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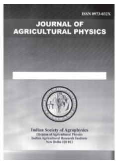

Research Article

Mobilizing Greater Crop and Land Potentials with Conservation Agriculture§

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ABSTRACT

The engine that supplies food and agricultural products is the way we farm. The current dominant engine of conventional tillage farming based on the Green Revolution agriculture mind-set is faltering and needs to be replaced to meet the Sustainable Development Goals (SDGs) and the future food and agricultural demands by consumers and society. This chapter elaborates on the alternate no-till Conservation Agriculture (CA) paradigm (involving no-till seeding in soils with mulch cover and in diversified cropping systems). This new paradigm of CA is able to raise productivity sustainably and efficiently, reduce inputs, regenerate degraded land, minimize soil erosion, and harness the flow of ecosystem services. CA is an ecosystems approach to regenerative farming which is capable of enhancing the economic and environmental performance of crop production and land management that can contribute to achieving several SDGs. The new CA paradigm also promotes a mind-set change of producing 'more from less' inputs, the key attitude needed to move towards sustainable production based on agro-ecological intensification of output. CA is spreading globally in all continents at an annual rate of around 10 M ha of cropland. The current (in 2015/16) spread of CA is approximately 180 M ha, of which 48% is located in the Global South. CA not only provides the possibility of increased crop yields and profit for the low input smallholder farmer, it also provides a pro-poor rural and agricultural development model to support sustainable agricultural intensification in low income countries in an affordable manner for poverty alleviation, food security and economic development. However, for SDGs to contribute real lasting value to the quality of human life and to nature, the current and future human and ethical consequences of the uncontrolled consumer demands and pressures placed upon agricultural production by the food and agriculture system as a whole must be addressed.

Key words: tillage agriculture, no-till, sustainable intensification, pro-poor development, smallholder farmer

Introduction

The ability of agriculture to meet future demand is generally analysed by mainstream scientists and policy analysts in terms of available resources and production inputs to supply the required level of agricultural products. Similarly, production systems are commonly assessed on the efficiency and effectiveness of different combinations of inputs, technologies and/or practices to produce certain agricultural outputs. Despite the continuous attention to ensure that

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§An extended abstract of an earlier version of this paper was published in the Hungarian Geographical Bulletin 66 (1): 3-11 (Kassam *et al*., 2017a) advances in agriculture are based on science, technology and innovation (STI), it is only relatively recently that analyses have begun to address externalities of production systems, such as: environmental damage; the associated input factor inefficiencies and sub-optimal yield ceilings; losses in agroecological production potentials due to land degradation; and poor resilience against major external biotic and abiotic challenges (Brisson *et al*., 2010; FAO, 2011, 2016; Li *et al*., 2016; Nkonya *et al*., 2016; Vlek *et al*., 2017; Gonzalez-Sanchez *et al*., 2017; 2018). However, relatively rarely do mainstream researchers question the actual agricultural paradigm itself (characterised here as conventional tillage agriculture) in terms of its continuing ecological appropriateness for the sustainable development agenda and for the environmental and land degradation challenges faced by agriculture and societies globally. Equally, the delivery of supportive, regulatory, provisioning and cultural ecosystem services to society by conventional tillage agriculture has not been an area of serious mainstream research concern (MEA 2005; Beddington, 2011; Lal and Stewart, 2013; Kassam *et al*., 2013; Palm *et al*., 2014). Of even greater longer-term concern is the fact that much of the mainstream agricultural education globally continues to promote STI and knowledge to support conventional tillage agriculture – the current dominant agricultural paradigm - which represents 'business as usual'.

Thus in general, mainstream approaches to agricultural assessments are simplistic, conservative and limited in scope. As a result they are unable to identify and address the root causes of the damage caused to land resources, the environment and human health by the current dominant agricultural paradigm. Such assessments are also decoupled from the human and ethical consequences of the demands and pressures placed upon agricultural production by the food and agriculture system as a whole, including consumer demand, diets, industry, government and the economy.

A number of the Sustainable Development Goals (SDGs) require greater crop and land potentials to be mobilised to produce food and other agricultural products. However, if this is to be done in a truly sustainable way, we must certainly ask: how economically, environmentally and socially appropriate and sustainable is the current production paradigm of tillage agriculture for meeting the SDGs[§§] related to food and agriculture, the management of natural resources and the environment? Equally, we must also consider how the SDGs can be met ethically, giving adequate attention to concerns of human health, equity, food justice and human and animal rights.

This chapter illustrates and discusses the inherent destructive and inefficient nature of the conventional tillage agriculture paradigm and therefore its inability to contribute sustainably and meaningfully to the SDGs. In particular it highlights the role of conventional tillage agriculture in causing soil, landscape and agroecological degradation, and its consequent inability to function optimally at maximum output with maximum efficiency and resilience at any level of agricultural and economic development, and to adequately deliver ecosystem societal services. The chapter elaborates the alternate production paradigm of Conservation Agriculture (CA) which can support sustainable production intensification to meet future food and agricultural needs (Kassam *et al*., 2009, 2013). It also describes how greater crop and land productivity potentials are being mobilized under CA which has been spreading rapidly in all continents, particularly since the 1990s (Goddard *et al*., 2007; Friedrich *et al*., 2013; Jat *et al*., 2014; Farooq and Siddique, 2015; Kassam *et al*., 2013, 2015, 2016, 2017b). It is beyond the scope of this chapter to address the ethical issues related to sustainability noted above. However, CA's ability

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[§§] The SDGs that are more directly relevant to this chapter are: SDG 1 (no poverty), 2 (zero hunger), 6 (water), 7 (energy), 8 (economic growth and employment), 12 (sustainable consumption and production), 13 (climate action), 14 (marine resources) and 15 (terrestrial ecosystems), although it is realized that all SDGs are interconnected.

to reduce inputs and increase outputs getting 'more for less' and thus provide a truly pro-poor solution for poor farmers, unlike the current paradigm, is most certainly an issue of ethics. As is the ability of CA to minimize land degradation, regenerate agroecosystem functions and sustainably deliver societal services for all communities.

