16 Summing Up

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Reducing soil disturbance by tillage began in the USA in the 1930s as a response to the 'dust bowls' in the Great Plains. Research on 'conservation' or reduced tillage, with early versions of a chisel plough, was initiated in the Great Plains in the 1930s to alleviate wind erosion of soil that was being pulverized by tillage and left exposed to wind and rain. Stubble mulch farming was also developed, and can be seen as a forerunner of no-tillage (NT) farming. This collection of practices led to what became known as conservation tillage. The modern successor of NT farming – now generally known as Conservation Agriculture (CA) – goes much further. It involves the simultaneous application of three practical principles based on locally formulated practices: minimizing soil disturbance (NT seeding); maintaining a continuous soil cover of organic mulch and plants (crop residues, stubbles and cover crops including legumes); and cultivation of diverse plant species that, in different farming systems, can include annual or perennial crops, trees, shrubs and pastures in associations, sequences or rotations, all contributing to enhancing system resilience. Conservation Agriculture, in conjunction with good crop, nutrient, weed and water management, is at the heart of FAO's new sustainable agricultural intensification strategy. Several organizations with global reach, such as CIMMYT, ICARDA, ICRISAT, CIRAD, ACIAR, AFD besides NARS institutions, universities, NGOs and farmer associations, are working to promote CA in different parts of the world.

Worldwide, CA is now practised on an estimated 125 Mha of arable cropland, mainly in North and South America, particularly the USA, Canada, Brazil, Argentina and Paraguay, and in Australia and New Zealand, but also increasingly in China, Kazakhstan, Ukraine and Russia. During the past decade, it has begun to spread in Asia more generally (including on the Indo-Gangetic Plains), in Europe (including in the UK) and in Africa. Conservation Agriculture has now spread over 1 Mha in Africa, including in South Africa, Mozambique, Zambia, Zimbabwe, Malawi, Madagascar, Kenya, Sudan, Ghana, Tunisia and Morocco, and some two-thirds of the area is under smallholder production. Much of the latter adoption has occurred in recent years as a result of more policy and extension attention and development resources being directed towards the promotion of CA through participatory dissemination and up-scaling approaches. Over the past decade the area of CA has increased at an average rate of 7 Mha year^{-1}, but in recent years the annual rate of spread has increased to some 10 Mha.

The above pattern of adoption and spread of CA is reflected across most of the chapters of this book but each chapter tells a country-specific or region-specific story of why, how and when it all began, what is the current status of adoption and how it is spreading, and what the future prospects are. In the USA, the initial impetus to reduce soil disturbance and adopt NT farming arose in response to the 'dust bowls' of the 1930s. In the case of countries such as Brazil, Argentina and Paraguay, where NT farming started in the 1970s and 1980s, the main initial driver was soil degradation due to water erosion from rainfall of exposed and loose topsoil from intensive tillage, in addition to low profitability of farming. In Canada and Australia, the initial driver towards CA was wind and water erosion. Subsequently, other factors such as the possibility of greater productivity and profit through greater adaptability to drier or wetter conditions, as well as reduction in production inputs of seeds, fertilizer, pesticide, energy and time also became important drivers for transformation from tillage farming to CA. More recently, CA has also begun to spread in a number of countries in Africa, Asia and Europe, the main drivers being the loss of or stagnating productivity due to soil degradation from erosion, loss of organic matter and soil structure, soil compaction, as well as rising costs of production. Conservation Agriculture is also being recognized as contributing to longer-term sustainability and resilience of crops and cropping systems, and of food and agriculture systems, against increased climatic variability and climate change. Although in some countries CA is still limited to the research sector, it is increasingly seen as an appropriate practical concept to promote in the future to achieve sustainable production intensification and to rehabilitate degraded agricultural lands and ecosystem services. While CA has its share of critics, differences in perspectives and appropriateness of CA are not over the efficacy of locally formulated CA practices but rather more with process of deciding where and how to promote the adoption and spread of CA.

