1 Conservation Agriculture for Sustainable and Resilient Agriculture: Global Status, Prospects and Challenges

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1.1 Introduction

Achieving food security for a burgeoning population, particularly in the less developed nations, and developing sustainable agricultural production systems are among the major challenges before the world in 21st century. The challenge is not only to ensure sufficient food for all the people but also to meet the ever increasing demand for meat, eggs, fruits and vegetables by the rapidly expanding middle class population in developing nations. The challenges are getting further confounded due to imminent climate change-related risks, the adverse effects of which have already started being experienced in one or other form in agricultural production systems in various parts of the globe. As more and more agricultural land is being diverted towards industrial and residential uses throughout the world, we have to produce more and more food from increasingly less-cultivated land. This will further strain the already fragile natural resource base, particularly land and water, making it more difficult to meet the food requirements of the world. Therefore, there is urgent need to conserve or even improve the natural resources from being degraded by water and wind erosion, which is accelerated manifold due to human activities.

> Although more than 99% of the world's food comes from the soil, experts estimate that each year more than 10 Mha of crop land are degraded or lost as rain and wind sweep away topsoil. An area large enough to feed Europe – 300 Mha, about ten times the size of the UK – has been so severely degraded it cannot produce food, according to UN figures (The Guardian, 2004).

Soil degradation is rampant both in developed and less developed nations. In fact the highest levels of land degradation are in Europe. 'Specifically degraded soils are found especially in semi-arid areas (Sub-Saharan Africa, Chile), areas with high population pressure (China, Mexico, India) and regions undergoing deforestation (Indonesia)' (Philippe Rekacewicz, UNEP/GRID-Arendal, 2007). The perception that land is an infinite natural resource has taken a heavy toll, leading to severe land degradation in many parts of the world. Every year millions of tonnes of sediments are discharged with runoff water throughout the world. This not only causes loss of agriculturally precious topsoil, but also affects aquatic ecosystems

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negatively by dumping nutrients and the silting of water bodies. Furthermore, widespread and severe decline of soil quality in almost all production regions also raises questions about the sustainability of current agricultural production practices (Verhulst *et al.*, 2010).

According to IPCC-based climate change predictions, most of the rainfall will occur in the form of high-intensity short-duration rain events due to global climate change effects (IPCC, 2007). If that becomes true, efficient use of rainwater through both *in situ* and *ex situ* moisture conservation practices will be imperative to achieve the objective of getting higher yields and conserving the natural resource base. This warrants that more proactive efforts should be made for developing and adopting resource-conserving technologies to increase global food production in a sustainable way amid the confounding challenges facing agriculture. Conservation Agriculture (CA), consisting of minimum mechanical soil disturbance, soil cover with plant biomass/cover crops and diversified crop rotations or associations, is viable and seems a more sustainable cultivation system than that presently practised. CA reduces soil erosion, improves soil quality, reduces soil compaction, improves rainwater use efficiency, moderates soil temperature, gives higher and stable yields, saves inputs, reduces cost of cultivation and helps in climate change mitigation and adaptation (Machado and Silva, 2001; Kassam *et al.*, 2009; Hobbs and Govaerts, 2010; Lal, 2010; Jat *et al.*, 2012b). CA principles are universally applicable to all agricultural landscapes and land uses with of course locally adapted practices (Kassam and Friedrich, 2012).

1.2 Conservation Agriculture: the Way Forward for Sustainable Agricultural Production

During the past few decades, rapid strides have been made all over the world to develop and disseminate CA practices. CA has emerged as a major way forward from the existing plough-based unsustainable conventional agriculture (ConvA), to protect the soil from water- and wind-led degradation processes and make agricultural production systems sustainable. Empirical evidences suggest that zero tillage-based agriculture along with crop residue retention and adoption of suitable crop rotations can be productive, economically viable and ecologically sustainable given that farmers are involved in all the stages of technology development and dissemination (Friedrich *et al.*, 2012). CA specifically aims to address the problems of soil degradation due to water and wind erosion, depletion of organic matter and nutrients from soil, runoff loss of water and labour shortage. Moreover, supporters of the CA movement claim that CA is able to address the negative consequences of climate change on agricultural production through improved rainwater use efficiency, moderating soil and plant canopy temperature and timely performance of agronomic operations (Gupta *et al.*, 2010; Jat *et al.*, 2012b). However, there is need to identify, evolve and disseminate region-specific CA practices through active involvement of farmers along with researchers, technicians, machinery manufacturers and policy makers (Fowler and Röckstrom, 2000).

1.3 Conservation Agriculture: Definition and Concept

According to the FAO, 'CA is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment' (Friedrich *et al.*, 2012). CA has been designed on the principles of integrated management of soil, water and other agricultural resources in order to reach the objective of economically, ecologically and socially sustainable agricultural production.

CA is characterized by three major principles (FAO, 2012):

- Minimal mechanical soil disturbance by direct planting through the soil cover without seedbed preparation;
- Maintenance of a permanent soil cover by mulch or growing cover crops to protect the soil surface;

- Diversifying and fitting crop rotations and associations in the case of annual crops and plant associations in the case of perennial crops.

Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for CA. The concept of CA has evolved from the zero tillage (ZT) technique. In ZT, seed is put in the soil without any prior soil disturbance through any kind of tillage activity or only with minimum soil mechanical disturbance. In zero-tilled fields, with time, soil life takes over the functions of traditional soil tillage such as loosening the soil and mixing the organic matter. In CA, due to minimum soil disturbance, soil life and biological processes are not disturbed, which is crucial for a fertile soil supporting healthy plant growth and development. The soil surface is kept covered either by crop residues, cover crops or biomass sourced *ex situ* through agroforestry measures, which provide physical protection for the soil against agents of soil degradation; and equally importantly provides food for the soil life. The burning or incorporation of crop residues is strictly avoided in CA. At the same time varied crop rotations involving legumes in CA help to manage pest and disease problems and improve soil quality through biological nitrogen fixation and addition of organic matter (Baudron *et al.*, 2009).

1.4 Global History, Current Status and Prospects of Conservation Agriculture

The origin of the CA movement can be traced in the 1930s when the dustbowls devastated vast areas of the mid-west USA. The new concepts of reduced tillage were introduced, as against the conventional intensive tillage-based cultivation systems, so as to ensure minimum soil disturbance and to protect the soil from water and wind erosion. Seeding machinery was developed for seeding directly with minimum soil disturbance through the surface-lying residues to ensure optimum crop stand (Friedrich *et al.*, 2012). But it was not until the 1960s that CA could enter into the farming practices in the USA. At present, CA is practised over an area of 26.5 Mha in the USA, which constitutes only 16% of the cropland. Protecting soils from devastating soil erosion, moisture conservation and timely planting of crops have been the major incentives for development and spread of conservation tillage in the USA. The no-till system entered into Brazil in the early 1970s as a potential remedial measure to the severe problem of soil loss due to water erosion in the tropical and subtropical regions of Brazil. The no-till practice was further refined in Brazil to suit the local requirements with the active collaboration of researchers, extension workers, progressive farmers; and with government support. Subsequently, the principles of keeping the soil covered either with crop residues or cover crops, and the adoption of suitable crop rotations/associations were added with the principle of minimum soil disturbance, and the term CA was given to this new concept of farming (Denardin *et al.*, 2008). Brazil became the cradle for evolution of the CA movement.