The 'Hidden' Reality and Societal Cost of Conventional Tillage Agriculture

Conventional tillage agriculture

Conventional tillage-based production systems are often referred to as the Green Revolution agriculture paradigm. Particularly since WWII, these systems have led to a paradigm for production intensification that is based on the intensification of tillage and the notion that more output can only come from applying more purchased inputs, especially of modern seeds, agrochemicals (for crop nutrition and protection) and water. Conventional tillage-based systems have generally become unsustainable due to the degradation they cause (Montgomery, 2007; Kassam *et al*., 2013). This degradation includes loss of agricultural land, productivity and ecosystem and societal services (Montgomery 2007; Goddard *et al*., 2007; Kassam *et al*., 2009, 2013; Lindwall and Sontag, 2010; Basch *et al*., 2012; Jat *et al*., 2014; Farooq and Siddique, 2015). Yet, agricultural STI that continues to be supported by most governments and institutions deals mainly with tillage agriculture. However, the situation is changing and increased attention is being directed toward generating and applying STI for CA (Kassam *et al*., 2013, 2018).

The Green Revolution approach does not seem to be going anywhere now, even in nations such as India and Pakistan where it is claimed to have made a special impact in the 60's and the 70's. For example, it is often stated that countries in Asia were the first to benefit from the Green Revolution paradigm, but the question that arises is why did the Green Revolution not continue to spread across India and Pakistan, or across Asia to benefit more and more smallholder farmers? (FAO, 2011, 2016). In fact, the conventional 'modern' approach to crop production intensification, based on expensive inputs of intensive tillage, modern seeds, high agrochemicals and energy, and the STI that accompanies it, is often not affordable by resource-poor smallholder farmers.

The input intensive Green Revolution mind-set also includes the indoctrination and creation of a certain behavioural culture in agri-*culture.* This culture suggests that farmers and their service providers and governments do not need to worry about the negative externalities that arise from the production practices being applied (Pretty, 2002; Beddington, 2011). The approach does not even call for an understanding by producers, dealers and their extension advisors, of the key ecological elements, functions and processes in the agroecosystem that should be managed and sustained to serve as the ecological foundation of sustainable production intensification (Kassam *et al*., 2009, 2013). In addition, the science and technology related to intensification under the Green Revolution paradigm has led to the application of economic models such as commodity specialization leading to extended monocropping (Pretty, 2002).

Thus, the question of how the ecological foundation of agriculture should be managed to enhance and deliver both the desired output and ecosystem services[§§§] to society, while performing

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[§§§] Ecosystem services are provided to society by nature. Such services include edible and nonedible biological products, clean drinking water, processes that decompose and transform organic matter, and cleansing processes that maintain air quality. Several categories of ecosystem services are recognized: provisioning, regulating, cultural, and supporting (Millennium Ecosystem Assessment - MEA, 2005). In agricultural land-scapes, provisioning ecosystem services can be delivered effectively and efficiently when the linked regulatory and supporting services are allowed to operate normally. Ecosystem functions that protect and enhance regulatory and supporting ecosystem services in the soil and landscape in which crops are grown appear, in general, to offer an effective way of harnessing the best productivity, ecological, and economic performances (Kassam *et al*., 2013).

at the highest possible levels of efficiency and resilience, including coping with the climate change, does not receive the attention it deserves. Nor is there any serious concern being expressed in the Green Revolution approach about agricultural land area continuing to be severely degraded and abandoned in the North and the South due to the negative impact of the conventional tillage-based production paradigm (Khonya *et al*., 2016; Vlek *et al*., 2017). Indeed, many areas which in human history were the cradle of culture and intensive tillage-based agriculture are deserts today (Montgomery, 2007).

Underestimation of land resources needed to meet future food and agriculture demand

Based on their Global Agro-ecological Zones (AEZ) assessment of available land and water resources, and crop and land potentials (FAO/IIASA, 2002; FAO, 2003, 2012a), FAO and their collaborators have maintained that it should be possible to meet 2050 global food, feed, biofuel demand (including wastage) within realistic rates for land and water use expansion and yield development (FAO, 2014). The quantities of yield and total output supply of food required to support the food demand at 2050 also appear agronomically doable. However, the reality on the ground on farms and landscapes tells a very different story. Various reports state that between 7 and 12 million hectares of agricultural land are lost or abandoned every year due to land degradation. We believe this area includes 0.4 to 0.5 billion hectares of agricultural cropland that was once suitable but has been degraded and abandoned over the years (Dregne and Chou, 1992; Pimentel *et al*., 1995; Montgomery, 2007; Gibbs and Salmon, 2015), particularly since WWII. This abandonment is due to the severe degradation and erosion arising from tillage-based agriculture systems, and the STI that support them, in both industrialized and less industrialized countries (Montgomery, 2007). A recent study puts the annual global cost of land degradation due to land use and cover change at 300 billion USD (Khonya *et al*., 2016). Other reports indicate much higher costs, and in cases where priceless ecosystem services are lost, it is not possible to put a cost value (Juniper, 2013).

