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Development of Conservation Agriculture Systems Globally[#]

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ABSTRACT

This manuscript outlines the development of Conservation Agriculture (CA) system globally in terms of its origin, pioneers and champions, main drivers for its spread, CA systems involved, regional adoption, challenges and future prospects. Reducing soil disturbance by tillage began in the United States in the 1930s in response to the devastation caused by mouldboard ploughing and prolonged drought in the mid-west prairies that led to the phenomenon known as the 'dust bowl'. Initially, a number of soil and water conservation practices was developed, which include contour ploughing, bunding and terracing. Stubble mulch farming was also developed and this became a forerunner of no-tillage farming which appeared in the 1940s in the United States and led to the term conservation tillage. Realizing that tillage was the root cause of soil erosion and degradation, the term conservation tillage was replaced by the term Conservation Agriculture in 1997 at the meeting of the Latin American Network for Conservation Tillage (Red Latino Americana de Labranza Conservacionista, RELACO) in Morelia, Michoacan, Mexico. Since 1998, the United Nations Food and Agriculture Organization (FAO) has been promoting the CA concepts and the practical application of the three interlinked principles (along with other complementary good agricultural practices) with further development of the universal applicability of the principles and their practical applications, as we now know them. In 2015-16, CA had spread over 180 M ha of cropland globally, the area being equally split between the Global North and Global South. Since 2008-09, the global rate of annual expansion of CA cropland has been about 10.5 M ha. While the main drivers that have contributed to the adoption and spread of CA, namely, the impact of soil erosion and degradation on crop productivity, increased cost of production particularly due to high cost of energy, dysfunctional ecosystem services in agricultural lands due to tillage agriculture have been included, the need for sustainable production intensification, climate smart agriculture and pro-poor agricultural development strategies has also been discussed.

Key words: Dust bowl, conservation tillage, stubble mulching, no-till, soil mulch cover, crop diversity, drivers

Introduction

Reducing soil disturbances by tillage in agricultural land began in the Great Plains in the United States in the 1930s in response to the devastation caused by intensive tillage with mouldboard plough accompanied by prolonged drought (Derpsch, 2004). This phenomenon became known as the 'dust bowl'. In response, a

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major soil and water conservation programme was established by USDA. Initial research on 'conservation' or reduced tillage involved early versions of a chisel plough, by which plant residues could be retained on the soil surface to alleviate wind and water erosion (Duley and Fenster, 1954; Mannering, 1979). Stubble mulch farming was also developed (Fenster, 1960), and this became a forerunner of no-tillage farming. This collection of practices led to what became known as conservation tillage, which by definition is any tillage leaving at least 30% of the soil surface covered with crop residues for erosion control, while no-till systems by definition avoid soil disturbances by no-till seeding and weeding, and maintaining a biomass mulch cover on the soil surface (King and Holcomb, 1985; Kassam *et al.*, 2009). Since 1990, there has been a steady development of no-till systems globally, and it was in 1997 that the term Conservation Agriculture (CA) was adopted and defined in terms of the three interlinked principles to represent the modern version of no-tillage farming. Since then, the development of CA systems globally, particularly in annual croplands, has continued, led by North and South America and Australia. Since 2008, CA systems with annual crops have been spreading in Europe, Asia and Africa. More recently, CA systems also include perennial systems including orchards, plantations and agro-forestry. Overall, CA principles are being applied to rainfed and irrigated systems, including rice-based systems, and there is increasing interest being shown in the CA approach by conventional tillage-based organic farming systems.

This paper provides an overview of the evolution of CA systems globally since its early development in the United States, from where it spread to South America in the early 1970s, Canada and Australia in the later 1980s, and more recently to Europe (including Russia and Ukraine), Asia and Africa since the late 1990s.

Development of No-till Farming and Some of the Pioneers and Champions

The book, *Ploughman's Folly* by Edward Faulkner (Faulkner, 1943), an extension agronomist in Ohio, was an important milestone in the development of conservation agricultural practices. Faulkner questioned the wisdom of inversion ploughing and explained the destructive nature of soil tillage. He stated: 'No one has ever advanced a scientific reason for ploughing' and 'There was nothing wrong with our soils except our interference'. Around the same time, in Japan, Masanobu Fukuoka started to question the appropriateness and sustainability of conventional tillage-based farming (Fukuoka, 1975). Further research in the United Kingdom, Unites States and elsewhere during the late-1940s and 1950s made no-tillage farming possible. The practice began to spread in the United States in the 1960s, in Brazil in the 1970s, and in Argentina, Paraguay and Uruguay in the 1980s and 1990s, with farmers such as Herbert Bartz, Manoel Henrique (Nono) Pereira, Frank Dijkstra and John Landers in Brazil, Heri Rosso, Rogelio Fogante, Victor Trucco and Mario Gilardoni in Argentina, Carlos Crovetto in Chile and Akinobu Fukamiin Paraguay championing the transformation of tillage farming into no-till farming systems. In Brazil, no-till research was pioneered in Londrina in 1971 with initiatives from Rolf Derpsch, collaborating with Brazilian colleagues such as Ademir Calegari on plots often visited by Herbert Bartz; in 1972 Rolf Derpsch sent his no-till wheat seeder to Herbert Bartz's farm 'Rhenania' at Rolandia, Paraná (30 km from Londrina), to seed a demonstration plot of half hectare of wheat after soybean.

In the United States in 1973, Shirley Phillips and Harry Young published the book *No-tillage Farming* (Phillips and Young, 1973), the first of its kind in the world. This was followed in 1984 by the book *No-Tillage Agriculture: Principles and Practices* by E.R. Phillips and S.H. Phillips (Phillips and Phillips, 1984). In Southern Rhodesia (now Zimbabwe), Tom Borland, a weed control specialist, published an article in 1974 in the Rhodesian Agriculture Today: '*Which way weed control and tillage?*' (Borland, 1974), after a study tour to the United States where he met with most of the no-till pioneers including Harry Young. He also published a series of articles on no-till in *The Rhodesian Farmer* magazine over the period from 1976 to 1979 and was later reprinted in *South African Farmer's Weekly* (Borland, 1980). This was followed in 1984 by Brian Oldreive in Zimbabwe designing an approach called 'Farming God's Way' (subsequently called Foundation for Farming) comprising no-till, mulch cover and rotation (Oldreive, 2006). In West Africa, research on no-till farming was started in 1970 at the International Institute for Tropical Agriculture (IITA), Nigeria, and a series of articles and bulletins on mulch farming techniques and no-till farming were published in the 1970s and 1980s (Lal, 1973, 1974a,b, 1975, 1976a,b,c, 1983).

In addition to these pioneers, there have been many other innovators in no-till farming since the early seventies who have made tremendous contributions to its growth and popularity. To mark the 40th Anniversary of the publishing of *No-Till Farmer*, its editor Frank Lessiter published a list of '40 Legends of The Past from North America' (Lessiter, 2011). They include the internationally popular names, such as Edward Faulkner, Dwayne Beck, Jill Clapperton, Steve Groff, Guy Lafond, Bill Richards, Shirley Phillips and Harry Young. However, the North American list of champions is longer than 40 and includes global promoters such as Keith Saxton, Don Reicosky,Tom Goddard, Scott Day, Sjoerd Duiker,Juli an Dumanski and David Montgomery. Elsewhere, other no-till farming champions[2] have included John Baker and W.R. Ritchiein from New Zealand, Rolf Derpsch, Terry Wiles, David Sharp, Ivo Mello, Joao Carlos de Moraes Sa, Ademir Calegari, Augusto Guilherme de Araujo, Rafael Fuentes Llanillo in Brazil, Gino Minucci, Mario Nardone, Jose Araya, Roberto Peiretti, Hugo Ghio, Jorge Romagnoli, Horacio Aguero, Cesar Belloso and Luis Giraudo in Argentina, Ken Moriya in Paraguay, Bill Crabtree, Jean-Francois Rochecouste, Steven Powles, Allen Postlethwaite, Jeff Tullberg, Jeff Esdaile, Tim Reeves and Richard Bell in Australia, Gao Huanwen and Li Hongwen in China, Wolfgang Sturny in Switzerland, Emilio Gonzales-Sanchez in Spain, Gottlieb Basch and Gabriela Cruz in Portugal, Benoit Lavier, Gerrad Rass, Frederique Thomas and Sara Singla in France, Tony Reynolds, Tony Gent and John Cherry in the United Kingdom, Michele Pisante in Italy and Soren Ilsoe in Denmark. Champions at FAO have included José Benites, Theodor Friedrich, John Ashburner, Amir Kassam, Francis Shaxson, Brian Sims and Josef Kienzle. From different parts of Africa there have been several champions such as Richard Fowler, Richard Findlay, Hendrik Smith, Rachid Mrabet, Kofi Boa, Martin Bwalya and Saidi Mkomwa; in the Consultative Group for International Agricultural Research (CGIAR), Jeff Sayer, Patrick Wall, Muratbek Karabayev, Mekhlis, Suleimanov, Aziz Nurbekov, Peter Hobbs, Harminder Singh Sidhu, Mangi Lal Jat, Yashpal Singh Saharawat, Raj Gupta, Christian Thierfelder, Colin Piggin and Stephen Loss;and in the Center for International Research for Agricultural Development (CIRAD), Lucien Séguy, Olivier Husson, Stephane Boulakia and Jean-Claud Legopil. In addition to those working for CGIAR, other champions in South Asia include Raj Paroda, Inder Abrol, Mushtaq Gill and Enamul Haque. In the global CA community, there are many more champions from different parts of the world who deserve to be mentioned here. Indeed, the list is long and honourable, and growing (Dumanski *et al.*, 2014).

The Modern Concept of CA

The modern concept of no-till farming or no-till system is now generally known as Conservation Agriculture (CA). The term was first used in 1997 at a regional workshop organized by FAO on the topic of Soil Management and Conservation – Efficient Tillage Methods for Soil Conservation in Ibadan, Nigeria, although the participants still talked more about conservation tillage than CA (Barbosa dos Anjos, 2000). Documented evidence shows that the term 'Conservation Agriculture' was first coined in Spanish at the IV RELACO meeting in Morelia, Michoacán, Mexico, in the year 1997 (RELACO

[2]There have been many champions of no-till farming in different parts of the world. The aim here is not to offer a comprehensive list but to mention some names of 'early' pioneers.

1997). In English, RELACO stands for 'Latin-American Network for Conservation Tillage'. The functioning and purpose of RELACO was described by Benites (1997) at the IV RELACO meeting. At that forum in Morelia, Rolf Derpsch presented a paper on 'New paradigms of agricultural production' (Derpsch, 1997a) and 'Development and diffusion of sustainable agricultural production systems in Paraguay' (Derpsch, 1997b) which incited a lot of discussion. Only two other papers (Veiga, 1997; Amado and Reinert, 1997) from a total of 28 papers presented also focussed on no tillage and did not use the words 'conservation tillage'. Only one paper used the wording 'Conservation Agriculture' in the title (Friedrich, 1997). Conservation tillage reflected the old paradigm and mainstream thinking until the 1990´s. During the RELACO meeting, Rolf Derpsch and Theodor Friedirich initiated a discussion to change the extended name of the organization from 'Red Latinoamericana de Labranza Conservacionista' (Latin-American Network for Conservation Tillage) to 'Red Latinoamericana de Agricultura Conservacionista' (Latin-American Network for Conservation Agriculture) arguing that one cannot conserve the soil while at the same time tilling it.

Conservation tillage is a contradiction, an oxymoron in the words of Don Reicosky (2015) because worldwide experience has clearly shown that tillage has nothing to do with conservation. In fact, tillage is a root cause of agricultural land degradation (Montgomery, 2007). The term conservation tillage was developed in the United States as a consequence of the soil and water conservation practices that followed the 'dust bowl' in the 1930´s. It was probably the right terminology for that time, but with the successful adoption of no-tillage since 1962 in the USA and its expansion to more than 180 M ha worldwide, the term has become obsolete.

After lengthy discussions at the RELACO meeting, the organizers (among them Theodor Friedrich and José Benites from FAO, Ramón Claveran, CENAPRO, Mexico) adopted the term 'Conservation Agriculture'. One reason for the relatively quick acceptance was that there was no need to change the acronym RELACO, which could stay the same for 'Red Latinoamericana de Agricultura Conservacionista'. An additional benefit for this denomination was the ease to translate it into English and even French. This name was also more appealing than no-tillage because it had a broader meaning and could be easily understood by any layman.

From there on, the two FAO representatives attending that meeting, Theodor Friedrich and José Benites, decided that CA was the term FAO should use for sustainable agriculture systems in the future. An interdisciplinary informal workgroup on CA was created in FAO with members from all divisions of the agricultural department. In 1998, FAO organized its first regional workshop on CA in Harare, where a code of practice for CA was drafted describing the three interlinked CA principles as we know them today and their practical application. Also, at the workshop, the African Conservation Tillage (ACT) Network was founded with support from GTZ. Yet, ACT still used the term Conservation Tillage, although FAO at that time already started talking about CA, and only many years later ACT adopted CA as its focus.

A year later, in 1999, both Theodor Friedrich and José Benites were approached to join the founding of the European Conservation Agriculture Federation (ECAF). Between ECAF and FAO they then came up with the idea of having a World Congress on Conservation Agriculture in 2001 – and that is how the World Congresses on CA started, and how the three principles of CA were globalized.