> The expansion of NT area in Brazil occurred mainly due to the availability of no-till seeders, adapted and developed with the support of research institutions and with farmers' evaluations as well, the attractive agricultural investment financing, the farmers' interest in changing their farming system and the machinery industries' interest in expanding their market' (Calegari *et al.*, Chapter 3, this volume).

Currently, Brazil along with other Latin American countries of Argentina, Paraguay and Uruguay, is among the leading countries of the world having the largest area under CA of their total cropland. However, there are serious concerns about the quality of CA being practised in these countries; for example, due to market pressures farmers are practising monocropping of soybean without growing cover crops in between two successive crops of soybean, leading to heavy soil erosion and land degradation (Friedrich *et al.*, 2012). In Canada, even though no-till started in the 1970s, its rapid adoption started only in the early 1990s (see Lafond *et al.*, Chapter 4, this volume). The necessity to protect the soil against devastating wind erosion during the fallow dry season, the introduction of winter wheat in the Prairies of Canada, availability of cheaper and effective herbicides, determined efforts of progressive farmers, supportive government policies, knowledge transfer through farmers' associations, design and development of no-till seeders by the private manufacturers according to the needs of local farmers, were the major factors that contributed to the spread and successful adoption of CA in the Canadian Prairies. Today, with 13.5 Mha area under CA in Canada, with the highest being in Saskatchewan followed by Alberta, Canadian farmers are witnessing the benefits of CA in terms of reduced wind erosion, increased hectarage under winter wheat, improved soil quality and biodiversity, among others.

The CA movement in Australia started in the mid-1970s following the visit of Australian researchers and progressive farmers to the USA and the UK; this was ably supported subsequently with availability of herbicides, particularly glyphosate, at competitive rates by private manufacturers. The main incentives for shifting from conventional intensive tillage-based farming systems to CA-based systems in Australia were: soil protection against water erosion (in northern cropping zones) and wind erosion (in western and southern cropping zones), soil moisture conservation (particularly in the dry western parts of Australia) and timely sowing of the crops. CA adoption was led in northern, central, southern and western states of Australia by the farmers in the more marginal areas where benefits in terms of soil moisture conservation and timely crop sowing were initially more obvious. The Australian government has been proactively supporting the CA movement in their country by giving important incentives through programmes such as 'Care for our Country', 'The Carbon Farming Initiative' and 'Clean Energy Future Plan', which led to a steady increase in hectarage under CA in Australia since the early 1990s (see Rochecouste and Crabtree, Chapter 5, this volume). Currently, Australia and New Zealand together have 17.16 Mha area under CA, which constitutes 14% of global CA hectarage.

CA is not widespread in Europe; the no-till systems cover only 1% of arable cropland (Friedrich *et al.*, 2012). In Europe, ECAF (European Conservation Agriculture Federation) has been promoting CA since 1999. Spain (650,000 ha), France (200,000 ha), Finland (160,000 ha) and the UK (150,000 ha) are the leading countries in the adoption of CA in Europe. Other countries practising CA to some extent in Europe are Ireland, Portugal, Germany, Switzerland and Italy. The agricultural policies in the European Union such as direct payment to farmers and subsidies on certain commodities, moderate climate and interest groups opposing the introduction of CA are the main reasons for slower adoption of CA in Europe (see Friedrich *et al.*, Chapter 6, this volume).

In Russia, hectarage under CA as per FAO definition is 4.5 Mha, while conservation tillage is reported to be practised on 15 Mha. In Ukraine, area under CA has reached 600,000 ha.

In Central Asia, with the active support of development agencies such as FAO, CIMMYT and ICARDA, Kazakhstan and Uzbekistan have made good progress to successfully adopt CA in large areas of their croplands. In Kazakhstan, CA is mostly practised in northern dry steppes and has 10.5 Mha under reduced tillage and 1.6 Mha under real CA. The concentration of large land areas under agricultural joint-stock companies, which are the main adopters of CA practices, and government subsidies for adopting CA practices have helped in rapid spread of CA practices in northern Kazakhstan (Kazakhstan Farmers Union, 2011; Kienzler *et al.*, 2012).

In China, the CA movement started in the early 1990s and currently has an area of 3.1 Mha under CA. However, Wang *et al.* (2010) reported that the adoption of CA in China is still low; in particular, the full adoption of CA is almost zero. According to them, the main reasons for slow pickup of CA by Chinese farmers are the low labour cost and low share of machinery and fuel in the total cost of cultivation, which gives few incentives to farmers to adopt CA technology.

In the Indo-Gangetic plains in South Asia across India, Pakistan, Bangladesh and Nepal, no-till is practised in wheat in about 5 Mha (Friedrich *et al.*, 2012). However, the adoption of permanent no-till systems and full CA is only marginal. In South-east Asia, CA was introduced in the late 1990s with the help of developmental agencies and international research organizations such as AFD (French Development Agency), CIRAD, NAFRI and USAID, but still CA is limited mainly to the research sector with limited extension to farmers' fields.

In the WANA (West Asia and North Africa) region, work on CA has been started since the 1980s in countries including Morocco, Tunisia, Algeria, Syria, Lebanon, Jordan and Turkey. In this region, currently Syria has the largest hectarage under CA, followed by Tunisia and Morocco. In Tunisia, it is mainly the large estates that have adopted CA. The owners had access to information, enough money to import quality seeders from Brazil, France or Spain; and they could bear the risk of trying new practices (Kurt G. Steiner, Schönau/Germany, 2012, pers. comm.).

In Africa, despite nearly two decades of promotional efforts by the national extension programmes and numerous international developmental agencies, the adoption of CA has been very low. Currently, Africa has only 1.01 Mha under CA, which is the lowest among all the continents (Table 1.1). South Africa (368,000 ha), Zambia (200,000 ha), Mozambique (152,000 ha) and Zimbabwe (139,300 ha) are the leading countries in the adoption of CA in Africa. The main reasons for a slow adoption of CA in Africa are numerous, namely: a low degree of mechanization within the smallholder system; lack of appropriate implements; lack of appropriate soil fertility management options; problems of weed control under no-till systems; lack of access to credit; lack of appropriate technical information; blanket recommendations that ignore the resource status of rural households; competition for crop residues in the mixed crop–livestock systems; and limited availability of household labour (Twomlow *et al.*, 2006).