The reason the FAO's future projections do not fully match the reality on the ground is because the AEZ crop and land suitability assessments on which they are based, assume the continued use of the tillage-based agricultural production systems (FAO 1978-81, 2003, 2012a, 2014; FAO/IIASA, 1982, 2002) without taking into account the resulting land degradation and loss of crop and land productivity. Land degradation will continue to occur in the future with tillage-based agriculture, leading to loss in land's agro-ecological potential, actual productivity and output, marginalization and abandonment, and desertification.

Thus, the current categories of 'marginally suitable cropland' and 'not suitable land' estimated in the FAO AEZ assessments include much of the degraded and abandoned agricultural land which originally would have been included in the agro-ecologically 'suitable' cropland categories. As a result, FAO's estimate of net agricultural land under crop production can appear to stay the same while in reality every year a certain amount of the cropland under use is being abandoned and replaced by a similar amount of new cropland.

Additionally, it is assumed that yield gaps can continue to be filled based on the current practice of intensive tillage-based soil management and increased application of costly and excessive production inputs, assuming the same or even higher production increase rates than in the past. In other words, the current agricultural paradigm incorrectly assumed to meet future food demand in the future scenarios of FAO and of their collaborators, is in reality the land degrading and land destroying 'business as usual'. This in turn contributes to maintaining the 'status quo' mind-set in politics and STI. This 'more of the same' approach to intensification and maintenance of sub-optimal yields, factor productivities and overall performance can no longer be considered to be economically, environmentally, socially or developmentally sustainable anywhere; not in industrialized nations nor in emerging economies (Montgomery, 2007; Beddington, 2011; Gibbs and Salmon, 2015; Khonya *et al*., 2016). In low-income countries, tillage agriculture based on the

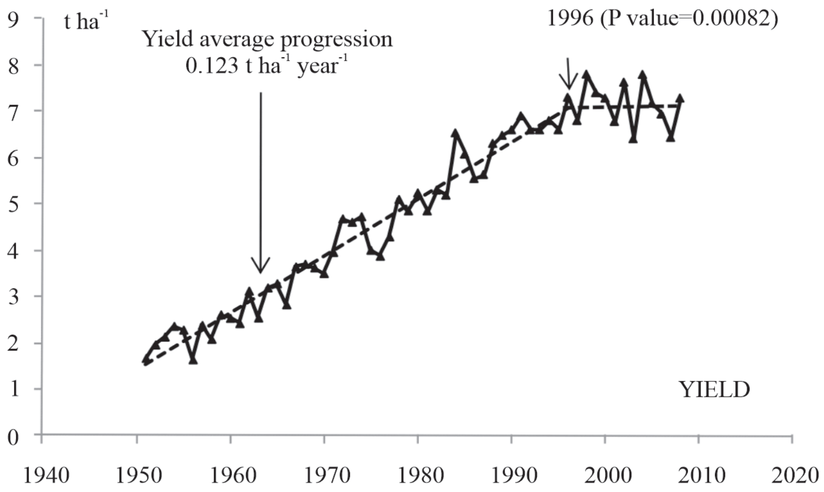

Fig. 1. Rising-plateau regression analysis of wheat yields throughout various European countries (Brisson *et al*., 2010)

use of hoes and animal traction to pull simple ploughs and tillage equipment also leads to land degradation and loss of top soil and soil functions, to the point where land is eventually abandoned. Often, the lack of mineral fertilizers and fertility enhancing and soil health promoting cropping systems accelerates the loss in crop and land productivity (Montgomery, 2007; Gibbs and Salmon, 2015; Khonya *et al*., 2016).

Further, in many important high yielding production areas, crop yields have reached sub-optimal ceilings. For example, national level yields of wheat crops appear to have stagnated at about 7 t ha^{-1} since around 1996 across several countries in Europe (Fig. 1) with inputs and input costs going up, and diminishing returns setting in (Brisson *et al*., 2010). In some countries in Europe such as Switzerland and Spain, wheat yields seem to have stagnated over 25 years ago (Table 1).

Structural unsustainability

As indicated earlier, 0.4-0.5 billion ha of agricultural lands are reported to have been abandoned since WWII due to severe soil and land degradation, and loss of biodiversity and resilience. Yields of staple cereals in industrialized and less-industrialized regions appear to have stagnated under tillage agriculture (Kassam *et al*., 2009, 2013, 2017b; Montgomery, 2007; Brisson *et al*., 2010; Jat *et al*., 2014; Farooq and Siddique, 2014; Gibbs and Salmon, 2015). These are signs of unsustainability and the institutionalization of the supporting systems of agricultural research to generate new technology and knowledge. Thus it is at the structural level, for both the supply and demand sides of food and agricultural security, that we need transformed mind-sets about: production, consumption and distribution; and policies and institutional capacities for STI to support an alternative agricultural paradigm described in the next section.

What is surprising though is that agricultural land degradation continues unabated despite the fact that there are several UN treaties and

Table 1. Year of stagnation in wheat yields in countries in Europe (Brisson *et al.* 2010)

Country	Year of stagnation
Denmark	1995 (**)
France	1996 (**)
Germany	1999
Italy	1994
Netherlands	1993 (**)
Spain	1989
Switzerland	1990 (**)
United Kingdom	1996 (**)

Year of stagnation ** very significant P<0.01 no star P>0.05

programmes that are supposed to address the problem (e.g. UN Programme on Combating Land Degradation and Desertification; UN Convention on Biodiversity). Some of them have been ongoing since 1992, after the Rio Earth Summit. However, as has been pointed out by Montgomery (2007), conventional tillage-based agriculture globally, and the STI system that maintains it, is the main driver of agricultural land degradation. This is not being addressed at the practical land management level for farmers and land managers by any of these treaties and programme.

