International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(2): 990-997

Received: 28-01-2019
Accepted: 30-02-2019

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Conservation agriculture: Building entrepreneurship and resilient farming systems: A review

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Abstract

"A good quality land yields good results to everyone, confers good health on the entire family, and causes growth of money, cattle and grain." As a source of livelihood, agriculture remains the largest sector of Indian Economy. While its output share fell from 28.3% in 1993-94 to 14.4% in 2011- 12 and employment share declined from 64.8% to 48.9% over the same period. Therefore, almost half of the workforce in India still remains dependent on agriculture. Given the low share of this workforce in the GDP, on average, it earns much lower income poorer than its counterpart in industry and services. Agriculture faces many challenges, making it more and more difficult to achieve its primary objective - feeding the world – each year. By 2050 the world's population will reach 9.8 billion, 34 percent higher than today. Annual cereal production will need to rise to about 3 billion tonnes from 2.1 billion today and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes. Agriculture produces an average of 23.7 million tonnes of food every day. To provide for a population of 9.8 billion in 2050, and 11.2 billion in 2100, food production will need to increase from the current 8.4 billion tonnes to almost 13.5 billion tonnes a year. Fifty percent of the additional food required to meet demand in 2050 will need to come from land already under cultivation. Seventy-five percent of the genetic diversity of crops has already been lost. By 2050, two out of three people on the planet will live in urban areas; a large portion of future urbanization will be caused by rural-urban migration (Buhaug and Urdal, 2013) [6]. CA addresses a wide range of agricultural production challenges that include declining soil fertility, increasing production costs; climate induced erratic rainfall patterns and increased demand for food production against severely reduced production capacities of agricultural lands. Solutions are workable options that can be tailored to raising system productivity or diversity, efficiency, resilience, value and profitability of farming, including the enabling mechanisms needed within diverse local contexts. Advances towards building entrepreneurship and resilient farming systems are the most effective and durable strategies, where all stakeholders work together to bring their ideas and support to developing and implementing site-specific solutions that allow for iterative, continuous improvement of the world's food systems and their key components. The paper offers ideas on how these problems can be addressed so as to accelerate agricultural growth in a sustainable manner.

Keywords: Agricultural value chains, system dynamics, food security

Introduction

Smallholder agriculture is the mainstay of food production in the world's developing countries and is the key to ensuring long-term global food security (FAO, 2014) [13]. With the global population on course to exceed 9 billion by 2050, the need to meet the growing demand for more food is immediate and pressing. The world's 500 million smallholder farms currently produce around 80 percent of our food and it is they who will have to bear the brunt of the need to increase food production by over 60 percent compared to 2007 levels. Currently many of these smallholder farms have limited access to production inputs and so achieve low levels of productivity. One key production input i.e. mechanization, is frequently neglected in farm productivity improvement efforts; in fact it has been described as the neglected waif of agricultural and rural development. Increasing food production whilst conserving the planet's natural resource base will not be a simple task. In second Green Revolution, which aimed at doubling of global food production in the second half of last century, became implausible. Rates of growth in the yields of the world's major food cereals (wheat, rice and maize) are now falling and this is due in no small part to the degradation of agricultural land.

Increase in food production via a process of sustainable intensification will necessarily, require the implementation of more natural resource-friendly production methods, for example reduced- and no-till farming, and this will require a major diffusion of novel mechanization technology.