'In the last 11 years, the CA systems have expanded at an average rate of more than 7 Mha per year globally, showing the interest of farmers and national governments in this alternate production method' (Friedrich *et al.*, 2012). Table 1.2 presents area under CA in different countries of the world. Originally, the CA movement was started as a remedial measure against wind and water erosion (in the USA and Canada, and Brazil, respectively), drought (in Australia), to increase crop area (in Canada), but more recently, pressed again by the severity of soil erosion and land degradation in many agriculturally important regions, besides increase in the cost of energy and production inputs, CA is being promoted by national governments in many countries. With the entry of local manufacturers in making available CA machinery at affordable rates, the area under CA is spreading fast in several parts of the globe. Combining agroforestry with CA is an important viable option to augment biomass supply for CA, particularly in the rainfed tropics and subtropics where crop

Table 1.1. Area under Conservation Agriculture by continent (adapted from Friedrich *et al.*, 2012).

Continent	Area (ha)	Percentage of total CA area in world	CA as percentage of arable cropland
South America	55,464,100	45	57.3
North America	39,981,000	32	15.4
Australia and New Zealand	17,162,000	14	69.0
Asia	4,723,000	4	0.9
Russia and Ukraine	5,100,000	3	3.3
Europe	1,351,900	1	0.5
Africa	1,012,840	1	0.3
World	124,794,840	100	8.8

Table 1.2. Area (ha) under Conservation Agriculture in different countries of the world: the area with >30% ground cover qualified for CA (1000 ha) (from FAO: http://www.fao.org/ag/ca/6c.html).

Country	Area (year)
Argentina	25,553 (2009)
Australia	17,000 (2008)
Bolivia (Plurinational State of)	706 (2007)
Brazil	25,502 (2006)
Canada	13,481 (2006)
Chile	180 (2008)
China	3,100 (2011)
Colombia	127 (2011)
Democratic People's Republic of Korea	23 (2011)
Finland	160 (2011)
France	200 (2008)
Germany	5 (2011)
Ghana	30 (2008)
Hungary	8 (2005)
Ireland	0.1 (2005)
Italy	80 (2005)
Kazakhstan	1,600 (2011)
Kenya	33.1 (2011)
Lebanon	1.2 (2011)
Lesotho	2 (2011)
Madagascar	6 (2011)
Malawi	16 (2011)
Mexico	41 (2011)
Morocco	4 (2008)
Mozambique	152 (2011)
Namibia	0.34 (2011)
Netherlands	0.5 (2011)
New Zealand	162 (2008)
Paraguay	2,400 (2008)
Portugal	32 (2011)
Republic of Moldova	40 (2011)
Russian Federation	4,500 (2011)
Slovakia	10 (2006)
South Africa	368 (2008)
Spain	650 (2008)
Sudan and South Sudan	10 (2008)
Switzerland	16.3 (2011)
Syrian Arab Republic	18 (2011)
Tunisia	8 (2008)
Ukraine	600 (2011)
UK	150 (2011)
United Republic of Tanzania	25 (2011)
USA	26,500 (2007)
Uruguay	655.1 (2008)
Venezuela (Bolivarian Republic of)	300 (2005)
Zambia	200 (2011)
Zimbabwe	139.3 (2011)
Total	124,795

residues are used for cattle feeding and/or biomass production is low due to water stress and several other factors (Sims *et al.*, 2009). With the recent unfavourable changes in rainfall patterns in different parts of the globe and higher temperatures during critical crop growth stages, CA is becoming even more relevant to achieve food security and protect our environment (Kassam *et al.*, 2011a; Corsi *et al.*, 2012).

1.5 Research Results Reported

1.5.1 Soil and water conservation

Soil degradation by water and wind erosion, as well as a decline in soil physical, chemical and biological properties, can be linked to excessive levels of tillage, removal and/or burning of crop residues and fallow systems that are associated with conventional farming systems (Lumpkin and Sayre, 2009). Higher soil degradation in conventional farming systems is due to the fact that conventional tillage (ConvT) causes more physical disruption and less production of aggregate stabilizing materials (Bradford and Peterson, 2000). Moreover, incorporation of crop residues by tillage or their removal from field for cattle fodder or burning leaves soils exposed to the actions of rain, wind and heating by the sun, leading to enhanced rate of soil degradation. Higher aggregate stability in CA practices as compared to conventionally tilled fields results in lower soil erosion potential in CA (Derpsch *et al.*, 1991; Packer *et al.*, 1992; Uri *et al.*, 1999; Chan *et al.*, 2002; Hernanz *et al.*, 2002; Pinheiro *et al.*, 2004; López and Arrúe, 2005; Govaerts *et al.*, 2007c; Li *et al.*, 2007; Márquez *et al.*, 2008; Kassam *et al.*, 2011a). ZT with residue retention resulted in a high mean weight diameter and a high level of stable aggregates (considered as a parameter for predicting soil erodibility) in the rainfed systems of Mexico (Verhulst *et al.*, 2009). Presence of crop residues on the soil surface in CA leads to profound increase in microbial activity, leading to secretions of aggregate-binding chemicals in to the soil. As CA leaves more plant residues over the surface compared to ConvT, it protects soil from deleterious actions of rainfall, gusty winds and heating effects of the sun.

The soil erosion in CA fields is further reduced due to the reduced amount of runoff under CA conditions (Rao *et al.*, 1998; Rhoton *et al.*, 2002; Araya *et al.*, 2012). Maintenance of crop residues on the surface in CA prevents surface sealing, improving infiltration, which ultimately results in reduced soil erosion. Mulching, which is a part of CA, halts soil erosion by providing a protective layer to the soil surface, increasing resistance against overland flow and enhancing soil surface aggregate stability and permeability (Erenstein, 2003). Annual soil loss was 3.8 and 8.1 times greater without mulch when compared to mulching with 3 t ha^{-1} and 5 t ha^{-1} of crop residues in humid highlands of Kenya (Danga and Wakindiki, 2009). The corresponding decrease in runoff volume was 2.1 and 4.6 times compared to no mulching. The placement of straw over the surface also reduced runoff velocity along the slope, thereby decreasing the erosivity of runoff water, besides trapping the sediments carried by overland flow. Under CA, the 30% threshold for soil cover is expected to reduce soil erosion by 80%, but greater soil cover is expected to suppress soil erosion further (Erenstein, 2002). However, no-till fields, when residue cover is low, may be more vulnerable to runoff because no-till surfaces lack roughness and can experience soil compaction (Hansen *et al.*, 2012). Readers are referred to a review by Jat *et al.* (2012b) for a detailed discussion on the role of CA in controlling soil degradation.

1.5.2 Soil quality

Soil quality is 'the capacity of a specific kind of soil to function, within natural managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation' (Karlen *et al.*, 1997). A simpler operational definition is given by Gregorich *et al.* (1994) as 'The degree of fitness of a soil for a specific use'. According to Verhulst *et al.* (2010), from an agricultural production point of view 'high soil quality equates to the ability of the soil to maintain a high productivity without significant soil or environmental degradation'. Evaluation of soil quality is based on physical, chemical and biological properties of the soil. 'With respect to biological soil quality, a high quality soil can be considered a "healthy" soil' (Verhulst *et al.*, 2010). A healthy soil is defined as a stable system with high levels of biological diversity and activity, internal nutrient cycling and resilience to disturbance (Rapport, 1995; Shaxson *et al.*, 2008).