Conventional tillage-based practices have all contributed to more soil and land degradation, decreased infiltration and water logging (Photo 1), runoff and erosion (Photo 2), water pollution, and vulnerability of agriculture to extreme climatic events. At all levels of agricultural and economic development they have resulted in loss of agricultural land, decrease in attainable yields and in input factor productivity (Montgomery, 2007). They have also contributed to excessive use of seeds, agrochemicals, water, energy and labour, all leading to increased cost of production. They have led to poor production system resilience, dysfunctional agroecosystems, degraded ecosystem services to society, including lower water quality and quantity, poor nutrient and carbon cycling, suboptimal water, nutrient and carbon provisioning and regulatory water services, and loss of soil and landscape biodiversity. They all constitute the high real cost of food production, of agricultural products for industry, and of environmental management being passed on to the general public, and to future generations (Kassam *et al*., 2009; 2013)..

Photo 1. Soil compaction and loss in water infiltration ability caused by regular soil tillage leads to impeded drainage and flooding after a thunder storm in the ploughed field (right) and no flooding in the no-till field (left). Photograph taken in June 2004 in a plot from a long-term field trial "Oberacker" at Zollikofen close to Berne, Switzerland, started in 1994 by SWISS NO-TILL. The three water filled "cavities" in the no-till field derive from soil samples taken for "spade tests" prior to the thunder storm. *Source*: Wolfgang Sturny

Photo 2. Erosion and runoff on conventionally tilled bare soil near Cordoba, Spain. Source: Emilio Gonzalez

Thus, if we are to: (i) mobilize greater crop and land productivity potentials sustainably to meet future food, agriculture and environmental demands; (ii) maintain the highest levels of productivity, efficiency and resilience (getting 'more from less' inputs); and (iii) rehabilitate degraded and abandoned agricultural land and ecosystem services, to meet the SDGs, we would need to replace the faltering production 'engine' of the conventional tillage-based production paradigm. We need to transform all the components of the food and agriculture systems, including the supporting STI that are built upon it. This transformation is now ongoing and needs to be accelerated (Goddard *et al*., 2007; Kassam *et al*., 2009, 2013, 2015, 2017b, 2018; Lindwall and Sonntag, 2010; FAO, 2011, 2016; Jat *et al*., 2014; Farooq and Siddique, 2015).

The following sections elaborate on an alternative agricultural paradigm and the supporting STI that can be applied to: minimize and reverse the agricultural soil and landscape degradation trends; and mobilize greater agricultural land potentials in support of the SDGs.

Replacing the Faltering Conventional Tillage-based Production Engine with No-Till Conservation Agriculture

Soil's productive capacity is derived from its many components (including physical, biological, chemical, hydrological, climate, cropping system, management, development level) all of which interact dynamically in space and time within cropping systems and within agroecological and socio-economic environments. A productive soil is a living biological system and its health and productivity depends on managing it as a complex biological system, not as a geological entity.

As FAO's 'Save and Grow' approach shows (FAO, 2011, 2016), to harness the conditions that are sufficient for achieving sustainable production intensification, agriculture must literally return to its roots and rediscover the importance of healthy soils, landscapes and ecosystems. At the same time it must conserve resources, enhance natural capital and the flow of ecosystem and societal services at all levels – field, farm, community, landscape, territory and national (and beyond). The no-till agricultural production paradigm, known as Conservation Agriculture (CA), is totally compatible with the above multi-dimensional goal.

The Principles of Conservation Agriculture

CA refers to the practical application of the following three interlinked principles, along with complementary good agricultural practices of crop and production management, namely (Kassam *et al*., 2018 (www.fao.org/ag/ca):

a) **Continuous no or minimum mechanical soil disturbance:** implemented by the practice of no-till weeding and seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic. Sowings seed or planting crops directly into untilled soil: reduces erosion; reduces the loss of soil organic matter and disruptive mechanical cutting and smearing of pressure faces; promotes soil microbiological processes; protects soil structure and connected pores; avoids impairing movement of gasses and water through the soil; and promotes overall soil health.

b) **Maintaining a permanent mulch cover on the soil surface:** implemented by retaining crop biomass, root stocks and stubbles and biomass from cover crops and other sources of biomass from ex-situ sources.**.** Use of crop residues (including stubbles) and cover crops: reduces soil erosion; protects the soil surface; conserves water and nutrients; supplies organic matter and carbon to the soil system; promotes soil microbiological activity to enhance and maintain soil health including structure and aggregate stability (resulting from glomalin production by mycorrhiza); and contributes to integrated weed, pest and nutrient management.

c) **Diversification of species:** implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops and cover crops. Use of diversified cropping systems: contributes to diversity in rooting morphology and root compositions; enhances microbiological activity; enhances crop nutrition and crop protection through the suppression of pathogens, diseases, insect pests and weeds; and builds up soil organic matter. Crops can include annuals, short-term perennials, trees, shrubs, nitrogen-fixing legumes and pastures, as appropriate.

The STI mind-set that is driving the CA community of practice defines CA as an ecosystem approach to regenerative sustainable agriculture and land management. CA 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 and Minimum Tillage are not CA, nor is No-Till on its own (Derpsch *et al*. 2014). A practice such as No-Till can only be referred to as being a CA practice if it is part of an actual CA system as per the above definition, Similarly for soil mulch practice and crop diversification practice, both of which can only be considered to be CA practices if they are part of a CA system based on the application of the three interlinked principles.