Cropping intensity can be raised in a variety of ways as a result of adopting conservation agriculture (CA) system. Plough-based tillage is intensely time and energy-consuming. Primary tillage can also only be easily accomplished when soil conditions are suitable-not too dry and not too wet. Waiting until the first rains before initiating soil preparation can waste valuable time, delay planting until late in the sowing window, and results in reduced yields. Although highly variable, yield losses of up to one percent per day of delay after the optimum planting date can be experienced. Yield increases can also be expected after switching to CA (Ngwira *et al*., 2013) [42] but improvements cannot always be expected to be immediate. Degraded soils will need time to recover their health, structure and fertility under a no-till regime so, some yield decline may be experienced before yields recover and exceed pre-switchover levels. Integrating livestock production with CA cropping is another possibility. Using leguminous cover crops to feed a livestock enterprises such as dairy, goats could be a possibility if cultural preferences and market conditions are appropriate. A current phenomenon affecting many rural economies in the developing world is the drift of healthy young males to urban centers in search of more rewarding payment for their efforts. Fifty percent of the world's global population is urban today and this is projected to rise to 70 percent by 2050 (FAO, 2011) [12]. This means that those being left behind to work on the farms are women, the elderly and children and the consequence is that farm power becomes an increasingly severe constraint. If the supply of human labor emanates principally from women, the elderly and children, it is clear that supply constraints will have a negative impact on farm productivity.

Improving smallholders' access to crucial mechanization inputs is frequently fraught with difficulties as the adoption of any innovation must be seen as a useful and profitable investment from the perspective of the farmer. This prerequisite would then trigger the necessary demand for these innovations which should lead to an increased or stabilized supply. However, very often this demand is non-existent due to the low income levels of small farmers which in turn also lead to only very rudimentarily developed mechanization input supply chains in rural areas. This situation is referred to as 'the vicious cycle of mechanization development'. It requires broad action among all actors involved in rural development and sustainable intensification programs from the farmers' level up to and including policies to disintegrate the cycle (Kienzle and Sims, 2014) [32]**.** Mechanization inputs are usually lumpy so that a smallholder with, typically, under two hectares of land, will be reluctant to be the sole investor in a machine which has the potential to operate over a much larger area. As always, there will be many demands on a farm families financial assets and the opportunity cost of capital may militate against adoption of machinery. The affordability of mechanization inputs in the developing country smallholder farming sector is closely correlated with their profitability. Almost by definition poor smallholder families struggling to emerge from subsistence farming will usually have difficulty in amassing the resources necessary for machinery purchase. An alternative is to borrow the money required but this can be expensive and formal sources of credit, such as banks, are notoriously reluctant to extend credit to the sector, citing the high level of risk involved. Where specialist equipment is required for the adoption of sustainable crop intensification by means of conservation agriculture, then a further obstacle to adoption arises in the form of low availability. Supply is frequently initiated by externally funded aid programs and projects and local supply chains are generally not adequately developed. Machinery is often donated or sold at cost under attractive loan arrangements which are typified by low interest rates, long payback periods and a benign attitude towards defaulters. This can lead to the situation where farmers outside the programed target group are unable to access the machinery, even if they are convinced that it would be beneficial, as there is no local supply network. This situation is slowly improving as donor organizations realize the value of involving local dealers in the supply of machinery. Purchasing power of small and marginal farmers can be improved through farmer groups and Farmer Producer Organizations (FPOs). This aggregation approach also helps small and marginal farmers in accessing various benefits of government schemes for rural development.

CA, in conjunction with good crop, nutrient, weed and water management, is at the heart of FAO's new sustainable agricultural intensification strategy (FAO, 2011) [12] which takes an ecosystems approach to enhance productivity and resilience as well as the flow of ecosystem services while reducing emissions that come from the agriculture sector (Kassam *et al*., 2011a) [31]. These characteristics are also an integral part of climate-smart agriculture that seeks to increase productivity in an environmentally and socially sustainable way, strengthen farmers' resilience to climate change, and reduce GHG emissions and sequester carbon (World Bank, 2012) [54]. At the heart of sustainable agricultural intensification, or sustainable land management, is the integration of soil and water conservation practices in agricultural production, with concurrent objectives of enhanced economic returns and environmental management.

Under no till, a much richer and more favourable soil biological environment is created in the soil, promoting larger amounts and diversity of microorganisms and soil meso and macro-fauna. These generate and control some of the ecosystem functions critical for good soil health, including soil carbon storage and nutrient cycling. They are also important in promoting larger and more stable soil aggregates (Wright, 1998) [55], as well as networks of soil "bio-pores", thereby promoting improved water infiltration and soil water storage.