Adoption of CA, following all the principles, for a sufficiently long period of time leads to significant improvement in soil quality, mainly in the surface layers (Hobbs, 2007; Mousques and Friedrich, 2007; Thomas *et al.*, 2007; Verhulst *et al.*, 2009; Lal, 2010). Soil structure is a key factor in soil functioning, and is an important factor in the evaluation of the sustainability of crop production systems (Verhulst *et al.*, 2010) and is often expressed as the degree of stability of aggregates (Bronick and Lal, 2005). ConvT results in reduced aggregation due to direct and indirect effects of tillage on aggregation (Beare *et al.*, 1997; Six *et al.*, 2000). Tillage breaks down the old aggregates and disrupts the process of new aggregate formation by fragmenting the plant roots and mycorrhizal hyphae, which are among the major binding agents for macro-aggregate formation, and also disrupts other biological activities in the soil. ZT with residue retention improves dry as well as wet aggregate size distribution compared to ConvT (Chan *et al.*, 2002; Filho *et al.*, 2002; Pinheiro *et al.*, 2004; Madari *et al.*, 2005; Govaerts *et al.*, 2007c; Li *et al.*, 2007; Lichter *et al.*, 2008; Verhulst *et al.*, 2009). In CA plots, increased microbial activity creates a stable soil structure through accumulation of organic matter due to retention of crop residues and addition of large amount of biomass by cover crops and legumes in rotation (De Gryze *et al.*, 2005; Lal, 2010; Verhulst *et al.*, 2010).

ConvT, for example, during long-term use of disc tillage equipment can cause compactness in soil subsurface layers leading to restricted root growth, waterlogging and poor aeration (Castro Filho *et al.*, 1991; Fageria *et al.*, 1997). CA has been reported to reduce soil compaction due to reduced traffic and growing of the deep-rooted cover crops or legumes in rotation, which break the compact layers in the subsurface (FAO, n.d. a; Kemper and Derpsch, 1981; Kayombo and Lal, 1993). CA has been found to reduce bulk density, particularly in surface layers, thereby facilitating better aeration and water retention (Machado and Silva, 2001; Nurbekov, 2008).

Residue retention and consequent greater microbial biomass and abundance of earthworms and macro-arthropods in soils under CA exert beneficial effects on soil fertility. CA leads to the stratification of nutrients, with higher amount of nutrients near the soil surface compared to deeper layers (Franzluebbers and Hons, 1996; Calegari and Alexander, 1998; Duiker and Beegle, 2006). As surface-placed residues decompose slowly, it may prevent rapid leaching of nutrients through the soil profile in CA fields (Kushwaha *et al.*, 2000; Balota *et al.*, 2004). CA may lead to lower nutrient availability because of greater immobilization by the residues left on the soil surface (Rice and Smith, 1984; Bradford and Peterson, 2000) in the initial years of adoption. But in the long run, as summarized by Verhulst *et al.* (2010), 'the net immobilization phase when CA is adopted is transitory, and the higher, but temporary immobilization of N in ZT systems reduces the opportunity for leaching and denitrification losses of mineral N'. The higher initial N-fertilizer requirement decreases over time because of reduced loss by erosion and the build-up of a larger pool of readily mineralizable organic N. Thomas *et al.* (2007) reported significantly higher total nitrogen in 0–30 cm soil depth and exchangeable K in 0–10 cm soil depth under no-till as compared to ConvT plots. Reduced tillage and addition of N by legumes in the cropping system increases total N in the soil under CA (Amado *et al.*, 1998).

The different cover crops have phosphorus (P)-recycling capacity; and this even further improves when the residues are retained on the surface (Calegari and Alexander, 1998). 'Numerous studies have reported higher extractable P levels in ZT than in tilled soil, largely due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation' (see Verhulst *et al.*, 2010). The organic acids resulting from the build-up of the soil organic matter may also increase P mobilization (Mousques and Friedrich, 2007). This helps enhance P-use efficiency when P is a limiting nutrient, but may cause environmental problems through loss of soluble P in runoff water when soil P levels are high (Duiker and Beegle, 2006). They also suggested that there may be less need for P starter fertilizer in long-term zero-tilled fields due to relatively high available P levels in the topsoil where the seed is placed. Micronutrients tend to be present in higher levels under CA compared to ConvT, especially extractable zinc and manganese near the soil surface due to the surface placement of crop residues (Franzluebbers and Hons, 1996).

The high organic matter contents in the surface soil layer, commonly observed under CA, can increase the cation exchange capacity of the surface layers (FAO, 2001; Duiker and Beegle, 2006). CA has been found to be effective in ameliorating sodicity and salinity in soils (Franzluebbers and Hons, 1996; Hulugalle and Entwistle, 1997; Sayre, 2005; Govaerts *et al.*, 2007c; Qadir *et al.*, 2007). For example, after 9 years of minimum tillage, the values of exchangeable Na, exchangeable sodium percentage and dispersion index were lower in an irrigated Vertisol compared to ConvT (Hulugalle and Entwistle, 1997). Thomas *et al.* (2007) also recorded lower exchangeable Na in surface layers due to no tillage (NT) compared to ConvT. The combination of ZT with sufficient crop residue retention reduces evaporation from the soil and salt accumulation on the soil surface (Nurbekov, 2008; Hobbs and Govaerts, 2010). Inclusion of legumes in crop rotations in CA may reduce the pH of alkaline soils due to intense nitrification followed by NO_3^- leaching, H_3O^+ excretion by legume roots (Burle *et al.*, 1997). Besides, in no-till all the N is placed on the soil surface and this leads to decrease in soil pH because of acidification following nitrification of the soil and applied N.

The soil microbial biomass (SMB) reflects the soil's ability to store and cycle plant nutrients (C, N, P and S) and organic matter (Dick, 1992; Carter *et al.*, 1999), and due to its dynamic character, SMB responds to changes in soil management often before effects can be measured in terms of organic C and N (Powlson and Jenkinson, 1981). SMB has a crucial role in plant nutrition. According to Weller *et al.* (2002), general soil-borne disease suppression is also related to total SMB, which competes with pathogens for resources or causes inhibition through more direct forms of antagonism. The rate of organic C addition from plant biomass is generally considered the most important factor determining the amount of SMB in the soil (Campbell *et al.*, 1997). In the subtropical highlands of Mexico, residue retention resulted in significantly higher amounts of SMB-C and N in the 0–15 cm layer compared to residue removal (Govaerts *et al.*, 2007b). Alvear *et al.* (2005) reported higher SMB-C and N in the 0–20 cm layer under ZT than under ConvT with disc-harrow in an Ultisol from southern Chile, and attributed this to the higher levels of C inputs available for microbial growth, better soil physical conditions and higher water retention under ZT. The favourable effects of ZT and residue retention on soil microbial population are mainly due to increased soil aeration, favourable temperature and moisture conditions, and higher C content in surface soil (Doran, 1980). Against this, each tillage operation increases organic matter decomposition with a subsequent decrease in SOM (Buchanan and King, 1992). Crop residue retention has been found to enhance enzymatic activities also mainly in soil surface layers (Alvear *et al.*, 2005; Roldán *et al.*, 2007; Nurbekov, 2008). Soil enzymes play an essential role in catalysing the reactions associated with organic matter decomposition and nutrient cycling.