What is now becoming increasingly clear is that because tillage-based agriculture at any level of technological development disrupts soil-mediated ecosystem functions and reduces soil productive capacity, it is not ecologically or economically capable of sustaining current production levels or production intensification. Further, tillage agriculture is not capable of fully harnessing necessary ecosystem services such as clean water, carbon sequestration, water and nutrient cycling, climate regulation and erosion control. Being a net emitter of greenhouse gases, tillage agriculture is also unable to mitigate climate change. In contrast, CA not only offers an approach to intensify production in an ecologically sustainable way, it is far less costly, economically and socially, than tillage agriculture. CA utilizes the whole ecosystem and the natural biodiversity including soil microorganisms and soil meso-fauna to build soil health and productive capacity and protect crops from weeds, insects and pathogens. Given CA's ability to improve rainfall infiltration and soil moisture storage as well as an increase in soil and root volume, there are improved interactions between plant roots and soil nutrients, and between plant roots and soil microorganisms such that there is greater resilience to biotic and abiotic stresses in CA systems compared with tillage systems.

Conservation Agriculture also allows greater precision with farm operations and higher efficiencies of input use in smallholder farms. This is particularly important in pro-poor development projects where purchased production inputs are not only scarce but must be made affordable. Higher input factor productivities with low levels of inputs in CA systems can provide a greater return to investment and a more robust basis for sustainable production intensification. On large farms with CA, it becomes possible to overlay controlled traffic farming and GPS-based precision farming to operate with best efficiencies of energy and input use. For several years now a carbon offset credit scheme has been operating in Alberta, Canada, based on CA to which controlled traffic farming and GPS-based precision farming are being added. Similarly, in Brazil, a programme called 'cultivating good water' has been operating in the Paraná

3 basin based on CA on large and small farms in order to improve the quality and quantity of clean water feeding into the Itaipu Dam whose working life has been extended considerably as a result. Elsewhere, in China, the spread of CA on small farms has helped in reducing the dust in the atmosphere in Beijing. In Spain, CA-based olive orchards have reduced soil erosion and flood risks in some 30% of the olive groves. In Western Australia, due to the adoption of CA in the semi-arid winter rainfall areas, there has been a significant reduction in land degradation and rehabilitation of degraded land from previous misuse with tillage agriculture. Such large scale ecosystem services of carbon sequestration, watershed services, cleaner air and reduced flood risks are not possible with tillage agriculture. Harnessing such services can be promoted through schemes in which farmers can receive payments for improved environmental and biodiversity management in agricultural landscapes.

When farmers decide to switch to CA from tillage farming, the expected mix of economic and environmental benefits manifests itself over time. The benefit mix varies in make-up and time scale depending on several factors including: agroclimatic conditions and variability within and between seasons; initial status of soil health and drainage under tillage systems; farm size and source of farm power; cropping system sophistication; yield levels under tillage systems; farmer expertise and experience of CA systems; access to production inputs, equipment and machinery; and competition for crop residues as livestock feed, and farm- and community-level arrangements for its enhancement and management. Given the infinite number of possible permutations in farm ecological and socio-economic conditions and social arrangements for changing from tillage-based systems to CA, a pattern of economic and environmental benefits can be recognized, which is increasingly supported not only by farmer performance but also by on-farm and on-station research across all continents and agroecologies.

In general, CA benefits can include: increased factor productivities and yields (depending on prevailing yield levels and extent of soil degradation); up to 70% decrease in fuel energy or manual labour; up to 50% less fertilizer use; 20% or more reduction in pesticide and herbicide use; some 30–50% less water requirement; and reduced cost outlay on farm machinery. Further, with CA it is possible to enhance climate change adaptability of cropping systems, farms and landscapes because of improved soil–plant moisture relations while at the same time mitigating climate change through greater carbon sequestration and lower emissions of greenhouse gases of CO_2, N_2O and CH_4. Due to much greater rainfall infiltration and reduced runoff and soil erosion, CA can also decrease flood risks, raise water resource quality and quantities as well as reduce infrastructure maintenance costs.

Conservation Agriculture does not provide a solution to all farming problems, although it does offer an alternative approach ecologically to underpin crop production systems so that they are sustainable and resource enhancing and conserving, offering on-farm productivity benefits and landscape-level ecosystem services. FAO refers to this as the 'Save and Grow' approach to sustainable production intensification with an ecosystem approach. However, like with any farming system, adoption of CA has its constraints that must be overcome for large-scale dissemination. The establishment of CA methods can be difficult in the initial years in some semi-arid areas and on heavy clay soils, compact soils and poorly drained land. Control of pests and diseases can be a concern in some instances where crop residues are left on the soil, and pesticides/herbicides may be required, at least in the initial years. Leaving crop residues on fields as mulch would eliminate an important source of animal fodder in areas where livestock play an important role in farm economies. There can be other location-specific socio-economic issues that must be addressed such as perceived risk of loss in productivity in initial years or possible displacement of paid farm labour. On larger farms, the lack of appropriate equipment for seeding and fertilizer placement through surface mulches can be problematic.