Benefits of Conservation Agriculture and their Potential Contribution to the SDGs

CA not only offers entirely appropriate solutions to the challenges described above, it also has the potential to slow or reverse productivity losses and environmental damages. Transforming a tillage-based production system to a CA-based system is a time related biological process. When implemented correctly, CA offers a range of benefits that correspond to the mobilization of greater crop and land potentials, and actual crop and land performance. The intensity and range of benefits generally increase over time as new and healthier soil productivity equilibrium, including a fuller range of soil functions and soil-mediated ecosystem services, is established. Key benefits of CA and their potential contribution to specific SDGs are presented below.

a) Increased productivity and profit

Benefits

CA increases yields, factor productivity, farm production and profit depending on the level of initial degradation and yield, and the agro-ecological potential of the location (ECAF, 2011; Soane *et al*., 2012; Jat *et al*., 2014; Farooq and Siddique, 2015; Li *et al*., 2016; Kassam *et al*., 2013, 2017b).

These benefits directly contribute to: reducing income poverty; improving food security and reduce malnutrition; reducing vulnerability to extreme events; and economic growth and employment.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6) and
- 12 (12.2, 12.4, 12.6, 12.a).

b) Improved soil health

Benefits

CA can decrease fertilizer use by 50% or more if already applying higher rates, and improve nutrient productivity with increased soil organic matter level. In cases where mineral fertilizers are not available, integrated nutrient management can provide the required nutrition from local sources (Carvalho *et al*., 2010; Sims and Kassam, 2015; Lalani *et al*., 2016, 2017; Kassam *et al*., 2017b).

These benefits can contribute to: reducing income poverty; improving food security and reducing malnutrition; efficient use of natural resources; climate change mitigation by reducing energy use in manufacturing of fertilizers; reducing N_2O emissions; reducing nutrient pollution of sea water and inland fresh water systems; and increasing soil biodiversity

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

c) Reduced or minimized use of pesticides and herbicides

Benefits

CA can decrease pesticides and herbicide use by 20-50% if already applying higher rates, and increase output per unit of pesticide or herbicide. In cases where pesticides and herbicides are not used or available, integrated weed and pest management can achieve adequate pest and weed control with less labour requirements (Lindwall and Sonntag, 2010; Sims and Kassam, 2015; Lalani *et al*., 2016, 2017; Kassam *et al*., 2017b; Sims *et al*., 2018).

These benefits can contribute to: improving income poverty and food security; sustainable production; climate change mitigation; and reducing pollution of sea water and inland fresh water systems.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

d) Reduced machinery, energy and labour costs

Benefits

CA can reduce machinery, energy and labour costs, and time requirement by 70%. In manual production systems there can be a 50% reduction in family labour requirement as there is much less labour required for seedbed preparation and weeding (Freixial and Carvalho, 2010; Kassam *et al*., 2013; Sims and Kassam, 2015) (Table 2).

These benefits can contribute to: reducing income poverty and food security; sustainable production, climate change mitigation, and promoting economic growth and employment through greater participation from smallholders, youth, service providers and innovative manufacturing industries.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 7 (7.3)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6)
- 12 (12.2, 12.4, 12.6, 12.a) and
- 13 (13.1, 13.2, 13.3).

Table 2. Summary of annual expenses for maintenance and repair of tractors and of tillage/drilling implements, for fuel and labour for a farm near Évora, South Portugal. Farm power – 4 tractors with 384 HP under tillage and 2 tractors with 143 HP under no-till. (Freixial and Carvalho, 2010)

	Conventional Tillage (Year 2000)	No-Till (Year 2003)	Reduction (%)
Maintenance andrepair of tractors	10.450,47 •	1.507,15 •	85
Maintenance andrepair of tillage/drilling implements	8.158,41 •	1.840,40 •	77,5
Fuel	17.460 •	7.110 •	60
Labour	25.000 •	15.000 •	40
Total Annual	61.068,88 •	18.347,55 •	70

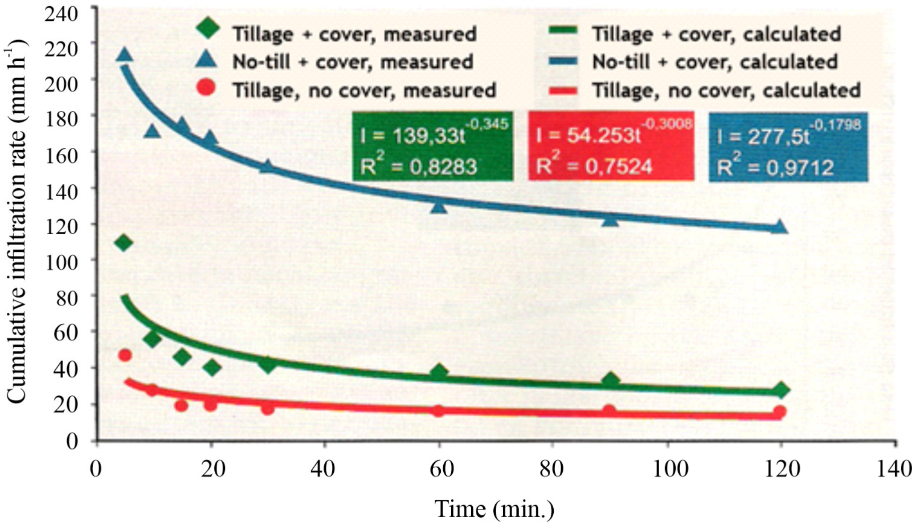

Fig. 2. Gains in rainfall infiltration rates with CA (Landers, 2007)

e) Decreased soil erosion and water runoff

Benefits

CA decreases soil erosion and water runoff (Derpsch, 2003), increases water infiltration (Fig. 2) and retention (Fig. 3). It can reduce water requirement by up to 40% and increase water productivity in rainfed and irrigated conditions (FAO, 2011, 2016; Basch *et al*., 2012; Kassam *et al*., 2013; Jat *et al*., 2014; Reicosky, 2015; Nkonya *et al*., 2016; Vlek *et al*., 2017).