RELACO over the following years struggled to survive with ever less support and a growing incidence of regional organizations promoting CA, such as the American Confederation of Associations for sustainable Agriculture (CAAPAS). The first World Congress in Madrid concluded with an official Congress Declaration and brought the term 'Conservation Agriculture' along with the concept to a global audience and after that date the terminology 'Conservation Agriculture' prevailed, gaining wider and wider acceptance with each new Congress being held and creating a global CA movement. Acceptance has been so strong and widespread, that some scientists are suggesting doing away with the term no-tillage (or its synonyms) and replacing it with 'Conservation Agriculture' when thinking of systems. The fact is that minimum soil disturbance with no-tillage as a practice is and will continue to be one of the main pillars or core principles to be applied in CA.

In 2001, the First World Congress on Conservation Agriculture was organized by ECAF and FAO in Madrid (Spain). Since then, there have been six more World Congresses, in Foz do Iguassu (Brazil, 2003), Nairobi (Kenya, 2005), New Delhi (India, 2009), Brisbane (Australia, 2011), Winnipeg (Canada, 2015) and Rosario (Argentina, 2017). The eighth World Congress was held in Europe under the aegis of ECAF in 2021. The World Congress process is now well established and operates on an informal basis with regional CA organizations taking an active part in ensuring that the process continues to function on a voluntary and collegial basis with decisions being made on a consensus. At every World Congress, bids are invited for the next Congress to be held in 3 years' intervals. Bids are considered by a committee made up of the representative of all the regional CA organizations. The general rule is that the world congresses should alternate between the Global North and the Global South in succession.

Alongside the process of holding world congresses, meetings on CA have been held regularly by sub-national, national and regional CA organizations in all continents. FAO regional and sub-regional offices also promote and support regional training and/or review workshops on CA. All these meetings are held to review progress, share experiences and learnings, address constraints, help with strategy and programme formulation and promote policy and institutional support decisions and actions. Also, CA organizations along with FAO and several other bilateral and multilateral development agencies support the adoption of CA by farmers, generally working in groups and through farmer field schools (FFS) and farmer cooperatives, associations and networks. Indeed, much of the CA success in all regions is a result of hard work of many farmer-led activities.

In 2007, Amir Kassam and Francis Shaxson organized an international workshop on The Importance of 'Improving Soil Conditions for Water, Plant Nutrients and Biological Productivity to Sustain Agricultural Growth under Rising Population Pressure in a Changing Climate' at Newcastle University under the aegis of the Tropical Agricultural Association (TAA) and in collaboration with University of Newcastle, University of Reading, University of Nottingham, University of Durham, Association of Applied Biologists and ICRAF (World Agro Forestry Centre). Several donor agencies were present at the meeting, including Gates, Rockefeller, Ford and Syngenta Foundations and DFID (Department for International Development, UK).Several international organizations participated including FAO, ICRISAT, ICARDA, IWMI and CIAT (International Center for Tropical Agriculture). FAO was represented by Theodor Friedrich, and several CA champions including from South America, Asia and Africa also attended. Organizations including Rothamsted, NRI (Natural Resources Institute, Greenwich), ICAR (Indian Council of Agricultural Research), EMBRAPA (Brazilian Enterprise for Agricultural and Livestock Research), Kilimo Trust, MSSRF (M.S. Swaminathan Research Foundation), FARA (Forum for Agricultural Research in Africa), ACSAD (Arab Centre for the Studies of Arid Zones and Dry Lands), GFAR (Global Forum for Agricultural Research), CIRAD (Centre for Cooperation on International Research on Agricultural Development), SEI (Stockholm Environment Institute) and universities of Exeter, Durham, Free University of Amsterdam, Queensland, Kingston, Cornell, Mekerere, Kwa-Zulu Natal and Zimbabwe also participated. The main outcome of the workshop was the recommendation that CA was the best option for making sustainable agriculture a reality and for the promotion of sustainable agricultural intensification. Further, it was recognized that there was an emergent Community of Practice (CoP) that needed to be linked up to promote CA globally. Also, there was a need to hold a follow-up of the full international workshop at ICRAF to discuss how this could be achieved (TAA, 2007). Indeed, there were indications that a quiet revolution with no-till was underway (Huggins and Reganold, 2008).

Having failed to secure a venue at ICRAF due to political riots in Kenya, FAO in Rome agreed to host the workshop. The '*International Technical Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health*' was held at FAO in the Plant Production and Protection Division in July 2008 (FAO, 2008) led by Amir Kassam, Theodor Friedrich, Francis Shaxson, Eric Kueneman and Andrew McMillan. Most of the CA champions around the world, some 100 individuals, including those in FAO, attended to discuss and review the basis for successful adoption and spread of CA in different countries and regions, and how CA could be globalized.

The Workshop prepared a global action plan to mainstream CA and recommended that a multi-stakeholder Conservation Agriculture Community of Practice (CA-CoP) communication platform, hosted by FAO, should be launched to facilitate the adoption and mainstreaming of CA globally (FAO, 2008). Justification for CA as the best choice for sustainable production intensification was published in 2009 based on the outcome of the international Workshop (Kassam *et al.,* 2009). The CA-CoP platform was launched in January 2009 with Amir Kassam serving as the Moderator. This platform has been running continuously since then and now reaches several thousands of subscribers around the world. Through the CA-CoP platform, all kinds of information about CA, including journal articles, official documents and news, is distributed practically every day. When CA-CoP was established, the global CA cropland area was 106 M ha. In 2015/16 it was 180 M ha, an increase of some 69% (Kassam *et al.,* 2018).

In 2011, FAO published 'Save and Grow: A Policymaker's Guide to Sustainable Intensification of Smallholder Crop Production', which was based on CA as the new paradigm of agriculture (FAO, 2011). With that publication, the sustainable intensification of crop production, later integrating other agricultural production sectors, became a strategic objective of FAO and a guideline for FAO's work on sustainable agriculture systems.

CA is significantly different from the conventional tillage agriculture (Hobbs, 2007; Shaxson *et al.,* 2008; Friedrich *et al.,* 2009; Kassam *et al.,* 2009). It represents a fundamental change in the agricultural production system paradigm. CA involves the simultaneous application of three inter-linked principles based on locally formulated adapted practices, along with several other complementary good agricultural practices of integrated crop, nutrient, pests (weeds, insects, pathogens), water, labour, farm power and energy management practices (Friedrich *et al.*, 2009; Kassam *et al.*, 2009, 2011 2018) along with the complementary practices are at the heart of FAO's new sustainable agricultural intensification strategy for smallholder farmers (FAO, 2011, 2016; Kassam *et al.*, 2011; Freidrich 2013) which takes an ecosystems approach to enhancing and sustaining productivity and resilience as well as the flow of ecosystem services while reducing greenhouse gas emissions that come from the agriculture sector (Kassam *et al.*, 2009, 2011, 2013; Gonzalez-Sanchez *et al.*, 2012, 2017, 2018). 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; IPCC, 2014). At the heart of sustainable agricultural intensification, or sustainable land management, is a strong focus on soil health and biology and the integration of soil and water conservation practices in agricultural production, with concurrent objectives of enhanced economic returns and environmental management (Kassam and Brammer, 2012; Kassam *et al*., 2013).

The description of CA used by the Moderator of the CA-CoP Communication Platform hosted by FAO is as follows:

'Conservation Agriculture is an ecosystem approach to regenerative sustainable agriculture and land management based on the practical application of context-specific and locally adapted three interlinked principles of: (i) Continuous no or minimum mechanical soil disturbance (no-till seeding/ planting and weeding, and minimum soil disturbance with all other farm operations including harvesting); (ii) permanent maintenance of soil mulch cover (crop biomass, stubble and cover crops); and (iii) diversification of cropping system (economically, environmentally and socially adapted rotations and/or sequences and/or associations involving annuals and/or perennials, including legumes and cover crops), along with other complementary good agricultural production and land management practices. Conservation Agriculture systems are present in all continents, involving rainfed and irrigated systems including annual cropland systems, perennial systems, orchards and plantation systems, agroforestry systems, crop-livestock systems, pasture and rangeland systems, organic production systems and rice-based systems. Conservation Tillage, Reduced Tillage and Minimum Tillage are not Conservation Agriculture, and nor is No-Till on its own'.

History and Adaptability of CA

Tillage, as a soil management concept, was questioned for the first time in the 1930s, when the 'dust bowl' devastated wide areas of the mid-west United States (Derpsch, 1998). Ideas for reducing tillage and keeping soil covered with crop biomass followed and the term 'conservation tillage' was introduced for practices aimed at erosion control. Seeding machinery developments allowed then, in the 1940s, to seed directly without any soil tillage. At the same time, theoretical concepts resembling today's CA principles were elaborated by Edward Faulkner in his book *Ploughman's Folly* (Faukner, 1943) and Masanobu Fukuoka with the 'One Straw Revolution' (Fukuoka, 1975). But only in the 1960s did no-tillage enter into farming practice in the United States (Derpsch 2004; Kassam *et al.*, 2010, 2014a).

In the early 1970s, as a result of un-controllable erosion problems in the southern states, no-tillage reached Brazil, where farmers together with scientists transformed the technology into the system which today is called CA. Yet it took another 20 years before CA reached significant adoption levels. During this time, farm equipment and agronomic practices in no-tillage systems were improved and developed to optimize the performance of crops, machinery and field operations. This process continues; the creativity of farmers and researchers is still producing improvements to the benefits of the production system, the soil and the farmer. While tillage-based agriculture has been researched for several centuries, CA is only half a century old and the functioning of CA systems can only be understood as the agro-ecosystems evolve under the new production management. From the early 1990s, the uptake of CA started growing exponentially, leading to a revolution in the agriculture of southern Brazil, Argentina, Paraguay and Uruguay.

During the 1990s, this development increasingly attracted attention from farmers and researchers in Europe, Asia, Africa and Australia, and from development and international research organizations such as FAO, World Bank, IFAD, GIZ, NORAD, CIRAD, ACIAR and the CGIAR system. Study tours to Brazil for farmers and policy makers, regional workshops, development and research projects were organized in different parts of the world. These produced increased levels of awareness and adoption in African countries such as South Africa, Zambia, Zimbabwe, Mozambique, Tanzania and Kenya as well as in Asia, particularly in Kazakhstan, India, Pakistan and China. The improvement of conservation and no-tillage practices within an integrated farming concept such as CA also led to a cropping system diversification and increased adoption of CA in industrialized countries, particularly Canada, United States, Australia, Spain, Italy, Finland, Ukraine and Russia after the end of the millennium (Derpsch *et al.*, 2010). The spread of CA has continued to more countries in Europe, Asia and Africa (Kassam *et al.*, 2014b, 2015, 2018).

CA crop production systems are popular worldwide. There are few countries where CA is not practised by at least some farmers and where there are no local research results about CA available (Jat *et al.*, 2014). The total cropland area under CA in 2008/09 was estimated to be 106 M ha (Kassam *et al.*, 2009; Derpsch and Friedrich, 2009a, 2009b). By 2010/11, the global spread had increased to 145 M ha (Friedrich *et al.*, 2012), and by 2013/14, 157 M ha (Kassam *et al.*, 2014a, 2014b, 2015, 2018). As reported below, the latest global estimate for CA cropland for 2015/16 is about 180 M ha.

CA systems are widely adaptable. Their presence extends from the equatorial tropics (e.g., Kenya, Tanzania, Uganda) to the arctic circle (e.g. Finland) North and to about 50º latitude South (e.g. Falkland Islands); from sea level in several countries of the world to 3000 m altitude (e.g. Bolivia, Colombia); from heavy rainfall areas with 2,000 mm a year (e.g. Brazil) or 3000 mm a year (e.g. Chile) to extremely dry conditions in the Mediterranean environments with 250 mm or less a year (e.g. Morocco, Syria, Western Australia) (Derpsch *et al.*, 2010; Jat *et al.*, 2014). In some countries, CA has even allowed expansion of agriculture to marginal soils in terms of rainfall or fertility (e.g. Australia, Argentina). In southern Brazil, CA has facilitated the restoration of the degraded savanna and forest soils - the *cerrados* - to productive agricultural lands (Derpsch *et al.*, 2010; Jat *et al.*, 2014).

CA is practised on soils that vary from 90% sand (e.g. North Africa, southern Mediterranean zone, coastal zones in tropical Africa, Australia) to 80% clay (e.g. Brazil's Oxisols and Alfisols). Soils with high clay content in Brazil or in Europe are extremely sticky but this has not been a hindrance to no-till adoption when appropriate equipment is available. Soils that are readily prone to crusting and surface sealing under tillage farming do not exhibit this problem under established CA systems. This is because minimum soil disturbance, mulch cover, diversified cropping and increased soil organic matter all contribute to enhancement of soil quality that avoids the formation of surface crusts and soil compaction.

No-tillage in CA is practised on all farm sizes from less than half a hectare or a few hectares (e.g., India, China, Zambia, Zimbabwe, Brazil and Paraguay) to thousands of hectares (e.g., Argentina, Brazil, Canada, South Africa, Australia and Kazakhstan). All crops can be grown adequately in CA systems and to the authors' knowledge there has not yet been a crop that would not grow and produce under this system, including root and tuber crops (Derpsch and Friedrich, 2009a, 2009b).