Thus, it can be concluded that soils under CA are in general physically, chemically and biologically stratified with improved soil quality in surface layers.

1.5.3 Rainwater use efficiency

In rainfed agriculture, improving rainwater use efficiency (RWUE) is imperative to obtain higher yields. Other than rainfall pattern, the crops grown and management practices, RWUE is determined by the rate of water infiltration, water-holding capacity of soils and evaporative loss of water. CA has been found to improve RWUE by improving rainwater infiltration (Calegari and Alexander, 1998; Erenstein, 2002; Govaerts *et al.*, 2007a; Shaxon *et al.*, 2008; Verhulst *et al.*, 2009), water-holding capacity (Hudson, 1994; Acharya *et al.*, 1998; Govaerts *et al.*, 2007a, 2009; Mousques and Friedrich, 2007; Nurbekov, 2008) and reducing loss of water through evaporation (Erenstein, 2003; Scopel *et al.*, 2004; Nurbekov, 2008). According to Scopel and Findeling (2001), in the short run, residue heaps act as a succession of barriers giving the water more time to infiltrate; while in the long run (>5 years), retention of crop residues increases average infiltration rates up to 10 times compared to ConvT by preventing crust formation. Improved soil cohesion, pore continuity and aggregate stability, and the protection of the soil surface from direct impact of the raindrop, are the most important factors that contribute to improved water infiltration into the soil (Basch *et al.*, 2012). Large pores due to greater numbers of earthworms, termites, ants and millipedes combined with the channels created by decomposing plant roots and their higher density result in increased water infiltration in CA plots (Blevins *et al.*, 1983; Roth, 1985). Residues intercept the rainfall and release it more slowly afterwards, which helps to maintain higher moisture level in soil, leading to extended water supply for plants (Scopel and Findeling, 2001). Increase in SOM due to residue retention in CA fields increases water-holding capacity of soil. Hudson (1994) showed that for each 1% increase in SOM, the available water-holding capacity in the soil increased by 3.7%. Mulching in CA fields reduces loss of stored soil moisture by checking evaporation (Erenstein, 2003).

Changrong *et al.* (2009), while working in China, reported 1% to more than 20% increase in water availability in dryland fields due to zero or reduced tillage with residue retention compared to conventional farming. ZT with residue retention decreases the frequency and intensity of short mid-season droughts (Bradford and Peterson, 2000).

Thus, in CA plots most or all of the rainfall is harnessed as effective rainfall, with little runoff and no soil erosion, leading to longer and reliable moisture regime for crop growth, and improved drought proofing (Shaxson *et al.*, 2008).

1.5.4 Nutrient use efficiency

Reduced runoff and the use of appropriate deep-rooting cover crops contribute to reducing nutrient losses in CA fields (FAO, 2001). Crop residues release nutrients slowly, which help prevent nutrient losses by leaching and/or denitrification. Moreover, the immobilization of mineral N due to residue retention may also prevent potential losses due to NO_3-N leaching (Thomas *et al.*, 2007). In the short run, lower fertilizer use efficiency may be recorded as a result of immobilization of mineral nutrients by microorganisms. However, in the long-run, nutrient availability increases because of microbial activity and nutrient recycling (Carpenter-Boggs *et al.*, 2003).

Phosphorus use efficiency can be improved if crop residues are added to the soils (Iyamuremye and Dick, 1996; Sanchez *et al.*, 1997), which is further increased when combined with NT (Sidiras and Pavan, 1985; De Maria and Castro, 1993; Selles *et al.*, 1997). Thomas *et al.* (2007) also recorded higher levels of bicarbonate-extractable P in 0–10 cm layer under NT than ConvT. Greater available P levels in the upper layers of NT soils may be due to reduced mixing of fertilizer P, possibly increased quantities of organic P, and shielding of P adsorption sites (Weil *et al.*, 1988).

Inclusion of legumes in cropping systems increases the turnover and retention of soil N and other nutrients (Drinkwater *et al.*, 1998; Hansen *et al.*, 2012). Sisti *et al.* (2004) reported, from a 13-year study in southern Brazil, significant increase in soil N stocks when vetch, legume green manure crop, was included in rotation along with ZT compared to no legume green manure crop. Burle *et al.* (1997) found highest levels of exchangeable K, calcium (Ca) and magnesium (Mg) when pigeon pea and lablab (*Dolichos lablab*) were included in the systems. Increased aggregation and SOM at the soil surface also leads to increased nutrient use efficiency in CA fields (Franzluebbers, 2002). Hobbs and Gupta (2004) reported improved fertilizer use efficiency (10–15%) in the rice–wheat system, mainly as a result of better placement of fertilizer with the seed drill in CA fields as opposed to broadcasting in the conventional system.

1.5.5 Input use efficiency

In the long term, besides reducing the need for chemical fertilizers, CA may bring down demand for fuel, labour, machinery and pesticides as well as time (Zenter *et al.*, 2002; Fernandes *et al.*, 2008; SoCo, 2009; Freixial and Carvalho, 2010). As the knowledge and understanding of tenants about CA increases with time, the need for operations and off-farm inputs reduces (Derpsch, 1997). Direct sowing without or with minimum soil disturbance implies less labour, energy, time and machinery requirement. Fernandes *et al.* (2008), from a study conducted in Brazil, estimated a diesel saving of 6.4 l ha^{-1} by tractors when ConvT was replaced by NT; and the total energy budget was lower by 25.5 l diesel equivalent ha^{-1}. In DPRK (Democratic People's Republic of Korea) the adoption of CA resulted in input savings of 30–50% (Mousques and Friedrich, 2007). Omission of tillage operations in CA systems can help reducing labour requirements during a critical time in the agricultural calendar (Giller *et al.*, 2009), which makes it convenient for farmers to perform other operations such as the timely sowing of relatively large areas. Adoption of integrated weed management and mulching in CA could lead to lesser weed intensity, which reduces labour requirement for weeding in the long term. However, during initial years, the increased labour requirement due to higher weed intensity in CA plots compared to ConvT plots may outweigh the labour saving due to NT (Jat *et al.*, 2012a). Moreover, due to the higher weed problem in CA, the labour burden could be shifted on to the women, who traditionally are responsible for weeding, from the men, who are responsible for tillage (Giller *et al.*, 2009).