Controlling soil erosion and water runoff will: improve soil health, nutrient and water retention and productivity; reduce land and ecosystem degradation; and enhance biodiversity. Reduced water requirement and increased water productivity will decrease water pollution, improve water quality and quantity and water use efficiency.

All of these benefits can contribute to: reducing income poverty and food security; sustainable production and climate change

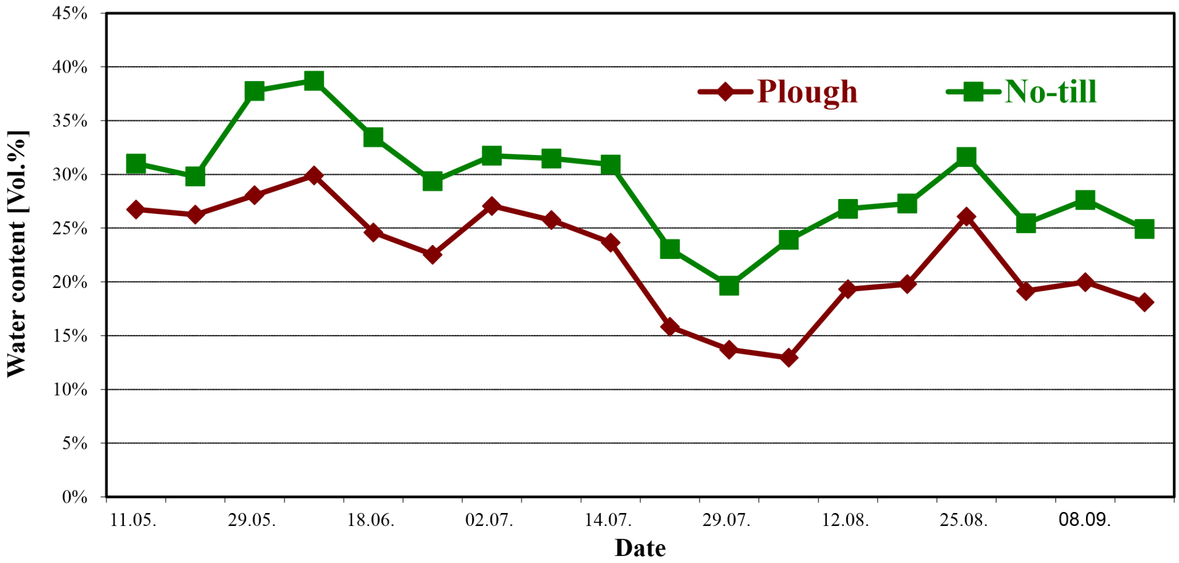

Fig. 3. Soil water content in 0-30 cm soil depth; average of 1998 and 1999 under maize (Derpsch, 2003)

adaptability; enhancing marine and fresh water resources; reducing ecosystem degradation; improving biodiversity; and regenerating ecosystems.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 6 (6.1, 6.3, 6.4, 6.5, 6.6, 6.b)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

f) Increased biomass for livestock

Benefits

Over time CA increases the biomass (along with greater yields) available for livestock as soil health improves, thus decreasing the initial ‘conflict situation’ and opening up the possibility of increased livestock carrying capacity and stocking rates (Landers, 2007, FAO, 2009; 2012b, 2013; Owenya *et al*., 2011, Lalani *et al*., 2018).

These benefits can contribute to: decreasing income poverty and improving food and nutrition security; sustainable production; reducing land degradation; regenerating ecosystems; and promoting economic growth and employment through greater participation from smallholders, youth, service providers and innovative manufacturing industries.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6)
- 12 (12.2, 12.4, 12.6, 12.a) and
- 15 (15.1, 15.5).

However it is important to note that promotion of livestock production is not a necessary component of sustainable agriculture, nor is it a core element of responsible and sustainable production and consumption, given the impact on climate change, human health and the wellbeing of animals.

Arguments for livestock contributing to sustainable production rest on recycling of nutrients leading to better plant nutrition. However, this can be achieved effectively in CA systems without livestock because CA promotes:

(a) the enhancement of soil health through biomass retention, incorporation of biomass and exudates into the soil by its root system and by mesofauna such as earthworms, which also add nitrogen from the atmosphere through the nitrogen fixing bacteria living in its gut, and

(b) the transformation of biomass into humus by microorganisms. Humus comprises organic forms of plant nutrients that are retained and made available to plants. In addition, soil micro- and macro-aggregate stability is achieved through the action of mycorrhizae through the production of glomalin.

Thus, CA is capable of nutrient and carbon cycling without any need of livestock. The environmental impacts of animal agriculture, including the high land and water requirements, have been widely reported, as have the human health impact of meat-based diets. Grain-based livestock feed formulations compete directly with food security based predominantly on plant-based diets. Thus the role of livestock in meeting the SDGs will remain a controversial issue given that millions of people live healthy lives on plant-based diets, and millions of hectares of agricultural lands are managed sustainably without any livestock.

g) Greater adaptability to climate change

Benefits

CA contributes to greater adaptability to climate change in terms of higher and more stable yields, lower impact of climate variability on ecosystem functions and services, reduced incidence droughts, heat stress, waterlogging and floods, less damage to infrastructure such as roads, bridges and communication, navigation, dams and reservoirs.