Despite the existence of several constraints to adoption, farmers in different parts of the world are continuing to find local solutions to support the spread of CA as well as to innovate with new practices and management methods to maximize the benefits. Major constraints to the adoption of CA practices continue to be knowledge about the existence of CA and on how to do it (know how), mind-set (tradition, prejudice), inadequate policies, for example, commodity based subsidies (EU, USA) and direct farm payments (EU), unavailability of appropriate equipment and machines (many countries of the world, including EU), and of suitable management strategies to facilitate weed and vegetation management, including mechanical, biological and chemical options as herbicides (especially for larger farms in low-income countries) (Friedrich and Kassam, 2009; Jat *et al.*, 2014; Farooq and Siddique, 2014). Other area-specific constraints in semi-arid areas during the transformation to CA system relate to initial low supply of crop and vegetation biomass for soil mulch cover development; to initial short-term competition for crop residue as livestock feed; and to initial adoption of new manual weed management practices when the soil mulch cover and integrated weed management practices are being established.

Yet farmers who do become seriously interested in adopting CA develop local solutions to all these barriers. Many such cases have been reported for smallholder and large-scale farms in all continents (see list of publications at:http://www.fao.org/conservation-agriculture). Further, more international and national organizations have increased their support for CA as they have increased their awareness of its effectiveness in sustainable production intensification. These organizations include FAO, International Fund for Agricultural Development (IFAD), World Bank, European Union (EU), African Union – New Partnership for Africa's Development (AU-NEPAD), CIRAD, ACT, some CGIAR Centres (International Maize and Wheat Improvement Centre - CIMMYT, International Centre for Agricultural Research in the Dry Areas - ICARDA, International Crops Research Institute for Semi-Arid Tropics - ICRISAT, ICRAF), NGOs, some governments in the Global North and the Global South, national and multi-national corporations, the growth of no-till/CA organizations worldwide, farmer to farmer support even across continents, and bilateral and multi-lateral donors. Thus, the continuing spread of CA globally is creating a need for effective national and regional policy and institutional support (Kassam *et al.*, 2014c; FAO, 2017) and the need to ensure that the core elements of CA systems are respected in conducting research and in education and training (Derpsch *et al.*, 2012, 2013) to safe-guard the quality and relevance of CA knowledge and information.

Global Adoption and Regional Spread

Drivers of adoption

Looking back to the days of the dust bowl and what we now know of how CA has been spreading globally, we consider the following to be major drivers that have and are contributing to farmers adopting CA in different regions of the world.

The initial driver as has been indicated was the wind erosion in the 1930s in the mid-west and elsewhere that was caused by intensive mouldboard ploughing for several years on large expanse of the prairies in the mid-west of United States. When this combined with several years of severe drought, the intensely disturbed and pulverized top soil took off with the wind, creating a dust storm that carried the soil all the way to the east coast. In addition, the opening up of the prairies also led to run-off and water erosion of the top soil on a vast scale. Similar situations elsewhere have also driven farmers to adopt CA in other parts of the world. Most notable example is that of Brazil, which led to the initial adoption of no-till farming in the early 1970s, in Canada, Ukraine, Russia, China and Australia where dust storms forced farmers to change from tillage to no-till farming. Because of the large areas being brought under CA in Canada and Australia, dust storms have disappeared, since about 1989. The situation is still not under control completely in Russia, Ukraine and China where dust storms are still reported. A recent case of a dust storm was in Germany in April 2011 which led to an 81 car pile-up on the highway and the death of eight people. The cause of the dust storm turned out to be intensive tillage combined with drought and high winds.

Severe droughts have been a major driver of adoption of CA. Well-known examples are the semi-arid area in western and south western Australia, northern Kazakhstan, Mongolia, northern China and southern Africa. The realization that tillage eventually leads to decrease in water infiltration and water retention by soil, due to loss of soil structure, only few days of dry weather lead to crops suffering from water stress. In dry semi-arid areas with moderate-to-high rainfall variability, drought can be a common feature of the agricultural environment.

In the early 1970s, there was a steep rise globally in the cost of fossil fuel and energy in general. This led to a direct increase in the cost of agricultural field operations and production inputs. Mechanized farmers in both industrialized and lower-income countries were forced to move away from intensive ploughing. More farmers, particularly in North and South America and in Australia, moved into no-till technology for crop establishment, whereas other farmers particularly in Europe moved into min-till technology which pulverized 100% of the top soil up to 100-150 cm deep. In both cases, there was a significant reduction in cost of fuel use, but in the former it was possible to evolve into no-till cropping system with mulch cover (i.e. CA system) and improve soil health, productivity and profit. But in the latter, it was not possible to evolve into CA system. Instead, areas under min-till in Europe and elsewhere are causing erosion, and are operating sub-optimally in terms of productivity and profit, often reverting back to full inversion tillage when economics allow.

In the 1980s and 1990s, it became more generally appreciated that agricultural land globally was degrading and causing loss in productivity and ecosystem services. This was documented by GLASOD and FAO and was confirmed by the Millennium Ecosystem Assessment in 2005 (MEA, 2005). Tillage was recognized by some farmers and countries as being the root cause of soil and land degradation globally. In some cases, such as Alberta, Canada, a carbon offset trading scheme was established to encourage farmers to move away from tillage agriculture and adopt CA to allow carbon sequestration for which they could be paid by industries that were emitting green-house gases beyond a certain limit. In Brazil, a programme was initiated in the Parana Basin III to enable farmers to adopt CA to generate clean water for the ITAIPU hydroelectric dam which earlier was being fed by water that was high in sediments because of tillage agriculture. Land degradation and dysfunctional ecosystem services became the driving force behind the change to CA in countries including Spain, Italy, Kazakhstan, China, India, Pakistan, Russia and Ukraine, while the need for increased output and farm economy continues to drive the expansion of CA in other countries such as Brazil, Argentina, Paraguay, Uruguay, USA, Canada and Australia.

During the early-2000s, in addition to land degradation and loss in ecosystem services in tillage-based agricultural land, climate change became an additional global challenge to be addressed along with the need for sustainable agricultural intensification. Both these challenges provided further reasons to promote CA. This is because CA systems are climate-smart as they have a high level of adaptability to climate change and can mitigate climate change, whereas conventional tillage agriculture is known to be poor in climate change adaptability and mitigation. Additionally, whereas tillage agriculture was becoming known for being unable to intensify sustainably without causing more degradation, CA systems were already known to be achieving intensification sustainably. More countries began to get interested in CA systems in the 2000s.

Within the context of the sustainable agricultural intensification goal, it was also becoming clear, based on the experience gained from different parts of the world that CA systems fitted much better into a pro-poor development strategy. This is because CA works well for smallholder farmers in any land-based ecology. Also, CA systems can be used to improve local agriculture with minimum inputs, saving time and labour while improving productivity, even without any purchased inputs, if necessary.

Today all the above drivers in various combinations are enabling CA systems to be promoted and adopted by smallholders, large-scale farmers, poor or rich farmers, men or women farmers in the Global South and the Global North. There is clearly a need to mainstream CA globally. This requires that governments, public, private and civil institutions should all be aligning themselves towards promoting CA and supporting its adoption and spread. However, for now, major constraints continue to be the fact that the education, research and development efforts continue to direct their attention to the development of conventional tillage agriculture. Indeed, hardly any of the education systems globally, particularly at the tertiary level, are directing resources to integrate CA into their curricula and teach it at both the theoretical and practical level. Much talk continues to be promoted in many academic and development circles about sustainable agricultural intensification, climate-smart agriculture, regenerative agriculture and more recently about the Sustainable Development Goals (SDGs), but without the understanding that CA is the functional principle of all these concepts. The CA community has much to contribute to such debate and practical action to meet several of the SDGs.

Adoption and spread

Farmer-led transformation of agricultural production systems based on CA is progressing globally. It is in all world regions the initial and principal driver and reason for success in the adoption and expansion of CA. Since 2008/09, the adoption has increased exponentially with the impulse of the need for a new paradigm for 'sustainable intensification of crop production' including the delivery of ecosystem services, and as a base for 'climate-smart agriculture'.

The information on the adoption of CA in 2015/16 presented in this paper applies only to annual cropland and is based on several sources: government statistics (e.g. Canada and United States); survey estimates by no-till farmer organizations (e.g. Australia, Brazil, Argentina, Paraguay and Uruguay), by Ministry of Agriculture (e.g. China, Malawi, Zimbabwe), NGOs (e.g. Europe, Russia, Madagascar, Zambia), well-informed individuals from research and development organizations (e.g. Pakistan, India, Kazakhstan, Ukraine). The database is up to date for 2015/16 for most countries with exceptions including Ukraine, India, DPR Korea, Lebanon, Azerbaijan, Chile, Colombia, Mexico, Venezuela, Kenya, Ghana and Sudan. For these countries, the information is from 2013/14. Besides, since 2013/14, CA annual cropland systems have been recorded in more countries such as Uganda, Swaziland and Algeria in Africa; in Asia, Pakistan, Tajikistan, Iran, Bangladesh, Laos, Vietnam and Cambodia; and in Europe, Austria, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Latvia, Lithuania, Luxemburg, Poland, Romania, Slovenia and Sweden.

There are reports of adoption of CA in individual countries in 2008/2009 (Kassam *et al.*, 2009; Derpsch and Friedrich, 2009a), in 2010/11 (Kassam *et al.*, 2010; Friedrich *et al.*, 2012) and in 2013/14 (Kassam *et al.*, 2015). There was an interim record of the global spread of CA in 2015/16 (Kassam *et al.*, 2017a) which was refined and expanded to include data for more countries and corrected any previous errors, particularly related to information from countries in Africa (Kassam *et al.*, 2018). There are also global state-of-the-arts reviews of CA systems and practices in Jat *et al.* (2014) and Farooq and Siddique (2014), and for Africa in Kassam *et al.* (2017b).

Global and regional data of CA adoption and spread in cropland in the following sections are based on the above-mentioned sources, including the latest global and regional CA data for 2015/16 as published in Kassam *et al.* (2018).

Global

It was estimated that the global extent of CA cropland in 2008/09 covered about 106 M ha (7.5% of global cropland) (Kassam *et al.*, 2009). In 2013/14, it was about 157 M ha (11% of global cropland), representing a difference of some 51 M ha (some 47%) over the 5-year period (Table 1) (Kassam *et al.*, 2015). In 2015/16, CA cropland was about 180 M ha (12.5% of global cropland), representing a difference of some 74 M ha (69%) over the 7-year period since 2008/09 or about 23 M ha (some 15%) over the 2 years since 2013/14.

CA in recent years has become a fast-growing production system for many reasons including greater factor productivity and farm output, reducing cost of production and improving profitability, greater resilience to biotic and abiotic stresses, minimizing soil erosion and degradation, building soil health, improving biodiversity, adapting to and mitigating climate change (Kassam *et al.*, 2013, 2017a; Jat *et al.*, 2014; Farooq and Siddique, 2014). Whereas in 1973/74 CA was applied only on 2.8 M ha worldwide (Fig. 1), the area had grown to 6.2 M ha in 1983/84 and to 38 M ha in 1996/97 (Derpsch, 1998). In 1999, worldwide adoption was 45 M ha (Derpsch 2004), and by 2003 the area had grown to 72 M ha (Benites *et al.*, 2002). During the period from 1999 to 2013, CA cropland area had expanded at an average rate of about 8.3 M ha per year, from 72 to 157 M ha (Kassam *et al.*, 2015). The growth of the area under CA has been especially significant in South America where the MERCOSUR countries (Argentina, Brazil, Paraguay and Uruguay) are using the system on more than 70% of their total cropland area (Kassam *et al.*, 2018).

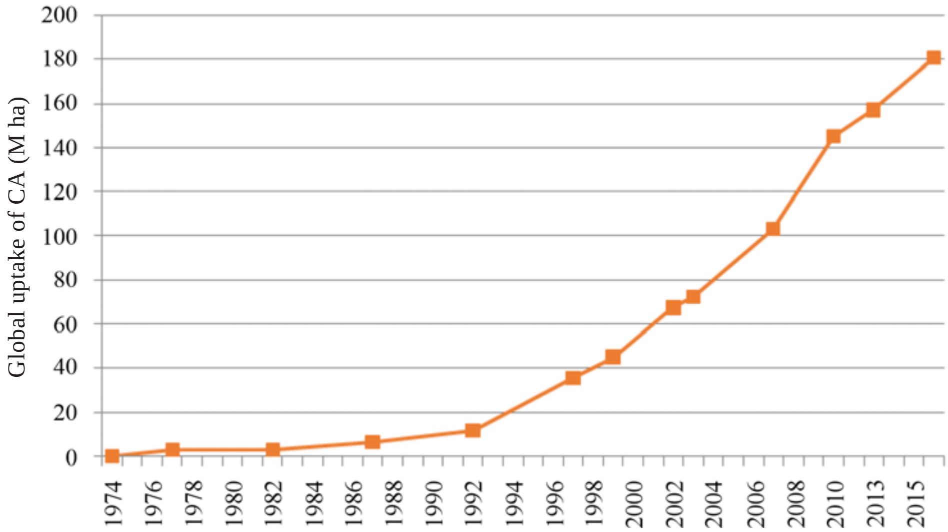

Fig. 1. Global uptake of CA in M ha of cropland (Kassam *et al.*, 2017a)

Since 2008/09, the annual rate of change has increased to about 10.5 M ha, from 106 to 180 M ha in 2015/16, showing the increased interest of farmers in the CA farming systems approach to sustainable production and agricultural land management. Earlier, this expansion was mainly in North and South America and in Australia and New Zealand. More recently, it is also occurring in Asia, particularly in Kazakhstan and China with large farms, and in India and Pakistan with small farms. Wheat-based CA cropping systems have been spreading in these countries in recent years. In Kazakhstan and China, rainfed wheat systems are being transformed into CA systems. Crop diversity is increasing as research has shown the feasibility of integrating legumes in the rotations. In India and Pakistan, wheat-rice cropping systems in the Indo-Gangetic Plains are being transformed into CA systems, referred to as –'double no-till' rice-wheat systems, and in some areas it has been possible to add a short season-legume crop such as mung bean in the cropping system.