The extensive cover of the soil surface by organic residues and stubble greatly reduces the amount and severity of water run-off and soil erosion. In turn, this reduces surface water pollution from the sediments and solutes that are regularly carried with the eroded soil. The surface litter associated with no tillage, as well as the increased soil organic matter, greatly enhance the capacity of the soil to capture and store rain and irrigation water. At the same time, it significantly reduces surface water runoff, soil erosion, and evaporation. These changes ensure at least some level of drought proofing during dry periods, and they help to reduce yield variability among seasons, thereby facilitating better farm planning. Under irrigated conditions, they significantly reduce the amount of water needed to bring a given crop to maturity.

New technologies will make it possible for conservation agriculture to building entrepreneurship and resilient farming systems to become the new global standard, not the exception;

the main factors resisting change are political will, lack of policy coherence at many levels, financing, governance and human behavior. We propose evidence-based indicators that could be applied to track progress towards meeting the entrepreneurship and resilient farming systems and their targets, at local, national, regional and global scales. Their effective use will require investing more in monitoring agriculture and food systems, taking advantage of rapid advances in digital information technologies. The transformation of agriculture will also require re-thinking of international and national structures. The global food system should morph into a true global partnership that widely shares information, experiences and new technology, following open access principles and practices that honor intellectual property but enable wide access and use. New models for implementation are needed that unlock the real potential of farmers, public and private sectors in solving complex problems. The private sector will be a key player in entrepreneurship and resilient farming systems and food systems. Good governance will be essential, including supporting farmer groups, managing risks, and deploying tools and accountability measures that foster greater private sector investment in agriculture, but also put clear constraints on unsustainable or inequitable exploitation of land, water, forests and fisheries.