Thus, CA lowers the environmental cost to society due to decreased levels of water pollution, and decreased damage to infrastructure, riverbanks and water bodies due to reduced erosion and flooding (ANA, 2011; ITAIPU 2011; Mello and van Raij 2006; FAO, 2011, 2016; ECAF, 2011; Thierfelder *et al*., 2015; Kassam *et al*., 2013, 2017b; Nkonya *et al*., 2016; Vlek *et al*., 2017; Gonzalez-Sanchez *et al*., 2017, 2018).

CA is considered to be the best core component of climate-smart agriculture because it can contribute to: sustainable food security, livelihoods and agricultural economic development; climate change adaptability; climate change mitigation. The adaptability benefits from CA contribute to: soil health and yield stability; improved yields; improved water cycling and soil water balance for agriculture; strengthens local, national and international climate actions on adaptability; sustainable production and development; quality of marine and fresh water resources; and regeneration of biodiversity and of degraded ecosystems. The adaptability benefits also include the promotion of economic growth and employment through greater participation from smallholders, youth, service providers and innovative manufacturing industries.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 6 (6.1, 6.3, 6.4, 6.5, 6.6, 6.b)
- 7 (7.2, 7.3, 7.a)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

h) Climate change mitigation

Benefits

CA increases the contribution of agriculture to climate change mitigation from enhanced soil carbon sequestration, reduced greenhouse gas emissions, and decreased use of fossil fuel (Haugen-Kozyra and Goddard, 2009). Additionally, CA lowers agriculture's carbon and environmental footprint due to the reduced use of manufactured inputs such as agrochemicals and machinery (Lal *et al*., 2007; ECAF 2011; Corsi *et al*., 2012; Gonzalez *et al*., 2012, 2017, 2018; Kassam *et al*., 2009, 2013).

The ability of CA to convert agricultural soils into sinks for carbon sequestration and storage is becoming increasingly known and research continues to provide evidence of how much carbon can be sequestered by CA in different agroecologies in different continents. All three core practices of CA contribute to carbon sequestration, as well as to lowering of greenhouse gas emissions. The former is due to greater amounts of biomass and root organic exudates being returned to the soil which builds soil health and productivity, thus contributing to reducing income poverty and food security. The latter is due to various reasons including lower use and application of inputs (such as fossil fuel and mineral nitrogen) per unit of biological output, and better soil drainage which lowers the emissions of CH_4 and N_2O, thus contributing to reducing income poverty and food security. Equally, it has been widely shown that emissions of all major greenhouse gases (CO_2, CH_4, N_2O) are decreased in CA systems (Gonzalez *et al*., 2012, 2017, 2018).

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 6 (6.1, 6.3, 6.4, 6.5, 6.6, 6.b)
- 7 (7.2, 7.3, 7.a)
- 12 (12.2, 12.4, 12.6, 12.a)

- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

i) Rehabilitation of degraded lands and ecosystem services

Benefits

CA contributes to the rehabilitation of degraded lands and ecosystem services from all agricultural land under use, as well as from abandoned agricultural land in which the eroded topsoil and the soil profile can be rebuilt (Kassam *et al*., 2013; Jat *et al*., 2014; 2017b).

Much of the agricultural lands worldwide is degraded and large areas have become marginal or abandoned. CA offers a method to enhance soil health and regenerate soil functions and productivity. There are examples of large-scale rehabilitation initiatives that have succeeded restoring degraded and even abandoned agricultural lands because of the adoption of CA systems such as in Brazil, Spain, China and Australia (Kassam *et al*., 2914).

Thus, such initiatives contribute to: reducing income poverty, improving food security, ecosystem services, sustainable production, natural resource management, reducing environmental and water pollution, improving biodiversity and degraded ecosystems. These improvements can make a major contribution to economic growth and employment including for youth. They can also encourage more smallholder farmers, land managers and service providers to invest into agriculture.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 6 (6.1, 6.3, 6.4, 6.5, 6.6, 6.b)
- 7 (7.2, 7.3, 7.a)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

j) Enhanced ecosystem services

Benefits

With CA there is greater opportunity for establishing large-scale, community-based, cross-sectorial ecosystem service programmes, such as the watershed services programme in the Parana Basin in Brazil and the carbon offset trading scheme in Alberta, Canada (Haugen-Kozyra and Goddard, 2009; Lindwall and Sonntag, 2010; ANA, 2011; ITAIPU 2011; Mello and van Raij 2006; Kassam *et al*., 2011, 2013).

The role of agriculture for society and for development has been going through a considerable change in recent decades. The conventional tillage agriculture based on the Green Revolution paradigm in the industrialised and low-income countries has led to large-scale degradation and pollution of ecosystems, especially since WWII. The conventional paradigm is not capable of sustainable production nor is it capable of delivering the full range of ecosystem services to the society at large. The future role of agriculture will be to be productive as well as to provide all the required ecosystem services. Only CA systems are capable of meeting such a goal. Two examples of how farmers and communities are benefiting from transforming the landscape through large-scale adoption of CA come from Brazil and Canada.

Benefits derived from CA have led to: sustainable agricultural land management; reduced income poverty; improved food security; enhanced natural resource management including energy, nutrient and water use efficiency; reduced degradation and water pollution; improved climate adaptability and mitigation; and improved economic growth and employment.