Major increases in the adoption of CA cropping systems are expected across Asia in the coming decades. The situation is also changing in Africa where more smallholder farmers are taking up CA, particularly in eastern and southern Africa, and medium-scale farmers in North Africa. CA in Europe, and in Russia and Ukraine, has been expanding steadily during the past decade. These trends are expected to continue as farmers continue to share their experiences among themselves and other stakeholders, particularly no-till seeder machine companies and researchers.

Since 2008/09, the number of countries where CA adoption and uptake is occurring has increased from 36 to at least 55 in 2013/14 and to 78 in 2015/16, as shown in Table 1. The table does not include several countries where CA is known to be practised, but either at very small levels or without being reported in any systematic form. They make a significant list: Ethiopia, Rwanda, Burkina Faso, Senegal and Cameroon in Africa, Jordan, Nepal, Timor Este, Philippines, Mongolia in Asia and Cuba, Costa Rica, Honduras, El Salvador, Guatemala, and Nicaragua in Central America.

Further, the area of CA systems based on perennial crops such as in orchards and plantations, or mixture of annual and perennial crops such as trees in association with annual crops, or agro forestry systems, or crop-livestock-tree systems, or pasture systems, *are not included* in the total CA area reported in this chapter. Such CA systems with perennial crops are on the increase in all inhabited continents in most agro-ecologies.

Table 1. Extent ('000 ha) of Adoption of CA worldwide by country in 2008/09, 2013/14 and 2015/16

No	Country 2008/09	CA area 2013/14	CA area 2015/16	CA area
1	USA	26,500.00	35,613.00	43,204.00
2	Brazil	25,502.00	31,811.00	32,000.00
3	Argentina	19,719.00	29,181.00	31,028.00
4	Canada	13,481.00	18,313.00	19,936.00
5	Australia	12,000.00	17,695.00	22,299.00
6	Paraguay	2,400.00	3,000.00	3,000.00
7	Kazakhstan	1,300.00	2,000,00	2,500,00
8	China	1,330.00	6.670.00	9,000.00
9	Bolivia	706.00	706.00*	2,000.00
10	Uruguay	655.10	1,072.00	1,260,00
11	Spain	650.00	792.00	900.00
12	South Africa	368.00	368.00*	439.00
13	Germany	354.00	200.00	146.00
14	Venezuela	300.00	300.00*	300.00#
15	France	200.00	200.00*	300.00
16	Finland	200.00	200.00	200.00
17	Chile	180.00	180.00*	180.00#
18	New Zealand	162,00	162.00*	366.00
19	Colombia	102.00	127.00	127.00#
20	Ukraine	100.00	700.00	700.00#
21	Italy	80.00	380.00	283.92
22	Zambia	40.00	200.00	316.00
23	Kenya	33.10	33.10*	33.10#
24	United Kingdom	24.00	150.00	362.00
25	Portugal	25.00	32.00	32.00#
26	Mexico	22.80	41.00	41.00#
27	Zimbabwe	15.00	90.00	100.00
28	Slovakia	10.00	35.00	35.00#
29	Sudan	10.00	10.00*	10.00#
30	Mozambique	9.00	152.00	289.00
31	Switzerland	9.00	17.00	17.00#
32	Hungary	8.00	5.00	5.00#
33	Tunisia	6.00	8.00	12.00
34	Morocco	4.00	4.00	10.50
35	Lesotho	0.13	2.00	2.00
36	Ireland	0.10	0.20	0.20
37	Russia	-	4,500.00	5,000.00
38	India	-	1,500.00	1,500.00#
39	Malawi	-	65.00	211.00
40	Turkey	-	45.00	45.00
41	Moldova	-	40.00	60.00
42	Ghana	-	30.00	30.00#

Contd...

43	Syria	-	30.00	30.00#
44	Tanzania	-	25.00	32.60
45	Greece	-	24.00	24.00#
46	Korea, DPR	-	23.00	23.00#
47	Iraq	-	15.00	15.00#
48	Madagascar	-	6.00	9.00
49	Uzbekistan	-	2.45	10.00
50	Azerbaijan	-	1.30	1.30#
51	Lebanon	-	1.20	1.20#
52	Kyrgyzstan	-	0.70	50.00
53	Netherlands	-	0.50	7.35
54	Namibia	-	0.34	0.34#
55	Belgium	-	0.27	0.27
56	Pakistan	-	-	600.00
57	Romania	-	-	583.82
58	Poland	-	-	403.18
59	Iran	-	-	150.00
60	Estonia	-	-	42.14
61	Czech Republic	-	-	40.82
62	Austria	-	-	28.33
63	Lithuania	-	-	19.28
64	Croatia	-	-	18.54
65	Bulgaria	-	-	16.50
66	Sweden	-	-	15.82
67	Latvia	-	-	11.34
68	Uganda	-	-	7.80
69	Algeria	-	-	5.60
70	Denmark	-	-	2.50
71	Slovenia	-	-	2.48
72	Bangladesh	-	-	1.50
73	Swaziland	-	-	1.30
74	Tajikistan	-	-	1.20
75	Vietnam	-	-	1.00
76	Cambodia	-	-	0.50
77	Laos	-	-	0.50
78	Luxemburg	-	-	0.44
79	Cyprus	-	-	0.27
	Total	106,505.23	156,738.96	180,438.64
	% difference		47.17 since 2008/09	69.42 since 2008/09 15.12 since 2013/14

*2013/14 values taken from 2008/09; # 2025/16 values taken from 2013/14.

Source: 2008/09 and 2013/14 data from FAO AquaStat as reported in Kassam *et al*. (2015). 2015/16 data collected by authors as reported in Kassam *et al*. (2018).

In semi-arid areas with winter rainfall in the temperate and sub-tropical environments, CA orchards and vines include crops such as olive, grape, fruit and nut trees. Such CA systems can also be tailored with the direct sowing of field crops, cover crops and sown or natural pastures and vegetation beneath or between rows, giving permanent cover and improved soil aeration and biodiversity. The common complaint made by farmers to practising this latter type of inter-cropping or association is competition for soil water between trees and other crops. However, careful selection of deep rooting tree species and shallow rooting annuals resolves this. Functional CA systems do not replace but should be integrated with current good land husbandry practices.

In sub-humid and humid tropical environments, CA plantation systems include crops such as oil palm, cocoa, rubber, tea, coffee, coconut but also sugar cane with cover crops or natural or sown pastures or natural vegetation underneath. Thus, the CA cropland areas reported in this chapter are *conservative estimates* of global CA land use.

As Table 2 shows, some 69.9 M ha (38.7%) of the total global area under CA is in South America, corresponding to some 63.2% of the cropland in the region, and some 63.2 M ha (35.0%) is in North America, corresponding to 28.1% of the cropland of the region. Some 22.7 M ha (12.6%) is in Australia and New Zealand, corresponding to 45.4% of the cropland, and some 13.9 M ha (7.7%) is in Asia, corresponding to 4.1% of the cropland in the region. Some 10.8 M ha (6.0%) of the total global CA area is in the rest of the world, comprising 5.7 M ha in Russia and Ukraine, 3.6 M ha in Europe and 1.5 M ha in Africa, corresponding to about 3.6%, 5.0% and 1.1% of their total cropland area, respectively. Thus, some 47.3% of the total CA area is located in the Global South and 53% in the Global North, involving millions of farmers particularly in the Global South.

In terms of CA adoption and uptake, Europe and Africa are the developing continents. Nevertheless, CA area in Europe of 3.6 M ha estimated in 2015/16 is greater by some 127.4% than the 1.56 M ha that was estimated in 2008/09. For Africa, the CA area of 1.5 M ha in 2015/16 corresponds to some 211% increase from 0.48 M ha in 2008/09. There has been this significant increase in CA area in Europe and Africa in recent years because many years of research in these continents have shown positive results for CA systems. There has also been the incentive of increased interest in CA systems shown by the New Partnership for Africa's Development (NEPAD), governments, European Commission (EC), NGOs such as ACT and ECAF and the

Table 2. Cropland area under CA (M ha) by region in 2008/09 and 2015/16, and the difference in %; CA area as % of global total cropland in 2015/16,and CA area as % of cropland of each region in 2015/16 (derived from Table 1)

Region	CA cropland area 2008/09	CA cropland area 2015/16	% difference since 2008/09	% of global CA cropland area 2015/16	% of CA cropland area in the region 2015/16
South America	49.56	69.90	41.0	38.7	63.2
North America	40.00	63.18	57.9	35.0	28.1
Australia & NZ	12.16	22.67	85.8	12.6	45.5
Asia	2.63	13.93	429.7	7.7	4.1
Russia & Ukraine	0.10	5.70	5600.0	3.2	3.6
Europe	1.56	3.56	127.4	2.0	5.0
Africa	0.49	1.51	211.0	0.8	1.1
Global total	106.5	180.44	69.4	100	12.5

private sector, international organizations and donors.

Besides other drivers mentioned earlier, the effects of climate change, which are more and more visible not only in the Global South, but also in the Global North, for example in Europe, are leading to change. For resource-poor smallholder farmers in low income countries, CA fits better in pro-poor development strategies across most land-based farming systems (FAO, 2011, 2016), and there are several examples of successful CA scaling involving smallholder farmers in Africa with little-or-no purchased inputs (e.g. Owenya *et al.*, 2011; Lalani *et al.*, 2016, 2017)

The continuous growth of CA systems as shown in Fig. 1 is largely a result of the initiative of farmers and their organizations. This is augmented by technical and financial support from governments, donor agencies and international organizations for CA research and development in Africa and Asia in recent years (FAO, 2012, 2013, 2014; ACT, 2014, 2018; Kassam *et al.*, 2017b). The uptake of CA in Africa and Asia is expected to accelerate in the coming years. When government policies support base-level initiatives, as in Kazakhstan and China, rapid growth rates occur (Nurbekov *et al.*, 2014; Li *et al.*, 2016).

In many countries such as United States, Canada, Australia, New Zealand, Brazil, Argentina, Paraguay, Uruguay, South Africa, Zambia, Zimbabwe, Malawi, Mozambique, Namibia, Kazakhstan, India and China, attempts have been ongoing for CA to be ‘mainstreamed’ through agricultural development programmes or in some cases backed by suitable policies and institutional support in certain areas within countries depending on local policy makers and institutional leaders. However, countries such as United States, Canada, Australia, New Zealand, Brazil and Argentina, despite a good progress in CA adoption, still lack national policies to support the spread and further development of CA. They either have state policies in support of CA such as Alberta in Canada or Paraná and Santa Catarina in Brazil, but unsuitable national policies, for example promoting certain commodities in monocropping systems, which could even endanger ongoing CA development, such as in United States, Argentina and more recently in Brazil. Yet, the total area under CA worldwide has increased by 69.4% since 2008/09, from 106 M ha (7 % of global cropland) to 180 M ha (12.5% of global cropland) in 2015/16. The adoption of CA globally since 1990 has been growing mainly in North and South America and in Australia, and more recently in Asia in particularly Kazakhstan, China, India and Pakistan, and in Europe especially in Spain, Italy, UK and France, and in Russia; and in Africa including in Zambia, Zimbabwe, Malawi, Mozambique, South Africa, Tunisia and Morocco. Thus, the area under CA is expanding in all regions of the world, and large areas of global agricultural land, including those under orchards and plantation systems, agro forestry systems and crop-pasture-tree systems are expected to transform to CA systems in the coming years and decades.

So far most of the CA development has been in rainfed annual cropping systems and some in irrigated crops in combination with rainfed crops such as the rice-wheat cropping system in the Indo-Gangetic Plains. The same CA principles apply for strengthening the ecological and economic sustainability of *irrigated systems*, including those in arid and semi-arid areas, with the additional benefit of improving water-use efficiency and avoiding or minimizing salinization problems (Basch *et al.*, 2012; Kassam and Brammer, 2012). This is happening in the tropics and sub-tropics with irrigated rice-based systems in Brazil, Argentina, Pakistan, India, Bangladesh, and with other cropping systems such as irrigated cotton-based systems in Uzbekistan, and in irrigated systems in Spain and Italy. However, for rice-based CA systems, it is important also to change the rice irrigation and water management to maintain mainly moist soil with aerobic conditions and not interfere with the building up of healthy soils permitting the development of large and strong root system along with many more head bearing tillers. This water management practice so far is not yet widespread and is mostly introduced in India, Pakistan and Bangladesh, and in some South-east Asian countries, while Latin American rice growers still maintain flood irrigation in no-till rice systems.