1.5.6 Insect-pest, disease and weed dynamics

Varying results of insect-pest dynamics in response to the adoption of CA have been reported in different studies from different parts of the globe. A review of 45 studies showed that 28% of the pest species increased with decreasing tillage, 29% showed no significant influence of tillage and 43% decreased with decreasing tillage (Stinner and House, 1990). Reduced tillage may lead to an increase in the number of insect-pests (Musick and Beasley, 1978), but it also tends to increase diversity of predators and parasites of crop-damaging insects (Stinner and House, 1990). Besides, crop rotations and plant associations, which are integral parts of CA, help break insect-pest cycles (FAO, n.d. b). Biological diversity processes and increased species and functional diversity due to reduced tillage, residue retention and crop rotations/plant associations in CA fields (Hobbs and Govaerts, 2010) also help keeping insect-pests and diseases under control. Therefore, better insect-pest management is possible in CA fields in the long term; none the less, higher incidence of insect-pests is quite possible during initial years of CA adoption when predators/parasites are not in sufficient number. Insect-pests may be harboured in the crop residues retained on soil surface (Hansen *et al.*, 2012) as well as in undisturbed soils in CA. The wheat stem sawfly (*Cephus cinctus* Norton) became a concern in the US Great Plains; and its spread is speculated to be associated with the spread of no-till area (Weaver *et al.*, 2009; Peairs *et al.*, 2010). However, these concerns were not confirmed and the pest occurrence was more related to wheat monocropping than to no-tillage (MANDAK, 2011).

As different pathogens have different survival strategies and life cycles, reduced tillage affects different plant pathogens in different ways (Bockus and Shroyer, 1998). Crop residue retention may directly affect the pathogens by changing composition of soil microbial community in favour of beneficial microorganisms; however, crop residues can carry over pathogens from one season to the next season. CA also affects pathogens indirectly through improved soil moisture, aeration and moderating soil temperatures (Krupinsky *et al.*, 2002). Crop rotations play a crucial role in CA to break disease cycles and neutralize the pathogen carry-over effects of residue retention and minimum mechanical disturbance of soils (Barker and Koenning, 1998). According to Forcella *et al.* (1994), due to one or more of the following mechanisms, the residues of some crops are able to reduce pathogen incidence: (i) leaching of inhibitory chemicals from decomposing residues; (ii) leaching of stimulatory chemicals from residues which promote populations of beneficial microbial control agents; (iii) enhanced populations of highly competitive non-pathogenic species in lieu of non-competitive pathogenic species due to high C:N ratios; and (iv) increased vigour of crops making them less susceptible to diseases due to higher soil water contents and improved soil quality. However, CA may increase or decrease disease incidence in different crops; for example, in maize, residue retention increased the incidence of root rot, while in wheat, residue decreased the incidence (Govaerts *et al.*, 2007a). Similarly, retention of wheat residues causes increased incidence of stem rot in groundnut.

Weed management is an important issue in promoting CA among smallholders. Muliokela *et al.* (2001) reported higher weed infestations with minimum tillage practices than ploughed fields in Zambia. Minimum tillage may lead to increased labour requirements for weeding, particularly during starting years of CA adoption if done gradually (Vogel, 1994; Haggblade and Tembo, 2003; Jat *et al.*, 2012a). Minimum tillage may lead to increased intensity of the perennial weed population in the long term (Vogel, 1994). For this reason, CA excludes minimum tillage by definition, since the level of soil disturbance in minimum tillage is still high enough to create weed problems (Friedrich and Kassam, 2012).

The net effect of crop residue retention in CA on weed control is somewhat contradictory. In some cases, crop residues suppress weed seed germination and/or seedling growth and thereby complement the effects of herbicides (Crutchfield *et al.*, 1986; Gill *et al.*, 1992; Vogel, 1994; Buhler *et al.*, 1996; Mashingaidze *et al.*, 2009). Gill *et al.* (1992) identified residue mulching as a practical method for early season weed control in minimum tillage systems for smallholder farmers in Zambia. They reported that the application of grass mulch at 5 t ha^{-1} significantly suppressed weed growth in the first 42 days of maize (*Zea mays*) grown under minimum tillage. In Zimbabwe, the retention of the previous season's maize residues significantly suppressed total dry weed biomass by more than 30% in the ripped plots compared to no mulching (Vogel, 1994).

However in some other cases, crop residue retention lessened the herbicide's efficacy (Erbach and Lovely, 1975; Forcella *et al.*, 1994; Jat *et al.*, 2012a). However, rainfall may wash the intercepted herbicides by crop residues into the soil and efficacy may remain high (Johnson *et al.*, 1989). Sometimes, weed suppression occurs only when relatively high rates of crop residues are applied, which makes it impractical for smallholders in the developing countries where biomass production is low or it has competing alternate uses (e.g. for cattle fodder).

In the long run, when appropriate weed control practices are adopted and the weed seed bank becomes exhausted the weed problem may reduce in CA fields (Blackshaw *et al.*, 2001; Nurbekov, 2008). Some cereal crop residues have been reported to inhibit the germination of some weed seeds due to their allelopathic properties (Steinsiek *et al.*, 1982; Lodhi and Malik, 1987; Jung *et al.*, 2004) and depriving weed seeds of sunlight (Ross and Lembi, 1985).

1.5.7 Crop productivity

Short-term effects of CA on crop yield vis-à-vis ConvT remain variable depending on the initial soil fertility status, climate, rainfall received in the season, tenants' management practices and the type and amount of crop residues retained, among others. Therefore, the short-term effects of CA on crop yield may be positive, neutral or negative (Gill and Aulakh, 1990; Mousques and Friedrich, 2007; Nurbekov, 2008; Lumpkin and Sayre, 2009; Jat *et al.*, 2012a). However, in the long term CA has been reported to increase crop yields due to associated benefits such as prevention of soil degradation, improved soil quality, better moisture regimes, timely field operations (mainly sowing) and crop rotational benefits. Over time, the benefits from reduced soil degradation and improved soil physical, chemical and biological properties due to mulching and legumes in rotations accumulate, resulting into higher and stable yields in CA fields (Erenstein, 2003; Sisti *et al.*, 2004). Under rainfed situations in dry climates where soil moisture is the most limiting factor, CA helps improve crop yields due to improved through increased infiltration, reduced evaporation loss and higher water-holding capacity of the soil. Moreover, CA gives more stable yields compared to ConvT due mainly to timely planting, maintenance of favourable soil moisture regime, improved soil quality, less soil erosion, and less incidence of diseases and insect-pests (FAO, 2001; Hobbs and Govaerts, 2010). Crop rotation, which is one of the underlying principles of CA, helps in better performance of crops compared to when the same crop is grown in the same field year after year (FAO, n.d. b; Kasasa *et al.*, 1999; Giller, 2001).

In dry climates, timely sowing is important to obtain higher yields as the window of sowing after first occurrence of rains remains short. Moreover, many smallholders may not have sufficient sources of traction and machinery for timely sowing of the crops during the critical period of sowing after the first rains (Twomlow *et al.*, 2006). This may lead to delays in crop sowing leading to yield penalties. CA may help to sow larger areas in the given sowing window span by removing the need for tilling the land before sowing. In light-textured soils where surface crusting is an important constraint, crop residue retention on the soil surface in CA can assist in better germination and emergence of seedlings (LeBissonnais, 1996; Lal and Shukla, 2004). Mulching in CA fields maintains more favourable temperatures for crop plants and soil life, favouring better plant growth and development (Bot and Benites, 2005; Fabrizzi *et al.*, 2005).