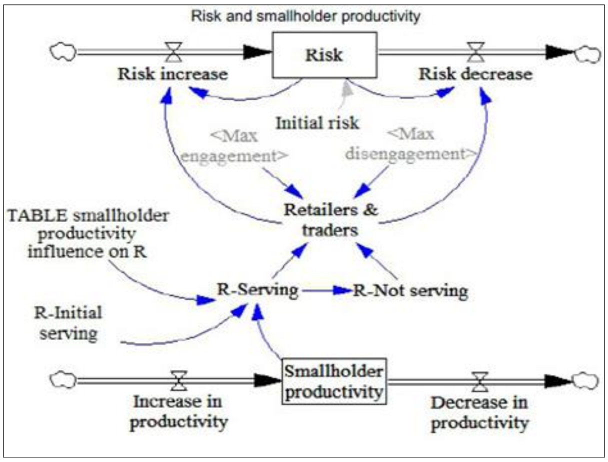

Fig. Risk and smallholder productivity

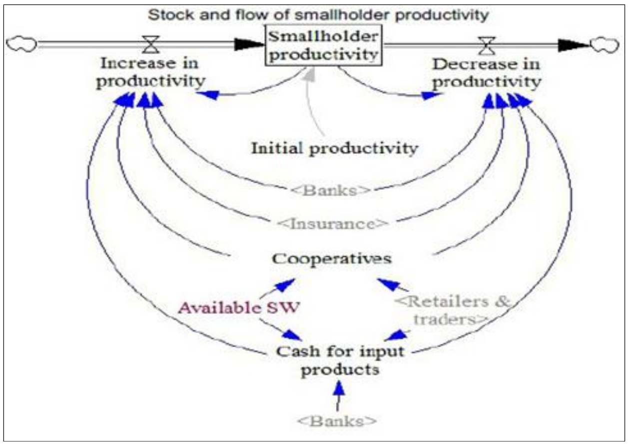

Fig. Smallholder productivity

Agriculture ecosystem services are usually called provisioning services, and have been regarded as the single most important role of farming (Scherr and McNeely, 2008) [50]. Farmers influence the capacity of the farming system to deliver ecosystem services. But farms not only sustain provisioning services but also provide supporting, regulating and cultural services. Supporting and regulating ecosystem services are mostly biologically regulated. Soil management is a key factor in many of the provisioning and supporting ecosystem services provided by farming systems. Maintaining a healthy soil is an important strategy for many supporting and regulating services: water infiltration and -retention, resistance to erosion, nutrient cycling and retention, and disease suppressiveness (Powlson *et al*., 2011) [46]. Farmers actively manage soil health to secure future production, by enhancing regulating and supporting services of soils. Moreover, in the process of agricultural intensification, farmers have replaced much of the regulating and supporting ecosystem services that originally were provided for by soil biota, by human external inputs. Decomposing functions of soil organisms have been replaced by inorganic fertilizers, disease suppressive functions of soil organisms and natural biodiversity have been replaced by chemical crop protection agents and the function of 'ecosystem engineers' like earthworms in building soil structure has been diminished by tillage. (Giller *et al*., 1997) [18].

Changing water flow and decreased storage: Agriculture modifies the plant species composition and below-ground root structure, the production of litter, the extent and timing of plant cover, and the composition of the soil biotic community: factors that influence to a major extent are water infiltration and retention in soil. The intensity of agricultural production and management practices affect both the quantity and quality of water in agricultural landscapes (Power, 2010) [45].

Increasing erosion: Soil erosion is a natural geological phenomenon that has created the vast fertile soils of alluvial flood plains and loess plateaus around the world. However, the accelerated soil erosion, exacerbated by human perturbations, is a destructive process. It depletes soil fertility, degrades soil structure and reduces the rooting depth of plants (Lal, 2003). As a result, the diversity of plants, animals and microorganisms is diminished. Ultimately, the resilience of the entire ecosystem is threatened (Pimentel and Kounang, 1998) [44]. Land which is covered by plant biomass, living or dead, is protected and will experience reduced soil erosion. Vegetation is the main component of ecosystem biomass, followed by belowground microbial biomass. Maintenance of vegetation is one of the main principles to prevent soil erosion. In forested areas, a minimum of 60% forest cover of the landscape is necessary to prevent soil erosion and landslides. Another factor influencing the susceptibility to erosion is soil structure. Soils with medium to fine texture, low organic matter content, and weak structural development are most easily eroded. Principles for preventing soil erosion should enhance soil organic matter contents (Pimentel and Kounang, 1998) [44].

Changing climate: The global release of soil organic carbon from agricultural activities has been estimated at 800 Tg C yr^{-1} (T = tera = 10^{12}) Soil biological degradation, by decrease of soil organic carbon, is an important factor leading to C emission from soil to atmosphere (Lal, 1997). Increased CO_2 represents the most important human enhancement to the greenhouse effect. Changes in land use and land cover, mainly driven by agriculture, may also influence climate through changes in evapo-transpiration. There is increasing concern about potential effects of land cover changes on agriculture, through adverse effects on the monsoons (Gordon *et al*., 2010) [19].

Table 1: General principles related to different concepts of building entrepreneurship and resilient farming systems.