If CA is to spread in Europe, Asia and Africa, it must be understood that in the context of sustainable agricultural mechanization it is more than just a technique, such as no-tillage and direct seeding. CA represents a fundamental change in the soil-crop-landscape system management and in the cropping system design and management which in turn lead to consequential changes in the required operations and mechanization solutions. This involves a major shift in the current mix of mechanical technologies, some of which will remain but with only marginal use in future, and there will be the development of completely new set of mechanical technologies, changes in farm power requirements and in land-use suitability for sustainable intensification (Baker *et al.*, 2007). This change process has been ongoing now in Europe, Asia and Africa.

In Europe, a range of machine companies over the past 5 years or so have become involved in manufacturing no-till seeders, including the angled disc seeders which are gaining in popularity, particularly in the United Kingdom. Equally, attempts are being made to innovate no-till weed management without the use of herbicides but based on equipment that can kill weeds using heat stress.

In Asia, there are now no-till seeders being manufactured in a number of countries including Turkey, Iran, India, Pakistan, Bangladesh and China. Two-wheel tractor-mounted seeders have a potential in Asia, particularly for smallholder farmers and an exciting seeder that is gaining popularity is the versatile multi-crop planter (VMP) from Bangladesh (Haque *et al.*, 2016).

Africa too has launched a sustainable agricultural mechanization initiative supported by African Union and FAO which is laying a collaborative foundation among stakeholders for mechanization including for CA production systems and value chains (ACT, 2018).

As indicated earlier, CA principles and practices are also applicable for orchards, plantations and vine crops with the direct sowing of associated field crops, cover crops and pastures beneath or between rows, giving permanent ground cover and biomass production, controlling soil erosion, improving soil health and biodiversity, water infiltration and retention and soil aeration. In the dry areas of Africa, there is an increase of agro forestry systems integrating nitrogen fixing trees such as *Faidherbia albida* with CA systems (Garrity *et al.*, 2010). Orchard crops and vines are being converted into CA systems in Europe (Franco and Calatrava 2006; Leyva *et al.*, 2007; Martinez, 2009; Gomez *et al.*, 2009). Plantation tree crops such as oil palm, rubber, cocoa, citrus and coconut are also being successfully managed under CA systems in several countries such as Malaysia (Othman *et al.*, 2012). In India, the area under CA rice-wheat and rice-maize cropping systems has significantly increased during the last 10 years or so (Saharawat *et al.*, 2010; Farooq and Siddique *et al.*, 2014; Jat *et al.*, 2009a, 2009b, 2010).

South America

The adoption levels of CA farming in Argentina, Paraguay, Uruguay and Southern Brazil are approaching 100%. Since 2008/09, the area under CA in the South America region has changed by some 41% from 49.6 M ha to 69.9 M ha in 2015/16. But there are serious concerns about the quality of some of the CA adoption. Following market pressures, which are partly increased by government policies, a considerable number of farmers are opting for soya mono-cropping, even without any cover crops between two soya crops. This approach, despite applying the no-till practice, has the bad results of erosion and soil degradation. Accordingly, the area under good-quality CA could be argued to be, particularly in Argentina, Uruguay and Brazil, significantly lower than the total area under no-till cropping. The problem was being solved in Brazil with strengthened extension, which more recently has again reverted, and in Uruguay with legal regulations for cover crops in the specific case of soya and subsidy programmes for good-quality CA. The problem has also been reported and is being solved in the recent no-till adoption report for Argentina, where recent policy changes have again opened up opportunities for farmers to grow crops other than soya (Nocelli, 2018).

Brazil has the longest experience in CA in South America, and in 2015/16 it had 32 M ha under various forms of CA. Since its first appearance in 1972, many useful lessons have originated from Brazil and from neighbouring Argentina and Paraguay, which now have respectively 31 M ha and 3 M ha of CA. They have also set important precedents for the engagement of farmers as principal actors in the development and adaptation of new technologies and practices including the integration of pasture, trees and livestock (Mello and van Raij, 2006; Landers, 2007).

The first set of no-tillage experiments in Brazil were started in April 1971 at the Brazilian Institute for Agricultural and Livestock Research(IPEAME, later EMBRAPA), in Londrina, Paraná, by Rolf Derpsch, one of the co-authors of this paper. The following year, Herbert Bartz, the first farmer to try the technology in Latin America, has already introduced the system on his farm. From there it took Brazil almost 20 years to reach the first million ha of no-tillage being applied by farmers, but after this milestone the practice has experienced an exponential growth.

Brazil took the initiative when herbicides (paraquat and diquat) and direct-drilling equipment became available in the United States, and the realisation that conventional ploughing was leading to a severe environmental and economic crisis for farmers in southern Brazil. Progressive and wealthy farmers led the way, some travelling to the United States to learn about soil conservation and management systems there and to purchase direct-drilling equipment. Common interest groups were then formed among large-scale farmers and subsequently among small-scale farmers, joining to the Brazilian Federation for Direct Seeding into Straw (FEBRAPDP). The spread of CA in Brazil is mainly the result of farmer innovation, giving the main impulse for subsequent problem-solving support from input supply companies, state and federal research and extension organizations, universities, as well as long-term funding commitments from international donors such as the World Bank and GTZ. However, the momentum for innovation and adoption is still with farmers and their organizations, and the farmer-led organizations enhanced and reinforced the educational components required for understanding CA principles and concepts (de Freitas and Landers, 2014).

Apart from enabling their land to be cropped more intensively without risk of degradation, CA attracted Brazilian farmers, because it increased crop yields (at least 10-25%), greatly reduced soil erosion, surface run-off and tractor use, resulting in big savings in fuel and production costs (Sorrenson and Montoya, 1984, 1991; Sorrenson, 1997). Such benefits explain why today, Latin American farmers practice CA systems on a continuous basis on some69.9 M ha. These systems are among the most competitive production systems anywhere in the world and they are sustained without any government subsidies.

In the early 1970's Argentina also began its first research and farm trials with no-till. Several farmers started with the system and then gave up because of the lack of adequate herbicides and machinery that, together with lack of know-how, constituted the main constraint for early adopters. A milestone in the development and spread of no-till in Argentina was the foundation in 1989 of the Argentinean Association of No-till Farmers (AAPRESID), based in Rosario. Since 1992, AAPRESID has been organizing no-till conferences in August of every year which have been attended by more than 1000 farmers at the beginning and nowadays exceeding 2000 farmers. Since the founding of AAPRESID, Argentina also experienced an exponential growth of the no-till farming.

Argentina experienced a paradigm shift with the advent of the no-tillage practice and finally discarded the idea that tillage was necessary to grow crops. In Argentina, the concept of 'arable' soils has been abandoned after recognizing that soils that cannot be ploughed can be directly seeded. According to AAPRESID (2010) in 2007/08, there were 25.8 million ha of no-tillage being practiced in Argentina (http://www.aapresid.org.ar), making it one of the most successful countries in terms of no-till adoption. The first group of farmers started using no-till in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned no-till experts from Chile, as well as with Shirely Phillips and Grant Thomas from the United States. At the beginning, growth was slow because of lack of experience, knowledge on how to do it, machines and limitations on the availability of herbicides. It took 15 years until 1992/93 when about 1 million ha under no-tillage was reached. Since then adoption increased year by year as a result of the intensive activities of AAPRESID so that in 2008/09 about 79% of all cropland in Argentina was under no-tillage system. In 2015/16, it was 31 M ha, about 95% of all cropland.

One of the main factors that made the rapid growth of no-tillage possible in Argentina was the fact that machine manufacturers quickly responded to the increasing demand in no-till seeders. Among the many big and small no-till seeders manufacturers in Argentina, there are at least 15 that are in good conditions to export their equipment. No-tillage in Argentina is almost exclusively performed with disc seeders.

Similar to other countries in South America, farmers in Argentina prefer to do permanent no-tillage once they have started with the system. At the beginning cover crops were not an issue for no-till farmers in this country, because it was believed that these crops would take too much moisture out of the soil. This has changed in recent years when research could show that water-use efficiency can be enhanced using appropriate cover crops. A milestone in no-tillage in Argentina was reached on 7 May 2010 when G. Cabrini with the help of AAPRESID became the first farmer to certify his no-till production system. The certification protocol is based on principles and criteria developed from international initiatives that focus on sustainability.

Paraguay has experienced a continuous and steady growth of CA adoption, almost all of it over the past 10 years. Tillage practices have disappeared almost completely. In tractor mechanized farming systems, about 90% (of the total 2.4 M ha in 2008) of all crop area was under CA (Derpsch and Friedrich, 2009b). In 2015/16, some 3 M ha (nearly all of the cropland) was in CA. Similarly, in small farmer production systems with animal traction or manual systems, no-till practices have increased to about 30,000 ha covering 22,000 small farmers. The increased interest in small-scale farmer CA systems has been a result of government support that provides extension services and grants for buying no-till equipment.

In Bolivia CA practices increased in the last 10 years especially in lowlands in the east of the country. The main crop is soybean whose area has increased from around 240,000 ha in the year 2000 to 706,000 ha in the year 2007 (Derpsch and Friedrich, 2009b), and to 2 M ha in 2015/16. The occurrence of wind erosion in conventional tillage systems has been one of the major driving forces for adoption. Also, farmers value the increased water-use efficiency with no-till system in this low and erratic rainfall region. However, CA is only promoted in the eastern plains around Santa Cruz by the Association of Oil crop and Wheat Producers (ANAPO). Early experiments with no-till systems were introduced by CIMMYT in the 1990s on the ANAPO experimental station, and ANAPO is the only organization providing technical assistance in CA cropping systems. Outside the ANAPO area, no-till is practiced to a minor extent, but permanent no-till systems such as CA are unknown. This is the case for the tropical eastern lowlands as well as for the Andean regions. Only recently, due to severe soil degradation, alarmingly low production levels and increasing pressures from climate change, the government is becoming seriously interested in CA.

In Uruguay, about 82% of cropland, that is 655,000 ha, was under no-till systems in the 2006/07 growing season, according to the Uruguayan No-till Farmers Association (AUSID). This was a great progress compared to the 2000/01 season when only 119,000 ha of no-tillage was reported, corresponding to 32% adoption. In 2015/16, CA area covered was 1.26 M ha (52% of total arable land) and the total cropland was much bigger, some 2.41 M ha, due to expansion of no-till cropland into pasture areas. Some 65% of arable crops are seeded on rented land for which contracts are renewed every year, and this hinders the planning of medium-term crop rotation and investment strategies. In Uruguay, the integration of crops with livestock is very popular, and CA systems fit well into the requirements for crop-livestock production systems. Pastures are grown for several years until they show signs of 'degradation'. Crops are then grown for several years according to the needs of the farmers and the market situation.

Venezuela, Chile, Colombia and Mexico each have modest amounts of their land under no-till systems, ranging from some 41,000 ha in Mexico and 127,000 ha in Colombia to 180,000 ha in Chile and 300,000 ha in Venezuela (Derpsch and Friedrich, 2009b; Kassam *et al.,* 2018).

The main crops grown under CA in Latin America include soybean, maize, wheat, sunflower, canola as well as cassava (Howeler *et al.,* 2013), and a number of horticultural and cover crops, while CA potato is marginal. CA practices are also being applied to perennial crops and tree crops. Soil cover is achieved by growing cash crops and cover crops either in association or sequentially. Main cover crops include oats, oilseed-radish, rye, lupine, vetch, *Mucuna* (velvet bean), *Dolichos* and pigeon pea. In recent years, mixtures of up to ten different cover crops are sown to address specific needs of the soil or subsequent crop in terms of cover, nitrogen release, weed suppression or other pest control effects (TiIman *et al.,* 1997). In some cases, especially among small-scale farmers herbicide use is reduced by direct-drilling of the seed into a cover crop that has been flattened with a knife roller. Specialized no-till equipment has been developed in Brazil and the Americas, including tractor-mounted, animal-drawn and hand tools (including jab planters). These are being exported to Africa and Asia and being adapted there for local use and manufacture.

North America

CA adoption is the highest in the North-Western Parts of North America and in the southern parts of South America with adoption levels above 50%. Since 2008/09, the area under CA in the North America region has changed by 57.9% from 40.0 M ha to 63.2 M ha in 2015/16.