However, some studies have reported that yield benefits due to CA are conspicuous only during dry years and yields are low during normal or above rainfall years (Giller *et al.*, 2009; Wang *et al.*, 2011). This is because rain water conservation effects of CA are more pronounced during dry years.

1.5.8 Climate change mitigation and adaptation

Conventional agriculture generally contributes more to climate change by greater emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) at various stages of input production, transportation and during and after their application in the field. Emission of CO_2 in ConvA occurs due to tilling of land, mixing of crop residues and burning of biomass (FAO, 2001; Hobbs and Govaerts, 2010).

CA can help to mitigate climate change through carbon sequestration and reduced emission of CO_2 and N_2O and probably of methane (CH_4). CA leads to carbon sequestration due to reduced decomposition of soil organic matter and addition of biomass as mulch (Corbeels *et al.*, 2006; Giller *et al.*, 2009) and through crop rotations followed in CA (Sidiras and Pavan, 1985; Calegari *et al.*, 2008). Reduced soil disturbance may also lead to higher carbon sequestration in CA fields due to slower decomposition and oxidation of SOM (Jat *et al.*, 2012b). Besides, greater micro-aggregation and aggregate stability due to CA (Lal, 1997; Six *et al.*, 2000; Verhulst *et al.*, 2009) may lead to higher carbon sequestration in the CA fields. Because crop residues are retained on the soil surface in CA, it avoids emission of CO_2 due to burning of crop residues. Due to direct sowing and avoidance of tillage operations, CA saves a considerable amount of fuel and thus leads to reduced CO_2 emissions (West and Marland, 2002; Hobbs and Gupta, 2004; Wang and Dalal, 2006; Erenstein *et al.*, 2008). N_2O emission may be lower in CA fields in the long term due to reduced need of nitrogenous fertilizers as a result of improved soil fertility status. Moreover, higher SOM and the presence of crop residues in CA fields leads to the immobilization of externally applied nitrogen, leading to decreased availability of NO_3^--N for denitrification. Depending on whether CA improves or worsens soil aeration under a particular set of agro-climatic and management conditions, it may increase or decrease CH_4 emission from the soil (Hütsch, 1998; Omonode *et al.*, 2007). Direct sowing or transplanting of young rice seedlings under aerobic soil conditions could reduce both CH_4 (Hobbs and Govaerts, 2010) and N_2O emissions (Kassam *et al.*, 2011b).

At the same time, CA can help adapt to climate change mainly through better soil moisture status, moderating extreme soil temperatures, timely farm operations and better health of crops in CA fields. ZT with residue retention generally increases surface soil water contents compared to tilled soils (Govaerts *et al.*, 2007b), and consequently decreases the frequency and intensity of short mid-season droughts (Blevins *et al.*, 1971; Bradford and Peterson, 2000). Due to improved soil quality and better plant nutrition, CA imparts greater resilience to crop plants against climatic variability (Hobbs and Govaerts, 2010). Moreover, CA has been reported to moderate extreme temperatures in the soil (Acharya *et al.*, 1998; Oliveira *et al.*, 2001) and reduces air temperature around the crop canopy (Jacks *et al.*, 1955; Gupta *et al.*, 2010). Hansen *et al.* (2012) reported that the inclusion of annual forage crops can improve precipitation use efficiency and resilience under climate change in the Great Plains of the USA.

1.5.9 Benefits at ecosystem level

Under CA, the minimal mechanical soil disturbance, maintenance of biomass on the soil surface, use of cover crops and adoption of crop rotations naturally favours abundance and diversity of both below- and above-ground flora and fauna (Nuutinen 1992; Chan and Heenan, 1993; Hartley *et al.*, 1994; Karlen *et al.*, 1994; Buckerfield and Webster, 1996; FAO, 2001; Clapperton, 2003; Govaerts *et al.*, 2007b; Verhulst *et al.*, 2010). Zero or reduced tillage, unlike ConvT, does not disturb activity and the habitats of soil-inhabiting organisms (Doran, 1980; Linn and Doran, 1984; Buchanan and King, 1992; Angers *et al.*, 1993; Chan and Heenan, 1993; Ferreira *et al.*, 2000). Retention of biomass provides sufficient food and creates a supporting microclimate to enable communities of organisms such as bacteria, fungi, actinomycetes, earthworms, arthropods, etc. to flourish in CA fields. Cover crops and residues moderate soil temperature. Several studies have reported greater abundance and diversity of earthworms and arthropods in the CA fields due to no or lesser soil mechanical disturbance and supply of abundant food (Chan and Heenan, 1993; Acharya *et al.*, 1998; Kladivko, 2001; Rodriguez *et al.*, 2006; Verhulst *et al.*, 2010). Thus, CA fields have near natural conditions for the biological communities to flourish therein. Cover crops and crop rotations favour several species of symbiotic microorganisms with crop plants (Hungria *et al.*, 1997; Ferreira *et al.*, 2000). CA has been found to improve above-ground biodiversity also by providing habitats and food for birds, mammals, reptiles and insects among others (FAO, 2001). Mousques and Friedrich (2007) reported a significant increase in the numbers and diversity of beneficial fauna in CA fields in DPRK.

CA has been reported to provide many ecological benefits in its surroundings, for example, recharge of groundwater bodies, reduced flooding in downstream areas, reduced siltation and chemical pollution of watercourses (Kassam *et al.*, 2011c). Improved macro-porosity in CA fields due to higher earthworm numbers and their activities and continuity of channels created by decay of deep roots of legumes such as pigeon pea lead to greater percolation of rainwater, which helps recharge aquifers (Barley, 1954; Disparte, 1987; Green *et al.*, 2003). This also helps reduce soil erosion, flooding in the catchment areas and the siltation of rivers and water reservoirs or other water bodies. As crops under CA are healthier due to improved moisture availability and improved soil quality, they require less fertilizers and pesticides to feed and protect them, which leads to reduced emission of chemicals into the environment at both input production and field level (FAO, 2008; Kassam *et al.*, 2011c).

However the environmental cost, if no-till is applied without the additional elements of CA, due to total reliance on herbicides for weed control, can be high, which is another argument for integrated weed control approaches under CA, differentiating CA from other no-till and from minimum tillage practices.

1.5.10 Farm profitability

Depending on the length of adoption of CA and management skills of individual farmers, profit gains due to CA may be neutral, positive or negative. During initial years of CA adoption, the net profits may remain unchanged or may even decrease. In CA, the cost saving due to reduced/zero tillage may be outweighed by increased cost of weeding and possible slight yield reductions in initial years compared to ConvT (Jat *et al.*, 2012a). Moreover, farmers need to invest in the form of new machinery for CA, which may put some financial burden on smallholders when they start to adopt CA. However, in the long term, when the positive impacts of CA on soil and water conservation, soil quality, input use efficiency, etc., start to accumulate and farmers become more acquainted with CA technologies, net profits due to CA are higher compared to CovT. Many studies have reported a significant decrease in the cost of cultivation in CA fields due mainly to less input (fuel, labour, time, etc.) use (FAO, 1998; Hobbs and Gupta, 2004; Sangar *et al.*, 2004;

Hobbs, 2007; Mousques and Friedrich, 2007; Changrong *et al.*, 2009).