Building entrepreneurship and resilient farming systems concepts	Principles	References
Diversified Farming Systems	Farming practices and landscapes that intentionally include functional biodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination	Kremen *et al*., 2012
Eco-agriculture Landscapes	Mosaics of areas in natural/native habitat and areas under agricultural production. Agriculture, biodiversity and ecosystem services are seen as interdependent. Rural communities are critical stewards of biodiversity and ecosystem services.	Scherr and McNeely, 2008
Sustainable Intensification	Intensification of resources, using natural, social and human capital assets, combined with the use of best available technologies and inputs (best genotypes and best ecological management) that minimize harm to the environment. Resource-conserving technologies are Integrated Pest Management, Integrated Nutrient Management, Conservation Tillage, Agroforestry etc.	Pretty, 2008
Conservation Agriculture	Conservation Agriculture is defined as minimal soil disturbance (no-till, NT) and permanent soil cover (mulch) combined with rotations.	Hobbs *et al*., 2008
Organic Agriculture	Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.	IFOAM (www.ifoam.org)
Direct-seeding Mulch-based Cropping Systems	A form of Conservation Agriculture, Direct seeding mulch-based cropping systems are characterised by ideally no tillage, soil surface protection through mulch from crop residue, crop rotation, keeping the soil permanently covered	Affholder *et al*., 2010
Evergreen Agriculture	Evergreen agriculture is defined as the integration of particular tree species into annual food crop systems. The intercropped trees sustain a green cover on the land throughout the year to maintain vegetative soil cover, bolster nutrient supply through nitrogen fixation and nutrient cycling, generate greater quantities of organic matter in soil surface residues, improve soil structure and water infiltration, increase greater direct production of food, fodder, fuel, fiber and income from products produced by the intercropped trees, enhance carbon storage both aboveground and below-ground, and induce more effective conservation of above and below-ground biodiversity.	Garrity *et al*., 2010

Basic mechanisms of resilience farming systems building

Stimulate nutrient cycling; Prevent nutrient losses; Stimulate nutrient storage and buffering; Increase nutrient-use efficiency; Regulating water flow and enhancing storage; Improve water infiltration capacity; Improve water retention by soils; Enhance root-ability of soils; Increasing water-use efficiency; Maintain water quality; Enhance soil protection by plant cover; Minimize soil disturbance by tillage; Maintain soil organic matter levels; Maintain high biodiversity of cultivar varieties; Employ crop rotation in time and/or space; Provide habitats for natural enemies and pollinators; Maintain soil organic matter levels; Enhance soil biodiversity; and Providing enough fodder of good quality.

Conservation agriculture and resilient farming systems

CA practices such as reducing tillage intensity, decreasing or eliminating the fallow period, using a winter cover crop, retention of crop residues on soil surface, changing from mono-cropping to rotation, or altering soil inputs to increase primary production (fertilizers, pesticides, irrigation, etc.,), all could contribute to greater organic C storage in the soil (West and Post, 2002) [53]. These practices result in increasing SOC to reach new SOM equilibrium (Johnson *et al*., 1995) [29]. Hobbs and Gupta (2004) [25] reported that farmers were able to save 40-60 L diesel fuel per ha in zero till wheat grown after harvesting of puddled rice as farmers can forego the practice of plowing many times to get a good seedbed for wheat. One litre diesel contains 0.74 kg C and emits 2.67 kg CO_2 (Environmental Protection Agency, 2009). Lifeng *et al*. (2008) reported that CO_2 flux were 135% and 70% more from soil in plowed field for residue cover and no cover plots respectively, compared to no-till field. Hutsch, (1998) [28] suggested that a reduction in tillage intensity could help minimize the adverse effects of cultivation on soil CH_4 uptake.

Hobbs and Govaerts, (2010) [24] also observed that the resulting improved soil quality and improved nutrient cycling due to CA can improve the resilience of crops to adapt to changes in local climate. ZT with residue retention has been reported to decreases the frequency and intensity of short mid-season droughts (Bradford and Peterson, 2000). Similarly, the increased infiltration under CA in combination with the permanent raised-bed system can help mitigate the effects of temporary waterlogging which is likely to increase in some parts due to climate change induced aberrant weather conditions (Hobbs and Govaerts, 2010) [24]. Mulch cover reduces soil peak temperature that can increase with global warming thus, favoring biological activity, initial crop growth and root development during the growing season (Oliveira *et al*., 2001) [43]. In CA, soil-surface-retained residue affects soil temperature through its effects on the energy balance; while tillage operations increase the rates of soil drying and heating because tillage disturbs the soil surface and increases the air pockets in which evaporation occurs (Licht and Al-Kaisi, 2005). Acharya *et al*. (1998) [36, 1] found that the presence of crop residues as mulch in the minimum tillage treatment raised the minimum soil temperature, measured at 0.05 m depth, by 0.5- 2^0 C compared to no mulch treatment during wheat growth. The maximum temperature under minimum tillage treatment however, was lowered at this depth by 0.3- 2^0 C. Govaerts *et al*. (2009b) [21] reported that ZT with residue retention had higher soil moisture content compared to the other treatments, especially in the dry mid-season period, i.e., 65-85 days after sowing of maize and wheat, albeit to lesser extent in wheat. Wheat stubble had higher time-to-pond (direct surface infiltration) compared to plots with maize.