In Canada, CA is estimated to be practised on 19.9 M ha (38.2% of the crop area) in 2015/16, although no-till technology is used over a much larger area, 67% of crop area (Derpsch and Friedrich 2009b). In 2008/09, CA area was estimated to be 13.5 M ha (25.9% of the crop area) and the regions with highest percentage of adoption of no-tillage were Saskatchewan (60.1%), Alberta (47.8%), Ontario (31.2%), Manitoba (21.3%) and British Columbia (19.0%). Canada has had a similar development as the United States, with heavy erosion problems in the 1930's and the subsequent focus on conservation tillage. However, after the year 2000 more importance was given to a systems approach, not only focussing on reduced or zero tillage and chemical fallows but including factors such as soil organic cover and crop rotations. As a consequence, between 1999 and 2004 the amount of wheat grown in Canada went down by 6.4%, while the oil crops increased by 48.7% and pulses by 452.7%. At the same time the use of fallow went down by 58.7% (Yuxia and Chi, 2007). These developments are parallel to the recent increase in the application of CA in Canada since the year 2000 (Goddard *et al.,* 2006, 2009; Lindwall and Sonntag, 2010). This long-term and wide adoption of CA, mostly in the western provinces, has resulted in visible environmental benefits, including the absence of dust storms and a greater biodiversity. The main co-benefits from CA in Canada have been documented by Baig and Gamache (2009, 2011). There was also excellent technical research done on crop diversification and on integrated weed management (Blackshaw *et al.,* 2007). Environmental services provided through CA are increasingly recognized, for example, through a voluntary carbon off-set trading scheme as in Alberta (Haugen-Kozyra and Goddard, 2009) that encourages industry under a 'cap and trade' regulation to purchase carbon off-sets from farmer associations whose members are practicing a production system based on the government-approved no-till protocol (similar to the CA concept) to sequester additional soil carbon and reduce greenhouse gas emissions carbon payment schemes as in Alberta.

More recently, research in Alberta, Canada, has shown that production cost savings and energy-use efficiency are best achieved if precision farming technology and variable rate technology (VRT) for fertilizer application are built upon no-tillage systems. No-tillage already forms a basis for operating an agricultural carbon offset trading scheme in Alberta, as well as for reducing greenhouse gas emissions from agriculture. For example, according to the research supported by the Agricultural Research and Extension Council of Alberta (ARECA), producers throughout Alberta can reduce their fuel use and become more energy-efficient by:

- converting from conventional tillage-based practices to zero-till practices;
- operating energy-efficient equipment technologies;
- adopting precision farming techniques and VRT for application of fertilizers.

Agriculture in Alberta, as elsewhere in the industrialized countries, is a major user of energy and conventionally tilled farms spend about 24% of their energy inputs on fuel and about 60% on fertilizer. Converting to zero-till practices alone increases energy efficiency, energy conservation and profitability. Fuel savings from converting from conventional tillage to zero-tillage averages around 38% (across all crop rotations). During the period of 2001-2006, zero-till practices increased by 1.6 M ha and during the same time period diesel fuel consumption fell by 70.2 M L. This led to decreased CO_2 emissions and improved soil conservation. Since 2007, Alberta has been operating an agricultural carbon offset scheme in which the protocol that defines the production system compliance characteristics is based on no-till (Haugen-Kazyra and Goddard, 2009; Goddard *et al.*, 2009).

As noted earlier, no-till agriculture systems in the modern sense originated in the United States in the 1960s, and from then up until 2007 the United States had the largest area under no-till worldwide. In 2008/09, CA was 26.5 M ha (21.5% of cropland) and in 2015/16, it was 43.2 M ha (35.1% of cropland), despite long time experience with no-till farming. Conventional agriculture with tillage remains in the majority even if CA is a valid option for farmers, as compared with southern Latin America where no-till has become the majority agricultural system with 63.3% of the crop area. The awareness about crop rotations and cover crops as well as the additional benefits of permanent no-till systems is growing because of organized farmers' associations at the state, and at the regional level. Research has shown that it can take more than 20 years of continuous no-till to reap the full benefits of CA. Farmers that practice rotational tillage (plough their soils occasionally) will not experience the full benefits of the system (Derpsch, 2004).

A particularly exciting development in no-till system in the United States is the practice of 'planting green'. This operation allows the establishment of a crop, following a cover crop, without using any herbicides but instead using a roller crimper to subdue the cover crop (Duiker, 2017; Gullickson, 2018). In the United States, much of CA cropping has used maize, soybean and canola crops, but more recently cotton systems also finds place.

Australia and New Zealand

The area of CA in Australia and New Zealand combined increased from 12.16 M ha in 2008/09 to 22.67 M ha in 2015/16, an increase of 85.8%.

In Australia, CA has been widely and quickly embraced by farmers, making it the country with the fourth largest area of 22.3 M ha in 2017, an increase from 12.0 M ha in 2008/09. It has improved weed control, time of sowing, drought tolerance and has enabled dry regions to use water most efficiently (Crabtree, 2004, 2010; Flower *et al.*, 2008; Llewellyn *et al.*, 2009; Jat *et al.*, 2014). In 2017, the adoption of no-till by Australian farmers, according to the Australian Bureau of Statistics, varied from 84.5% in northern New South Wales to 93.5% in South Australia and 96.3% in Western Australia. Overall adoption of no-till in Queensland is approximately 72%. CA methods have led to large increases in profitability, sustainability and positive environmental impact in the Australian cropping belt. Also, the use of cover crops is getting popular among no-till farmers. Because of the water, time and fuel savings with no-till systems as well as the other advantages, cropland under no-tillage is expected to continue to grow. Another complementary technology used in Australia on no-tillage farms is controlled traffic farming to avoid soil compaction. Particularly in Eastern Australia, the adoption of CA is needed to reduce the contamination of water bodies with sediments, nutrients and pesticides, which is threatening the existence of the Great Barrier Reef on the eastern coast of Australia.

New Zealand has about 366000 ha under CA, which corresponds to about 56% of all cropland area including pasture, forage crops and arable crops (Baker, 2015). In 2008/09, the area of CA was 166,000 ha. New Zealand is among the first in the world to use and develop the no-till technology. In the beginning in the seventies, pasture renovation without tillage was tried and practiced successfully. Later, also annual crops were seeded with the no-till. However, the majority of the increase in CA area has occurred since 2000.

Asia

Asian countries have adopted CA in many areas during the past 10-15 years, and since 2008/09, CA area has increased more than four-fold (429.7%), from some 2.6 M ha in 2008/09 to some 13.9 M ha in 2015/16. In 2008/09, CA area was reported in only two countries in the Asia region, but in 2013/14 CA area was reported in 11 countries, and in 2015/16 in 18 countries.

In Central Asia, earlier work on CA practices in Eurasia has been reported by Gan *et al.* (2008), for Kazakhstan by Suleimenov (2009) and Fileccia (2008), and for Uzbekistan by Nurbekov (2008) and FAO (2009). ICARDA and CIMMYT have also been active in CA research in the Central and West Asia and North Africa (CWANA) region (Pala *et al.*, 2007; Karabayev, 2008; Suleimenov, 2009; Nurbekov, 2008). A faster development of CA can be observed in the last 10 years in Kazakhstan, which now has 10.5 M ha under reduced tillage, mostly in the northern drier provinces, out of which some 2.5 M ha (15.6 % of crop area) are 'real' CA with permanent no-till and rotation. Kazakhstan is amongst the top ten countries in the world with the largest crop area under CA systems. No-till adoption was promoted for some time by CIMMYT and FAO, who introduced no-tillage systems in a CA project from 2002 to 2004. No-till adoption started from 2004 onwards in the north Provinces (North-Kazakhstan, Kostanay and Akmola), where the highest adoption rates have been registered. CA has had an impressive development in recent years as a result of farmers' interest, accumulated research knowledge, facilitating government policies and an active input supply sector (Derpsch and Friedrich, 2009b). Extra incentive is offered to no-till farmers by government which has also supported long-term research work to provide solutions to farmers on issues such as the need to maximize effective winter snowfall through stubble trapping; to increase the generation of biomass through cover crops replacing bare or chemical fallows; to diversify cropping systems; and to improve integrated weed management (Suleimenov and Thomas, 2006; Suleimenov and Akshelov, 2006).

In addition, Uzbekistan, Azerbaijan, Kyrgyzstan and Tajikistan, as well as Laos, Vietnam and Cambodia have made a committed start to promoting rainfed and irrigated CA cropping systems (Nurbekov *et al.*, 2014, 2016; Lienhard *et al.*, 2014) and so have other countries in West Asia such as Iran, Turkey, Lebanon, Syria and Iraq (Loss *et al.*, 2016; Asadi, 2018). Iran and Turkey now report some 150,000 ha and 45,000 ha under CA, respectively. Area under CA in Syria and Iraq has continued to increase because of shortages of fuel (Piggin *et al.*, 2014).

In India, the adoption of no-till practices by farmers has occurred mainly in the wheat-rice double cropping system and initially was adopted primarily for the wheat crop. The main reason for this is the fact that tillage takes too much time resulting in delayed seeding and yield loss of the wheat crop after rice (Hobbs and Gupta, 2003; Hobbs *et al.*, 2008). The Rice–Wheat Consortium for the Indo-Gangetic Plains, an initiative of CGIAR, led by the International Rice Research Institute (IRRI) and CIMMYT, which involved several National Agricultural Research Centres, promoted no-till practices that have resulted in the massive uptake of no-till wheat in the region (Erenstein *et al.*, 2008). The uptake of the technology was rapid in the north-western states, which were relatively better endowed with respect to irrigation, mechanization and where the size of holdings was relatively large (3-4 ha) compared to the eastern region, which was less equipped and mechanized and where the average land holding was small (1 ha) (Derpsch and Friedrich, 2009a, 2009b). CA research and extension work now is spread over much of the Indo-Gangetic Plains including the eastern parts of India and in Bangladesh with promising results.

In general, in the Indo-Gangetic Plains across India, Pakistan, Nepal and Bangladesh, large adoption of no-till wheat with some 5 M ha is reported, but only modest adoption of permanent no-till systems and full CA (Farooq and Siddique, 2014; Hobbs *et al.*, 2008). The exception appears to be India and Pakistan, where significant adoption (1.5 and 0.6 M ha, respectively) of no-till practices by farmers has occurred in recent years in the rice-wheat double cropping system (Farooq and Siddique, 2014; Kassam *et al.*, 2018), and also in the rainfed upland areas in India for crops such as maize, sorghum, millets, cotton, pigeon pea and chickpea. Recent reports suggest that in the Indo-Gangetic Plains in India, there may be up to 3.5 M ha of CA-based rice-wheat system (Paroda, 2018). Bangladesh has begun to report some CA area with rice-based system, particularly on permanent beds. This is expected to expand because farmers can now access no-till seeding service from service providers with locally produced CA equipment (Haque *et al.*, 2018).

China has been experiencing an equally dynamic development of CA. It began in 1990 with research on no-till and controlled traffic systems (Li *et al.*, 2007), and then the adoption of CA increased during the last few years and the technology has been extended to rice production. A main driver for CA in China has been the need to reduce the danger of dust storms during the Olympic Games in 2008. In the years preceding the games, CA adoption was promoted particularly in Hebei province, surrounding Beijing, while in Beijing province the sales of ploughs were forbidden. Subsequently, China adopted CA also as a national policy. In 2013/14, some 6.7 M ha were under CA in China and 23,000 ha in DPR Korea. In 2015/16, China reported CA area of some 9 M ha (Li *et al.*, 2016). The introduction of CA in DPR Korea has made it possible to grow two successive crops (rice or maize or soya as summer crop, and wheat or barley as winter crop) within the same year, through direct drilling of the second crop into the stubble of the first. The feasibility of growing potatoes under zero tillage and CA has also been demonstrated in DPR Korea (FAO, 2007) and elsewhere.

Europe (including Russia and Ukraine)

Since 2008/09, the CA area for annual crops in Europe has changed from 1.6 M ha to 2.0 M ha in 2013/14, and increase of 30%, and to 3.5 M ha in 2015/16, an increase of 127.4%. In 2008/09, CA was reported in 11 countries but in 2013/14, this increased to 15 countries, and in 2015/16 to 29 countries. Since 1999, ECAF and its national association members, comprising many farmers, have been promoting CA systems in Europe, with significant adoption in Spain, Italy, Finland, France, Romania, Poland, United Kingdom, and Switzerland. They have also been active in bringing CA to the notice of officials at the European Commission as well as members of the European Parliament. However, progress has been slow in terms of integrating CA principles and practices as part of Common Agricultural Policy (CAP) support to European farmers, although more recently there has been a revival of interest in providing support practices that would improve soil health management. Another positive change in Europe that is facilitating the uptake of CA has been the availability of improved no-till drills and other equipment manufactured in Europe, particularly in the United Kingdom. This has led to farmers and machine companies to organize on-farm events to demonstrate no-till drills and participate in on-farm conferences to discuss their experiences and successes with CA practices which to them seem to be addressing their practical agro-ecological interest in climate-smart regenerative agriculture to build soil health, reduce input costs and raise productivity and profit. One popular event of this nature is the Groundswell No-Till Show and Conference which is held annually in the United Kingdom where some dozen machine companies demonstrate their CA no-till drills and farmers and CA experts from the United Kingdom and abroad make presentations on different topics related to regenerative and sustainable agriculture based on CA principles and practices (Kassam *et al.*, 2018).

Russia and Ukraine also show significant adoption of CA, and they also have active farmer groups promoting CA. In Russia, the area under reduced tillage is believed to be some 15 M ha, but CA according to FAO definition is estimated to be about 5.0 M ha. In Ukraine, CA has reached some 700,000 ha in 2013/14 but an accurate estimate of CA area was not possible in 2015/16.