Adoption and spread of CA internationally offers lessons that show that the above-mentioned challenges can be and are being overcome by farmers, rich and poor, small and large, through locally formulated solutions involving a range of public and private sector stakeholders working together with farmers along different pathways of adoption and transformation. The negative effects of difficult biophysical conditions can be reduced as improved, physical and biological soil conditions are established through CA practices, and diversified crop rotations and associations can keep crop pest/disease risks low. Integrated weed management is easier where hand cultivation is practised; and the use of an initial herbicide application followed by crop rotations and maintenance of a continuous soil cover by plants and mulch can eventually reduce weed competition. Crops whose yield is located below ground, such as white potato, sweet potato, cassava, groundnut and sugarbeet, can also be planted into untilled soil, and harvested with minimal soil disturbance using appropriate harvesting equipment or changes in cropping practices. Rice too is produced without puddling the soil. In CA systems with livestock husbandry, total biomass production is increased over time so that it is possible to manage on-farm residue allocation between livestock feed and soil protection dynamically in order to satisfy both goals. Where communal grazing of crop residues is a constraint in maintaining soil cover, a community-based solution can be found so that some crop residue is retained. The constraint of lack of suitable mechanical equipment diminishes over time as a sufficient market develops for the local manufacturer.

In the coming decades, every effort by all concerned must be made to transform tillage agriculture to CA. There are several ways to support immediate and widespread up-scaling of CA:

- In all new agriculture development projects, include CA as the basis for sustainable production intensification and engage all the relevant stakeholders to ensure success.
- Revise universities' agriculture curricula to include teaching the next generation of farmers and agricultural development practitioners about CA as an alternative and sustainable way of farming.
- Fund more innovative practical research to tackle soil, agronomic and livestock husbandry challenges through our universities and research centres.
- Advocate for initial government support in terms of subsidies to make appropriate farm equipments more readily accessible and to reduce any risks of possible productivity losses during the initial years of switching to CA.
- Encourage governments to update their agricultural policies and bring institutional reforms that support the up-scaling of CA, especially in Asia, Africa and Europe – where it is perhaps most urgently needed.
- Develop large-scale programmes that would offer payments to CA farmers for harnessing ecosystem services such as carbon sequestration, watershed services for increasing the quality and quantity of water resources, control of soil erosion and reduction in flood risks, and enhancing pollination services.

Fuller advantage of the benefits offered by CA can be taken if all stakeholders become involved in facilitating the transformation process as is happening in countries such as Brazil, Argentina, Paraguay, the USA, Canada and Australia. This is also beginning to occur in countries in Europe (e.g. Finland, Spain), Africa (e.g. Zambia, Zimbabwe) and Asia (e.g. Kazakhstan, China). However, a more structural response to the opportunities presented by CA calls for a realignment of agricultural institutions, including research, extension and education, as well as agriculture development policies to enable CA to become the preferred agriculture paradigm choice around which to strengthen national and international food and agriculture systems. As a result of the process of World Congresses on Conservation Agriculture, there is now a global multi-stakeholder CA Community of Practice (CA-CoP) that is facilitating the uptake and spread of CA internationally. During the past decade, the effort to promote CA has become increasingly better organized, and donor agencies, governments, national research and extension systems, private sector firms, NGOs and farmers themselves are engaged in finding ways and means to introduce and spread CA.

The future requires that farming and agricultural landscapes everywhere must be multi-functional, ecologically sustainable and integrate into the greater ecosystems alongside non-agricultural land uses. This means that any agricultural production enhancement must go hand in hand with the enhancement and delivery of desired ecosystem services, and production systems must be efficient with high production factor productivities as well as resilient in on-farm performance and in their socio-economic development at the civil society level. Food and agriculture systems internationally need effectively to address local, national and international challenges, which include: food, water and energy insecurity, climate change, pervasive rural poverty and degradation of natural resources. As this volume of national and regional assessments clearly shows that the principles of CA and their locally formulated adapted practices, with their potential capacity to slow and even reverse productivity losses and environmental damages, appear to offer an entirely appropriate solution to all types of farms in all agroecologies. While to some readers this statement may sound overly optimistic, to all the authors who have contributed their practical expertise to this book, CA-based farming systems appear to be the best available option for meeting future food security needs sustainably, while alleviating poverty and building livelihoods, and rehabilitating and enhancing ecosystem functions and services.