These results are similar to those reported by McGarry *et al.* (2000) [39] who obtained higher time-to-ponds both under low as well as high-energy rainfall in ZT with residue compared to CT. Thierfelder and Wall (2009) [51] reported higher rain-water infiltration and soil moisture content in CA plots than in the plowed plots. They found infiltration three to five times in CA compared to plowed plots. The greater numbers of worms, termites, ants, and millipedes combined with a higher density of plant roots result in more large pores, which in turn increase water infiltration in CA plots (Roth, 1985) [48]. Water-use efficiency increased in the no-till wheat following rice because often the first irrigation could be dispensed with, and when the first irrigation was given the water moved faster across the field (Hobbs, 2007). Systems using no-till and permanent ground cover showed reduced water runoff (Freebairn and Boughton, 1985) [15], better water infiltration (Fabrizzi *et al*., 2005) [11], and more water in the soil profile throughout the growing period (Kemper and Derpsch, 1981a) [30]. The biological activity combined with the previous crop's root channels results in interconnected soil pores that lead to improved water infiltration (Kay and Vanden Bygaart, 2002). The improved pore space is a consequence of the bio-turbating activity of earthworms and other macro-organisms and channels left in the soil by decayed plant roots (Bot and Benites, 2005b) [4]. No tilled soils with surface cover mulch had higher surface water content than conventional tilled fields because mulch acts as a porous media developing a top soil structure with worm channels, macro-pores, and plant root holes, producing higher infiltration rates (Mielke *et al.*, 1986) [40].

The consequence of increased water infiltration combined with a higher organic matter content, is increased storage of water in the soil profile (Gassen and Gassen, 1996) [17]. Moreover, organic matter intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity, especially in the topsoil, where the organic matter content is greater and more water can be stored. Bot and Benites (2005b) [4] observed that conserving fallow vegetation as a cover on the soil surface, and thus reducing evaporation, results in 4% more water in the soil. This is roughly equivalent to 8 mm of additional rainfall. This amount of extra water can make the difference between wilting and survival of a crop during temporary dry periods. Hudson (1994) [27] showed that for each 1% increase in SOM, the available water holding capacity in the soil increased by 3.7%. Unger (1978) [52] showed that high wheat-residue levels resulted in increased storage of fallow precipitation, which subsequently produced higher sorghum grain yields. High residue levels of 8-12 tha^{-1} resulted in about 80-90 mm more stored soil water at planting and about 2tha^{-1}more of sorghum grains yield compared to no residue management.

Calegari *et al.* (2008) [8] reported that the mean annual seed yield of soybean in a nine- year study were 2.54 and 2.41 Mg ha^{-1},respectively for NT and CT. They also reported that annual corn grain yields over eight seasons were 5.82 and 5.48 Mg hae1, respectively for NT and CT. Lal (1991) [33] reported from two eight years or longer studies that larger maize grain yields were maintained with a mulch-based NT system than in a Plow-based system. Gupta *et al.* (2010) [22] reported that wheat grain yields were 5393, 5056 and 4537 kg ha^{-1}under zero-till with residue retention, zero-till without residue and CT with rotavator broadcast, respectively. Better and stable yields under CA occur due to timely planting or buffering of moisture stress, improved soil physical and biological properties, improved water infiltration, less soil and wind erosion, and a potential for biological control and less incidence of disease and pest disease (Hobbs and Govaerts, 2010). Acharya *et al.*(1998) [24, 1] observed that minimum tillage in combination with mulching significantly increased rooting density and grain yield of wheat as compared to that in CT and no-mulching (farmers' practice).

