants. It improved the nutrient use efficiency and reduced the rate of inputs during the crop production. ZT reduced the CO_2 emission and improved the SOC in soil. The environmental hazards contributed by agriculture can be minimised through the CA. Problematic weed infestations are the major constraints in adoption of CA; however modified tillage practices provided an opportunity for effective weed management in CA system. ZT could increase certain weed species, but decrease other weed species depending upon the crops. Development of low-dose, high-potency, selective, post-emergence herbicides and herbicide mixtures are necessary for managing weeds in CA system. Herbicide-tolerant crops also provide opportunity to managing weeds. Therefore, the paradigm shift from tilled field to ZT–CA systems requires a thrust on nutrient management to improve soil and crop productivity and environmental quality and spread rapidly across the globe.

Acknowledgements Authors are highly thankful to Dr. K. Ramesh, Principal Scientist (Agronomy), ICAR-Indian Institute of Soil Science, Bhopal, India, for the needful help during the writing of the book chapter.

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