1.6 Challenges in Up-Scaling and Out-Scaling CA Worldwide

Even though CA is known to provide numerous benefits at the field, ecosystem and society level, its adoption has not been widespread globally except in a few countries, despite about eight decades since the start of the reduced tillage movement in the USA in the 1930s. However, Mercosur countries of Argentina, Brazil, Paraguay and Uruguay, and Australia, the USA, Canada, Ukraine etc. have made good progress in adopting CA due to consistent efforts and coordination among farmers, scientific community and policy makers. The more common factors that hinder the widespread adoption of CA in different parts of globe include tillage mindset and lack of awareness of how ConvT leads to soil degradation, lack of sufficient biomass for mulching, need for new implements and operating skills for CA, weed menace in CA fields, probable initial yield reductions, and the lack of sufficient research and government policies in many countries. Although soil degradation due to soil erosion is widespread in both developed and less-developed nations, it seems there is a lack of a sense of urgency on the part of both farmers and policy makers to check soil degradation probably due to its slow, creeping and often unnoticeable nature. Farmers and policy makers in general do not recognize how CA can contribute to reverse the rampant process of soil degradation and thereby lead to sustainable agricultural intensification. Moreover, there is a prevailing feeling among farmers that to obtain good crop yields, tilling the land is essential. As Hobbs and Govaerts (2010) pointed out, overcoming this mindset about tillage is probably the most important factor in the large scale promotion of CA. It is difficult to convince famers, particularly in less developed countries, about the potential benefits of CA, except about cost reductions due to zero/reduced tillage. Further, probable yield reductions during the initial years of the adoption of CA may dampen the spirits of smallholders. In CA fields, higher weed intensity due to no/reduced tillage (Mousques and Friedrich, 2007; Jat *et al.*, 2012a), nutrient immobilization (Abiven and Recous, 2007; Giller *et al.*, 2009), and higher number of insect pests (Mousques and Friedrich, 2007; Giller *et al.*, 2009) and disease (Cook *et al.*, 1978; Hinkle, 1983) during the conversion phase may cause slight yield reductions compared to ConvT. Weed management is a major challenge in the successful adoption of CA. Zero tillage and no mechanical inter-cultivation can lead to heavy weed infestation (Jat *et al.*, 2012a). Herbicides alone do not provide proper weed control in the presence of crop residues on the soil surface. Moreover, intermittent rains that reduce the efficacy of applied herbicides and the lack of availability of herbicides, particularly for local popular intercropping systems, further make it difficult to achieve successful weed control in CA fields. Retention of fresh biomass, mainly cereal residues with high C:N ratio as mulch in CA, results in net immobilization of plant nutrients, especially N (Abiven and Recous, 2007). This is more evident during the early years of CA adoption and may lead to nutrient deficiency in crop plants unless extra amount of nutrients are applied externally (Nurbekov, 2008). Many farmers, mainly in tropical and subtropical countries, due to their cash-crunch situation are not able to make new investments for CA machinery (rippers, zero seed drill etc.). As CA is a paradigm change in production technology, farmers need to learn and equip themselves with new skills and even do experiments and innovate at their individual level in their specific set of operating conditions. This is where many farmers hesitate to take risks to venture into a new field for them.

Maintaining soil cover with crop residues or growing cover crops is essential to obtain the benefits of CA, but supply of crop residues is a limiting factor in successfully promoting CA in the tropics and subtropics. Not only are current biomass production levels are low, but also priority is given to the use of crop residues as cattle fodder due to high economic and cultural importance of livestock for smallholders. Prevalence of communal grazing and termite menace are other major hurdles in maintaining residue mulch in many African and Asian countries (Giller *et al.*, 2009; Umar *et al.*, 2011). Moreover, resource-poor farmers in the less developed countries are not in a position to grow cover crops during the fallow season because it requires extra inputs, but no direct economic returns are received (Ali and Narciso, 1996). It has been found that farmers do not follow all the principles of CA due to reasons such as the shortage of crop residues, lack of sufficient resources and input supply (herbicides), market pressures, labour constraints, etc. (Baudron *et al.*, 2007; Shetto and Owenya, 2007). However, problems of high residue supply and its management, particularly in temperate climates, are also not uncommon (see Duiker and Thomason, Chapter 2, this volume). Further, there is lack of sufficient research on weed control, suitable machinery, cropping systems and cover crops for CA, and on the long-term effects of CA on yield and soil quality (soil acidity, alkalinity, compaction, nutrient behaviour, etc.), particularly in the context of less-developed nations. For a detailed discussion on various factors limiting widespread adoption of CA, readers are referred to a recent review by Jat *et al.* (2012b).

To ensure sufficient biomass for use in CA, particularly in tropics and subtropics, there is a need to improve total biomass yield of the production systems. Additional sources of biomass could also be explored, for example, by integrating agroforestry systems with CA. Plants such as *Cassia tora, Gliricidia maculata, Leucaena leucocephala,* which grow and produce relatively large biomass in the low rainfall areas, could be appropriate plants for this purpose. These and other plants used for providing additional biomass could be grown on field bunds, wastelands and around water bodies.

1.7 Conclusions

To promote CA, a two-pronged strategy is needed. First, efforts should be made to share information, and discuss and make farmers aware about the benefits of the CA, especially in the longer term, and convince them on 'why they should follow CA'. Second, from the point of initiation, an active participation of all the concerned stakeholders needs to be ensured. In an effort to promote CA and its relevance among farmers, it is necessary to educate them on the link of excessive tillage and residue removal with soil quality sustainability problems, and as to how these problems can be reduced or alleviated through the adoption of CA (Lumpkin and Sayre, 2009). Once farmers become convinced and are ready to adopt CA, there should be active involvement of researchers, farmers, policy makers, input suppliers, NGOs and others in promoting CA. Governments can facilitate in CA adoption by providing subsidy for purchasing zero-till machinery and by making credit available on easy terms to tenants; besides, of course, protecting the tenants' rights. Active participation of equipment manufacturers is essential so as to help design and supply machinery, which is best suitable to the local conditions and meets the requirements of different categories of farmers. The NGOs can facilitate linking farmers with other stakeholders including researchers, input suppliers and government agencies. NGOs can also target specific potential areas for CA to begin with, and facilitate to the formation of farmers' self-help groups, organize farmers' visits, workshops, provide information on input supply, credit lines and take new technological advancements to the farmers' doorsteps. To make CA attractive to farmers, research should be undertaken to make CA profitable in the shorter term also. Developing an economic weed control strategy remains a major challenge for the successful adoption of CA. This also needs to be seen in the light of the fact that a total reliance on the use of herbicides for weed control in CA could lead to heavy environmental costs. Therefore, there is need to develop an economic and effective weed control strategy that is based on integrated weed management for the site-specific implementation as a component of CA (Friedrich and Kassam, 2009).

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