Presence of crop residues on soil surface can help in better germination and emergence of seedlings in light-textured soils where formation of surface crusts and seals due to breakdown of soil macro-aggregates are the major constraints to crop productivity (seems to be inappropriate as a continuation) (Lal and Shukla 2004). Bot and Benites (2005a) [3] discussed the effect of high temperature on plant growth and development and how CA can be helpful in mitigating the adverse effects of high temperature on plants. According to them, soil temperature adversely influences the absorption of water and nutrients by plants, seed germination and root development, as well as soil microbial activity and crusting and hardening of the soil. High soil temperature is a major constraint to crop production in much of the tropics. Maximum temperature exceeding 40ºC at 5 cm soil depth and 50ºC at 1 cm soil depth are commonly observed in tilled soil during the growing season, sometimes with extremes of up to 70ºC. Bot and Benites (2005a) [3] further argue that such high temperatures have an adverse effect not only on seedling establishment and crop growth, but also on the growth and development of the microbial population.

The potential of CA to reverse the process of soil degradation and make agricultural production more secure is so significant a factor that farmers need to be encouraged and supported proactively in practical ways to start and complete the transition to CA for the benefit of themselves, their local and national communities, and the future generation (Lal, 2010) [34]. CA has the potential to emerge as an effective strategy to address the increasing concerns of serious and widespread degradation of natural resources including soil degradation (Sangar, 2004). Castro (1991) [49, 9] compared water, soil and plant nutrient loss in conventional agriculture and direct seeding in a wheat-maize rotation and found that the losses were less under direct seeding due to the soil cover, which reduced the rainfall impact on the soil surface. In CA by avoiding the detachment of soil particles by raindrop impact, which accounts for 95% of erosion, soil losses are avoided or reduced, and at the same time the soil can be cultivated in conditions similar to those found in forests (FAO, 2000) [14].

Soil cover protects soil against the impact of raindrops and gusty winds, and also protects the soil from the heating effect of the sun (Govaerts *et al*., 2006) [20]. At the same time, practices of minimum/ zero tillage and direct sowing techniques as alternatives to the conventional practices lead to minimum disturbance of soil. The presence of crop residues over soil surface under CA prevents aggregate breakdown by direct impact of raindrop as well as by rapid wetting and drying of soils (LeBissonnais, 1996) [35] which can be of special importance for heavy textured soils in semi-arid tropics. The mulch used in CA promotes more stable soil aggregates as a result of increased microbial activity and better protection of the soil surface. Hobbs *et al.* (2008) [23] also observed that under CA the soil biota ‘‘take over the tillage function and soil nutrient balancing’’ and that ‘‘mechanical tillage disturbs this process’’.

Calegari and Alexander (1998) [7] reported that after nine years, the phosphorus (P) content (both inorganic and total) of the surface layer (0-5 cm) was higher in the plots with cover crops. Depending on the cover crop, the increase was between

2 and almost 30%. This indicates that different cover crops have an important P-recycling capacity and this was even improved when the residues were retained on the surface. This was especially clear in the fallow plots where the CT plots had a P-content 25% lower than that in the ZT plots. Mousques and Friedrich (2007) [41] reported that CA practices improved soil pH, organic matter and available nutrient contents in most of the farms compared to CT: organic matter content was raised by an average of 0.2%; the available N was raised by 20-25 mg kg^{-1} soil, available P increased by 10 mg kg^{-1} soil. This could be the result of increased P mobilization by organic acids resulting from the build-up of SOM; the available potassium (K) content was also improved by 10-15 mg kg^{-1} soil. It was also observed that straw decomposed better and faster in the wheat-paddy field than in the wheat-maize-rape-cotton field.