A description of the status of adoption in some of the countries in Europe is presented below based on Derpsch and Friedrich (2009a, 2009b), Basch *et al.* (2008), Derpsch *et al.* (2010), Friedrich *et al.* (2014) and Kassam *et al.* (2015, 2018).

No-tillage research in Spain started in 1982. On the clay soils of southern Spain, no-tillage was found to be advantageous in terms of energy consumption and moisture conservation, as compared to both, conventional or minimum tillage techniques (Giráldez and González, 1994).

Spain is the leading country in terms of no-till adoption in Europe. According to AEAC/SV (Spanish Conservation Agriculture Association – Living Soils), no-tillage of annual crops is practiced on 650,000 ha in Spain. Main crops under no-tillage are wheat, barley and much less maize and sunflowers. Besides annual crops grown in the no-tillage system in Spain, many olive plantations and fruit orchards have turned to no-till systems. AEAC/SV reports 893,000 ha of no-tillage being practiced in perennial trees in most cases in combination with cover crops and livestock (generally sheep). Main tree crops in no-tillage systems in combination with cover crops are olives and much less apple, orange and almond plantations. The extent of no-tillage practices in tree crops is not included in the global estimates in Table 1 and 2. In total, it is reported that CA is applied on about 10% of arable land in Spain, and farmers practicing CA are receiving extra payment (from local, national and EU sources of funds) over and above the CAP-based single farm payment.

In France, long-term experiments with different minimum tillage techniques (including no-tillage) were started by the French National Institute for Agricultural Research (INRA) and the Institute for Cereal and Forage Technology (ITCF) in 1970, mainly with cereals (Boisgontier *et al*. 1994). The authors concluded that a comprehensive range of technical and economic data is now available in France in relation to where minimum tillage can be developed and how it can be implemented. France is among the more advanced countries in Europe in terms of adoption of CA/No-till farming. The French No-till Farmers Association (APAD) estimates that no-tillage is practiced on about 200,000 ha in this country, corresponding to just over 10% of arable land in France. Some farmers have developed superior no-till systems with green manure cover crops and crop rotation that are working very well. The 2008 International Conference on Sustainable Agriculture, organized by the Institute for Sustainable Agriculture (IAD) under the High Patronage of Mr. Nicolas Sarkozy and the launching of the IAD Charter for Sustainable Agriculture, were expected to show results in terms of greater acceptance of CA practices at all levels and especially at the political level, which is also needed across the whole EU in order to increase farmers' acceptance. This notwithstanding, CIRAD has been researching on and promoting CA internationally for many years under the term 'Direct Seeded Mulch-Based Cropping System' (DMC) (Séguy *et al.*, 2006a, 2006b; Seguy *et al.*, 2008).

The adoption of no-tillage technologies was very fast in Finland in the initial years. According to the Finnish Conservation Agriculture Association (FINCA) in less than 10 years no-tillage grew from some 100 ha to 200,000 ha in 2008. In this way Finland managed to advance to one of Europe's leading no-till countries. The reason for this rapid adoption was that those farmers who believed in the no-till system and made it work communicated their experiences to their peers. The extension service and research organizations as well as agribusiness took interest in this development only later. FINCA has played a major role in spreading no-tillage in Finland. One manufacturer of no-till seeders in Finland took interest in no-tillage very early and claims to have sold almost a thousand no-till seeding machines until 2007, having about 50% of the market share in the country. About ten no-till seeder manufacturers from around the world have been able to place their no-till machines in the Finnish market and four of them are made in Finland. Another interesting fact about no-tillage in Finland is that no-tillage is practiced successfully from the far South of the country up to the Arctic Circle in the North (66º N).

Switzerland has made remarkable progress in terms of research, development and adoption of no-tillage practices. Research performed in Switzerland over more than 10 years has shown equal or better yields under no-tillage in a variety of crop rotations. No-till tends to be more and more accepted in Switzerland. This is because conventional tillage (and also reduced tillage practices as chisel ploughing) exposes the soil to erosion under the topography prevailing in this country. According to Swiss No-Till, CA approach was applied on about 12,500 ha in 2010 and this corresponds to about 3.5% of arable land in this country. In 2013/14, CA area was estimated to be 17,000 ha.

Investigations into no-tillage technologies in Germany started in 1966. Intensive and long-term research has concluded that no-tillage is a viable cultivation system. According to Teebrügge and Böhrensen (1997), no-tillage is a very profitable cultivation system compared to conventional tillage because of the lower machinery costs and lower operating costs. No-tillage decreases the purchase costs, the tractor power requirement, the fuel consumption, the amount of required labour as well as the variable and fixed costs. Since the same crop yields can be achieved by no-tillage compared to plough tillage, on average the profit will be greater with no-tillage systems.

Despite these facts and opportunities and long-term research, adoption of no-till farming in Germany is still very low. Well-informed scientists, farmers and experts with a thorough understanding of no-till farming as practiced in most parts of the world do not coincide so that probably till today there are no more than about 5,000 ha of this technology being practiced by farmers in Germany. At the same time, one can recognize that there are outstanding farmers practicing no-tillage in this country like for instance Thomas Sander who farms in Oberwinkel, Saxony and receives many visitors every year. The quality of his no-tillage operation with crop rotations and cover crops earned his farm the Environmental Award of the State of Saxony 2006. With increased fertilizer and fuel prices, erosion problems in some regions and regular droughts in others, interest in no-tillage farming is growing steadily but adoption appears to some 140,000 ha in 2015/16 which is lower than the CA area reported earlier. Some farmers such as Alfons Bunk from Rottenburg, Suabia have been using continuous no-till for 20 years successfully.

Portugal and Italy**,** despite showing significant signs of soil degradation and erosion already since antique times (Montgomery, 2007), have still fairly low levels of CA adoption. According to ECAF, Portugal had some 32,000 ha under CA/No-Till system in 2015/16, a modest increase from 28,000 ha in 2008/09. CA in Italy is referred to as *Agricultura Blue* (Pisante, 2007). In 2015/16, CA cropland area covered some 284,000 ha, a considerable increase from 80,000 ha in 2008/09. In Italy, there is also a significant and growing adoption of CA concepts such as no-tillage and cover crops in fruit and olive orchards, and regional governments in Italy do subsidize farmers for applying reduced tillage.

Ukraine is a country where estimates on the adoption of no-tillage vary greatly depending on the source of information. Estimates vary from less than 30,000 ha to more than a million ha. Official government statistics on no-tillage state an adoption of 250,000 ha. Unfortunately, CA systems as understood by the authors of this paper (see definition above), have not progressed as much as some people might wish. According to AgroSoyuz (a large cooperative farm in Dnipropetrovsk), there are about 1.1 million ha of Direct Seeding technology being practiced in Ukraine. AgroSoyuz has organized several no-till conferences in Dnipropetrovsk inviting many renowned international speakers and since then understanding has been growing that only low disturbance systems bring additional benefits, justifying the focussing on no-tillage. The estimate of CA in 2013/14 by AgroSoyuz was 700,000 ha.

Compared to other world regions CA development in Europe has been particularly slow, with some few exceptions, such as for example Finland, Spain, Italy and United Kingdom. There is a number of reasons for this slow adoption in Europe, some of which are the moderate climate which does not cause too many catastrophes urging for action, agricultural policies in the EU including direct payments to farmers and subsidies for certain commodities, which take the pressure off the farmers for extreme cost savings and discourage the adoption of diversified crop rotations. Cheap imports of soya as animal feed has also practically eliminated the market for locally grown legumes, an important component of CA rotations. In addition to this, there are interest groups opposed to the introduction of CA, which results for example in difficulties for a European farmer to buy a good-quality no-till direct seeder with low soil disturbance and high residue handling capacity. Most of the European farmers practicing CA have directly imported CA equipment or have had contact with small import agents. However, the environmental pressur as well as the effects of climate change in EU are also increasing, and the next European CAP soon to be reviewed and reformed seems likely to turn more favourable towards CA.

Africa

In Africa, innovative participatory approaches are being used to develop supply-chains for smallholders to access CA equipment. Similarly, participatory learning approaches such as those based on the principles of farmer field schools (FFS) and lead-farmer networks are being encouraged to explain the ecological principles underlying CA and to make it attractive for use in local farming.

CA is spreading in eastern and southern Africa, and North Africa, using indigenous and scientific knowledge, and equipment design from Latin America based on the earlier development work promoted by FAO, CIRAD, the ACT Network, ICRAF, CIMMYT, ICRISAT, IITA (Fowler and Rockstrom, 2001; Haggblade and Tembo, 2003; Kaumbutho and Kienzle, 2007; Shetto and Owenya, 2007; Nyende *et al.*, 2007; Baudron *et al.*, 2007; Boshen *et al.*, 2007; SARD, 2007; Erenstein *et al.*, 2008; FAO, 2008; Owenya *et al.*, 2011; Thierfelder *et al.*, 2013, 2018). There is also collaboration now with China, Bangladesh and Australia, and CIMMYT, ICARDA, ICRISAT, ICRAF, CIRAD, ACT, FAO, IFAD, African Development Bank (AfDB)and NGOs. These have all stimulated the trend to have local practices and local equipment, with advantages in maintenance and repair. Farmers in at least 22 African countries are promoting CA (Kenya, Uganda, Tanzania, Rwanda, Sudan, Ethiopia, Swaziland, Lesotho, Malawi, Madagascar, Mozambique, South Africa, Namibia, Zambia, Zimbabwe, Ghana, Burkina Faso, Senegal, Cameroon, Morocco, Tunisia, Algeria). CA has also been incorporated into the regional agricultural policies by NEPAD, and it is recognized as a core element of climate-smart agriculture (Kassam *et al.*, 2017b; 2018).

CA systems help Africa's resource-poor farmers to maintain subsistence with sustainability, so as to meet the challenges of climate change, high-energy costs, environmental degradation, and labour shortages. The CA area is still relatively small mainly because of the small land holdings as well as greater attention being paid to the promotion of conventional tillage agriculture, without much success. But there is a developing trend, a CA movement of some 2 million small-scale farmers on the continent. Since 2008/09, CA has spread further (details lacking) in countries such as Kenya, Madagascar, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Currently, South Africa is undertaking a national consultation process to facilitate the integration of CA into national agricultural development policy. Similarly, AFDB has announced that it will promote agricultural development in the Guinea Savanna zone of Africa based on CA systems.

In 2008/09, CA was reported in nine countries, but in 2013/14 there were 14 countries with area under CA, and in 2015/16, 17 countries. The total area of CA in Africa in 2015/16 was more than 1.5 M ha, an expansion of some 211% since 2008/09, from 0.48 M ha. From expert and scientific knowledge expressed on building CA-based farming systems at the 1st Africa Congress on CA in March 2014, and on making climate-smart agriculture real in support of the Malabo Declaration expressed at the 2nd Africa Congress on Conservation Agriculture in October 2018, it is clear that a significant research and development effort is being directed in Africa towards transforming conventional agriculture to CA. African Union and FAO have also launched the sustainable agricultural mechanization for Africa (SAMA) with CA as the preferred approach. It is thus likely that the adoption and spread of CA systems in Africa will expand in the coming decades to increase food production with fewer negative effects on the environment and energy costs, and to result in the development of locally adapted technologies consistent with CA principles (Kassam *et al.*, 2017b, 2018; ACT, 2018).

West Asia and North Africa

Research and practical field demonstrations in the West Asia and North Africa (WANA) region, , much of the earlier CA work done in various countries had shown that yields and factor productivities could be improved with no-till systems (Kassam *et al.*, 2012; Piggin *et al.*, 2015; Gonzalez-Sanchez *et al.*, 2015; Loss *et al.*, 2016; Bashour *et al.*, 2016; Lalani *et al.*, 2018). Extensive research and development work were conducted in several countries in the WANA region since the early 1980s such as in Morocco (Mrabet, 2007, 2008a,b,c); and more recently in Tunisia (M'Hedhbi *et al.*, 2003, Ben-Hammouda *et al.*, 2007), in Syria, Lebanon and Jordan (Belloume, 2007; Bashour, 2007; Pala *et al.*, 2007; Ghosheh, 2007) and in Turkey (Avci *et al.*, 2007).

In the WANA region, Centero-Martinez *et al.* (2007), Lahmar and Triomphe (2007) and Pala *et al.* (2007) endorsed the potential benefits that could be harnessed by farmers in the semi-arid Mediterranean environments while highlighting the need for longer-term research including on weed management, crop nutrition and economics of CA systems.

According to Centero-Martinez *et al.* (2007), the main reasons for adoption of CA are (1) better farm economy due to reduction of costs in machinery and fuel and time-saving in the operations that permit the development of other agricultural and non-agricultural complementary activities; (2) flexible technical possibilities for sowing, fertilizer application and weed control; (3) yield increases and greater yield stability; (4) soil protection against water and wind erosion; (5) greater nutrient-efficiency; and (6) better water economy in dryland areas. Also, no-till and cover crops are used between rows of perennial crops such as olives, nuts and grapes. CA can be used for winter crops, and for traditional rotations with legumes, sunflower and canola, and in field crops under irrigation where CA can help optimize irrigation system management to conserve water, energy and soil quality and to increase fertilizer-use efficiency.