Conclusions

Wider adoption of CA technologies requires concerted effort of all the stakeholders in the expanded partnership and participatory approaches in which farmers' experiments and provides rapid feed-back. This would need to be supported by institutional changes that promote knowledge-sharing, flexibility and decentralized decision-making for rapid adoption of technologies to maintain production and productivity, increased food security and livelihood of the farmers. Available evidence shows continuously declining cereal crop yields during the past decade despite the large areas that are planted each year and this can be attributed to the major constraints of low and erratic rainfall, inherently low soil nutrient status, timely non-availability of inputs and lack of appropriate technologies. It is therefore important to note that intensification of crop production systems should aim at increasing crop productivity per unit area through building entrepreneurship and resilient farming systems and the use of technologies that address moisture management issues, increase the efficiency with which both external and natural recourses are used, while maintaining and improving soil fertility. However, a shift to CA has become a necessity in view of widespread problems of resource degradation, which accompanied the past strategies to enhance production with little concern for resource integrity. Farming systems should enhance resilience in order to be able to cope with change. Resilience can be viewed upon from different levels. The soil as the central regulatory center provides a valuable starting point from which to develop a broader understanding of resilience on farm level. Not only production, but many other ecological functions are dependent on soil health. Biodiversity at different levels is supporting resilience in soils, crops and animals. Rethinking farming systems in terms of resilience, without a priori rejecting solutions on ideological grounds, can overcome differences in approaches to sustainable agriculture, and bridge the gap between highly productive agriculture and conservation goals. Conservation agriculture offers an opportunity for arresting and reversing the downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource – use-efficient, competitive and sustainable:

- **Sustainable intensification**: The smallholder farming sector is key to producing the food requirements of an increasing, and increasingly urban, population. Increased production must be accompanied by natural resource conservation if mankind is to have a future on this planet. CA requires specific entrepreneurship and mechanization inputs. Smallholder farmers are not often in a position to invest in expensive farm machinery and the best vehicle to provide them with the required services is via well trained and well equipped private sector entrepreneurial CA service providers.
- **Local manufacture**: Local manufacture of CA equipment is a desirable goal as it not only helps to stimulate the local economy, but also provides the opportunity to adapt technologies to local conditions be they crops, soils, climate, production systems, technical knowledge, manufacturing skills or material supply, amongst other factors.
- **Policy guidelin**es: Governments will often need guidance on how to provide the best environment for nurturing a local CA equipment manufacturing industry. Financial support to the smallholder farming sector to assist farmers in the purchase of CA equipment will directly stimulate the local supply chain. The correction of anomalies affecting local manufacture, such as the existence of import duty on machine components and raw materials, but not on imported agricultural machinery, will need to be removed to provide an equitable environment for local industry.
- **Demand creation**: Efforts at creating demand for CA should be on-going. Although the public sector has a major role to play (for example in organizing field days and improving extension efforts), the private sector should also be encouraged through demonstration plots, out-grower technical support, machinery fairs and the formation and consolidation of CA farmer mutual support groups.
- **Service provision**: Given the problems of affordability and availability of CA equipment, including power sources, a promising solution is to equip and train entrepreneurial CA service providers. Equipment can be centrally procured and delivered on credit to would-be service providers. Loan payments are repaid from the resulting business activity. E-voucher systems can be employed to stimulate initial demand for the services but they should be withdrawn as soon as demand is sufficiently high.
- **Training:** Service providers not only need good CA equipment, but will also often need training in the technical aspects of its correct use, calibration and maintenance, as well as training on the managerial skills of identifying and running a successful service provision model.

CA addresses the problem of low and erratic rainfall through the use of technologies that reduce water losses from runoff and soil evaporation and increase infiltration and soil moisture holding capacity, and improve low soil nutrient status by increasing soil carbon and nitrogen through the use of organic soil cover and legumes in rotations and interactions.

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