Work by ICARDA and CIMMYT has shown benefits of CA especially in terms of increase in crop yields, soil organic matter, water-use efficiency and net revenue. CA also shows the importance of utilizing fallow periods for cropping and of crop diversification, with legumes and cover crops providing improved productivity, soil quality, N-fertilizer-use efficiency and water-use efficiency. CA is perceived as a powerful tool of land management in dry areas, according to Lahmar and Triomphe (2007). It allows farmers to improve their productivity and profitability especially in dry areas while conserving and even improving the natural resource base and the environment. However, CA adaptation in drylands faces critical challenges linked to water scarcity and drought hazards, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat and so forth. Poverty and vulnerability of many smallholders, who rely more on livestock than on grain production, are the other key factors.

Since 2008/09, the area under CA in WANA region has increased substantially from 10,000 ha to 103,200 ha in 2013/14, and to 269,300 ha in 2015/16, an increase by about 269%. In 2008/09, only two countries reported the existence of CA area, but in 2013/14 the number increased to six countries, and in 2015/16, it was eight countries.

Morocco, Tunisia and Algeria have shown a modest growth in CA adoption, but the adoption has been enormous in Iran and Syria, increasing in only a few years to 150,000 ha and 30,000 ha, respectively. Iran is the largest adopter in the region followed by Turkey (45,000 ha) and Syria as the second and third largest CA adopters, respectively. Iraq too now has some 15,000 ha of CA, benefitting from the work done by ICARDA in Syria, Iraq and elsewhere (Piggin *et al.*, 2015). The main reason for the rapid uptake is the increased availability of locally produced affordable no-till seeders in Syria, Iran and Turkey, which are also being exported elsewhere in the WANA region, and the efforts of development and promotion activities by organization such as the German International Cooperation (GIZ), ICARDA, FAO and the Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD) as well as bodies such as INRA in Morocco, American University in Beirut, Aga Khan Foundation in Syria, and the Mediterranean Agro-Systems Innovation Network(RCM)across the WANA Mediterranean region. At the Climate Summit COP 22 in Marrakesh, the Moroccan government proposed the ‘Triple A’ programme for Africa (Adaptability of African Agriculture to Climate Change) which was accepted. The Moroccan government also set for itself a target of 5 M ha of land under conventional tillage agriculture to be transformed to CA systems over the next 10 years. Thus, the ‘Triple A’ initiative and the decision taken by Morocco to adopt CA are likely to help African farmers and governments to accelerate the spread of CA across Africa.

International experiences about CA and considerations for its implementation in the Mediterranean region show the potential benefits that can be harnessed by farmers in the semi-arid Mediterranean environments and highlight the need for longer-term research including on weed management, crop nutrition, crop-livestock integration, biomass management and economics of CA systems. Some of the crop-livestock integration issues such as biomass management need to be resolved at the community level because post-harvest crop biomass is in demand by livestock herders and the traditional arrangement between crop farmers and herders is not conducive to CA development (Kassam *et al.*, 2012; Lalani *et al.*, 2018). Besides, unless farmers are engaged through an enabling policy with institutional support and the opportunity to learn CA practices and how to integrate them into crop-livestock production system, rapid uptake of CA is not likely to occur. Examples exist for the technical feasibility of successful crop-livestock integration in such environments. But since the traditions and community structures are country specific, only locally developed procedures for introduction and adoption of CA systems will be successful in the long term.

Conclusion

CA is a new paradigm for farming worldwide. It changes the thinking and mindset on production system and agricultural land management. Originally, the adoption of CA was mainly prompted by acute problems faced by farmers, especially wind and water erosion, as for example southern Brazil or the Prairies in North America, or drought in Australia. In all these cases, the farmers' organization generated knowledge that eventually led to mobilizing public, private and civil sector support. More recently, again pressed by erosion and drought problems coming with climate change, exacerbated by increase in cost of energy and production inputs, government support has accelerated the adoption rate of CA in Kazakhstan, China, India and Pakistan, but also in some African countries such as Zambia, Zimbabwe, Malawi and Mozambique among others, and this is attracting support from other stakeholders. In Europe too, there has been greater concern shown by the EU towards soil degradation and the need for greater environmental and soil health management in agriculture. Thus, by means of the CAP, Member States of the EU have been able to provide incentives to farmers to adopt soil and water conservation practices that are also climate-smart.

The main reasons for adoption of CA by farmers and societies can be summarized as follows:

(1) better farm economy (reduction of production inputs of seeds, fertilizer, pesticides and water, and lower costs in machinery and fuel, and time-saving in the operations that permit the development of other agricultural and non-agricultural complementary activities);

(2) delivery of a range of ecosystem services to society and nature, including cleaner water resources, greater carbon sequestration, minimum pollution and soil erosion, greater biodiversity in the agro-ecosystems, and normal functioning of carbon, nutrient and water cycling, and avoided environmental costs;

(3) equal yields, or yield increases (depending on the starting level of soil degradation) and greater yield stability (as long-term effect) and higher overall seasonal production;

(4) greater nutrient-use efficiency and retention;

(5) fewer crop protection problems and costs;

(6) soil protection against water and wind erosion;

(7) better water-use efficiency and retention, and better water economy including in dryland areas;

(8) flexible technical possibilities for sowing, fertilizer application and weed control (allowing for more timely operations and adaptation to climate change); and

(9) farming based on climate-smart regenerative agriculture.

In reality, farmers have higher profits with CA systems. Otherwise, they would not be practising CA on more than 180 M ha of cropland globally, nor would it be spreading at an annual rate of more than 10 M ha. No-till and cover crops are used between rows of perennial crops such as olives, nuts and grapes or fruit orchards, and in plantation systems. CA can be used for winter crops, and for traditional rotations with legumes, sunflower and canola, and in field crops under irrigation where CA can help optimize irrigation system management to conserve water, energy and soil quality, reduce salinity problems and to make fertilizer use more efficient.

At the landscape level, CA enables several environmental services to be harnessed at a larger scale, particularly C sequestration, cleaner water resources, drastically reduced erosion and run-off, and with this, flooding, as well as enhanced biodiversity. All this not only bring benefits for the farmer as production resources are saved, but also brings direct economic benefits for society, as treatment costs for drinking water are reduced and damages to infrastructure from flooding or sedimentation are avoided. Overall, CA as an alternative paradigm for sustainable production offers many benefits to producers, the economy, consumers and the environment that cannot be obtained from tillage agriculture. With CA, production intensity becomes a matter of output rather than inputs. So, CA is not only climate-smart, but smart in many other ways.

Globally, the total CA area is still relatively small compared to the total arable land areas using tillage. Yet this is changing, and the spread of CA worldwide appears to have been expanding at the rate of 10.5 M ha per annum since 2008/09. It is expected that large areas of agricultural land in Asia, Africa, Europe and Central America will increasingly be transformed by CA in the coming decades as can already be seen in Kazakhstan, India, Pakistan, China, South Africa, Zimbabwe, Zambia, Malawi, Morocco, Spain, Italy, France and the United Kingdom. This is because, in the last two decades, the adoption of CA has been important to farmers themselves, to governments, donor agencies, international technical assistance-agencies, NGOs and Foundations and service sectors. In some countries, such as the United States, Canada, Australia, Brazil, Argentina, Paraguay and Uruguay, it appears that CA is being 'mainstreamed' in agricultural development programmes. But only a few countries such as Canada, Switzerland, Italy, Spain, Kazakhstan, China, Zambia, Zimbabwe, Mozambique, Malawi and South Africa *emphasize* its importance. This will change. CA is the future of sustainable agriculture and land use upon which food systems and supply chains will increasingly rely upon to meet national and international food security and environmental service needs, requiring support from all stakeholders in public, private and civil sectors.

The crucial role of the national and international corporate institutions and private business sector is to ensure that CA machinery and equipment, fertilizer and pesticide (against insect pests, weeds and diseases), particularly low-risk herbicides, are available to the farmers through government-assisted programmes, as appropriate. It is in the interest of everyone if the farmers involved in CA adoption were part of a CA-based producer organization.

At the same time, national and international knowledge systems must increasingly align their work in research, education and extension to helping to promote CA systems and practices. Research in particular must help to solve farmer and policy constraints to CA adoption and spread. It would not be out of place to suggest that it would be considered negligent if the stakeholders (including politicians, policy makers, institutional leaders, research scientists, schools, universities and academics, extension agents, private sector) who carry the responsibility of transforming the tillage-based agriculture into CA practices do not earnestly align and support the national and regional agricultural innovation systems towards this goal. In fact, every country in the world must begin to set target for change towards CA and use all available means and processes to set the transformation in motion, thereby securing significant economic, socioeconomic and environmental benefits for the farmers and for the population at large in the world. People and institutions, both public and private sector, everywhere have everything to gain from adopting CA as a basis for sustainable agricultural intensification and ecosystem management. The greater impact that can result from the adoption of CA as a matter of policy and good stewardship is that agriculture development in the future everywhere will become part of the solution of addressing national, regional and global challenges including resource degradation, land and water scarcity, climate change.

CA practices offer a new way of effectively and efficiently managing agricultural environments and the natural resource base for multifunctional services to the society. As full benefits of CA take several years to fully manifest themselves, fostering a dynamic CA sector requires an array of enabling policy and institutional support over a longer-term time horizon. This will allow farmers to take advantage of the future carbon and water markets and support for environmental services currently under discussion internationally. As with climate change, any delayed or missed action now might lead to an Earth where lands are desertified and soils become unproductive, and food security for mankind is no longer secured.

It is perfectly feasible to meet food security needs globally at lower economic and environmental costs through CA systems linked to energy-efficient equipment technologies, precision farming and VRT, other remote sensing technologies and autonomous machines working alone or in swarms, as well as controlled traffic farming. The transformation to such systems will require effective political will and commitment backed by active support from the farming industry, including the farm machinery sector, which are currently inadequate in most regions.

Acronyms

AAPRESID	Argentinean Association of No-till Farmers - Asociación Argentina de Productores en Siembra Directa
ACSAD	Arab Centre for the Studies of Arid Zones and Dry Lands
ACT	African Conservation Tillage Network
AfDB	African Development Bank
ANAPO	Association of Oilcrop and Wheat Producers - Asociación de Productores de Oleaginosas y Trigo
APAD	French No-till Farmers Association - Association pour la Promotion d'une Agriculture Durable
AU-NEPAD	African Union – New Partnership for Africa's Development
AUSID	Uruguayan No-till Farmers Association – Asociación Uruguaya de Siembra Directa
CA	Conservation Agriculture
CAAPAS	American Confederation of Associations for Sustaniable Agriculture - Confederación Americana de Asociaciones para la Agricultura Sostenible
CAP	Common Agricultural Policy
CENAPRO	Nacional Center for Productivity - Centro Nacional de Productividad
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture - Centro Internacional de Agricultura Tropical
CIRAD	Centre for Cooperation on International Research on Agricultural Development – Centre de coopération internationale en recherche agronomique pour le développement
CIMMYT	International Maize and Wheat Improvement Centre - Centro Internacional de Mejoramiento de Maíz y Trigo
COP	Conference of Parties
CWANA	Central and West Asia and North Africa
DIFD	Department for International Development
DMC	Direct Seeded Mulch-Based Cropping System
EC	European Commission
ECAF	European Conservation Agriculture Federation
EU	European Union
FAO	United Nations Food and Agriculture Organization
FARA	Forum for Agricultural Research in Africa
FEBRAPDP	Brazilian Federation for Direct Seeding into Straw – Federação Brasileira de Plantio Direto na Palha
FFS	Farmer Field Schools
GIZ	German International Cooperation

	– Deutsche Gesellschaft für Internationale Zusammenarbeit (former GTZ)
GTZ	German Technical Cooperation – Deutsche Gesellschaft für Technische Zusammenarbeit (now GIZ)
GFAR	Global Forum for Agricultural Research
FINCA	Finnish Conservation Agriculture Association
IAD	Institute for Sustainable Agriculture - Institute de l' Agriculture Durable
ICAR	Indian Council for Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICRAF	World AgroForestry Centre
ICRISAT	International Crops Research Institute for Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IITA	International Institute for Tropical Agriculture
INRA	French National Institute for Agricultural Research - Institut national de la recherche agronomique
IPEAME/ EMBRAPA	Brazilian Enterprise for Agricultural and Livestock Research - Empresa Brasileira de Pesquisa Agropecuária
IRRI	International Rice Research Insitute
ITCF	Institute for Cereal and Forage Technology - Institut Technique des Céréales et des Fourrages
IWMI	International Water Management Institute
MSSRF	M.S. Swaminathan Research Foundation
NGO	Non-Government Organization
NRI	Natural Resources Institute, Greenwich
RCM	Mediterranean Agro-Systems Innovation Network - Réseau Innovations Agro-Systèmes Méditerranéens
RELACO	Latin American Network for Conservation Tillage/Agriculture – Red Latino Americana de Labranza/Agricultura de Conservación
SAMA	Sustainable Agricultural Mechanization for Africa
SDG	Sustainable Development Goal
SEI	Stockholm Environment Institute
TAA	Tropical Agricultural Association
UK	United Kingdom
USA	United States of America
VRT	Variable Rate Technologies
WANA	West Asia and North Africa

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