Contribution to SDGs

These benefits would contribute to meeting SDGs:

- 1 (1.1, 1.2, 1.5)
- 2 (2.1, 2.3, 2.4)
- 6 (6.1, 6.3, 6.4, 6.5, 6.6, 6.b)
- 7 (7.2, 7.3, 7.a)
- 8 (8.1. 8.2, 8.3, 8.4, 8.5, 8.6)
- 12 (12.2, 12.4, 12.6, 12.a)
- 13 (13.1, 13.2, 13.3)
- 14 (14.1) and
- 15 (15.1, 15.5).

Global Evidence of Benefits from Conservation Agriculture

Some academic researchers have argued that the benefits of CA have been overstated and that CA proponents have presented biased evidence regarding the superior performance of CA compared to conventional tillage agriculture (Giller *et al*., 2009, 2015; Gowing and Palmer, 2008; Powlson *et al*., 2011, 2014; Sumberg and Thompson, 2012; Pittlekow *et al*., 2014). These critiques have often originated from a lack of experience and understanding about what CA actually is at the practical level and what it takes to establish a CA system (Derpsch *et al*., 2014; Reicosky, 2015). As a result, some researchers have included mixed or undifferentiated data sets in their analyses in terms of varying lengths of time the CA systems under study have been operating for, in terms of cropping system complexity, as well as using data sets from systems that are not CA compliant or genuine CA (e.g. Powlson *et al*., 2011. 2014; Arslan *et al*., 2013; Pedzisa *et al*., 2015a, 2015b; Pittlekow *et al*., 2014; Panell *et al*., 2014). This has led to a number of studies and meta-analyses which have drawn erroneous conclusions about CA and its global potentials.

Empirical evidence from the millions of farmers who practice CA globally is unequivocal about the superior performance of CA and the large array of productivity, economic, environmental and social benefits CA offers. Equally relevant is the empirical evidence represented by the annual rate of uptake by farmers of CA globally which has been more than 10 M ha since 2008/09. This evidence indicates that challenges and constraints related to CA adoption are being overcome by farmers in different ways in different agroecologies and in different continents through their own organized efforts and STI support. In a few cases, government institutions have lent their support to farmers who have decided to move away from conventional tillage agriculture. The previous section presented evidence regarding the ability of CA to mobilize greater crop and land potentials. This evidence is further discussed in the following section along with empirical evidence from the farms that practice CA globally.

Scientific and empirical evidence

The above described benefits have now been documented on large and small farms in all major ecologies throughout the world (Goddard *et al*., 2007; Jat *et al*., 2015; Farooq and Siddique, 2015; Kassam *et al*., 2013, 2015, 2017b, 2018). Consequently, increasingly greater attention is being paid to support the adoption and up-scaling of CA by governments, international research and development organizations, national research and development bodies, NGOs and donors. They see CA as a viable option for sustainable production intensification and climate-smart production systems to support local and national food security, poverty alleviation, especially of smallholders, improve ecosystem services, reduce the cost of production and minimize land degradation (Jat *et al*., 2014; Farooq and Siddique, 2015; Kassam *et al*., 2013, 2015, 2017b, 2018).

A regularly tilled soil, whether with a hand hoe or with a plough, eventually collapses and becomes compacted, cloddy and self-sealing. Instead of having 50 to 60% pore volume (air space) as in a healthy undisturbed soil with 2% or more soil organic matter, most tilled soils with degraded soil structure and lower soil organic matter content (often less than 1%) have much lower volume of air space (10% to 30% when collapsed) (Shaxson, 2006). This is due to poor soil structure and aggregate stability and no significant network of functional macro and micro biopores. Of the 50 to 60% pore space in a healthy soil, some 50% of the pore volume can be filled with water, of which 60-75% can be considered as being available to the crop (between field capacity and wilting point) depending on soil texture, thus serving as a major buffer against climate variability (FAO, 2005; Shaxson, 2006).

On the other hand, a regularly tilled soil would not only hold much less water due to its low pore volume and poor aggregate stability, but it will also have a low infiltration rate, leading to much of the water being lost in runoff. For example, in southern Brazil, infiltration rates of more than 100 mm hr^{-1} were measured in untilled agricultural soils with mulch cover, whereas the conventional tilled soil had infiltration rates of around 20 mm hr^{-1} (Fig. 2, Landers, 2007). Also, due to tillage, the top soil is in a destructured or pulverised state with a surface that is self-sealing when dry or wet, thus serving as an obstruction to water flow into the soil causing much of the rainwater to runoff. Greater infiltration rates and moisture holding capacities in CA soils lead to better soil moisture content throughout the growing season (Fig. 3), which can often be longer by 3 to 5 weeks under CA soil management (Derpsch, 2003; FAO, 2008, 2009).

Scientific studies and empirical evidence worldwide have shown that the biology of the soil and all the biological processes along with the other chemical, hydrological and physical processes depend on soil organic matter content. The real secret of maintaining a healthy soil is to manage the carbon cycle properly, so that the soil organic matter content is always as high as possible, above 2%. To do this the soil should not be disturbed mechanically to minimize the decomposition of organic matter, and the soil surface should be protected with a permanent layer of organic mulch cover which also serves as a substrate for soil microorganisms and mesofauna (Kassam *et al*., 2013).

It has also been shown often that as soil organic matter increases, there is an improvement in crop nutrient response. In Portugal, it was shown by Carvalho *et al*. (2012) that with a soil under conventional tillage containing 1% soil organic matter it took 160 kg N ha^{-1} to produce 3 t ha^{-1} of wheat grain (Fig. 4). However when the same soil built up 2% soil organic matter through continuous CA, 3 t ha^{-1} yield was obtained with

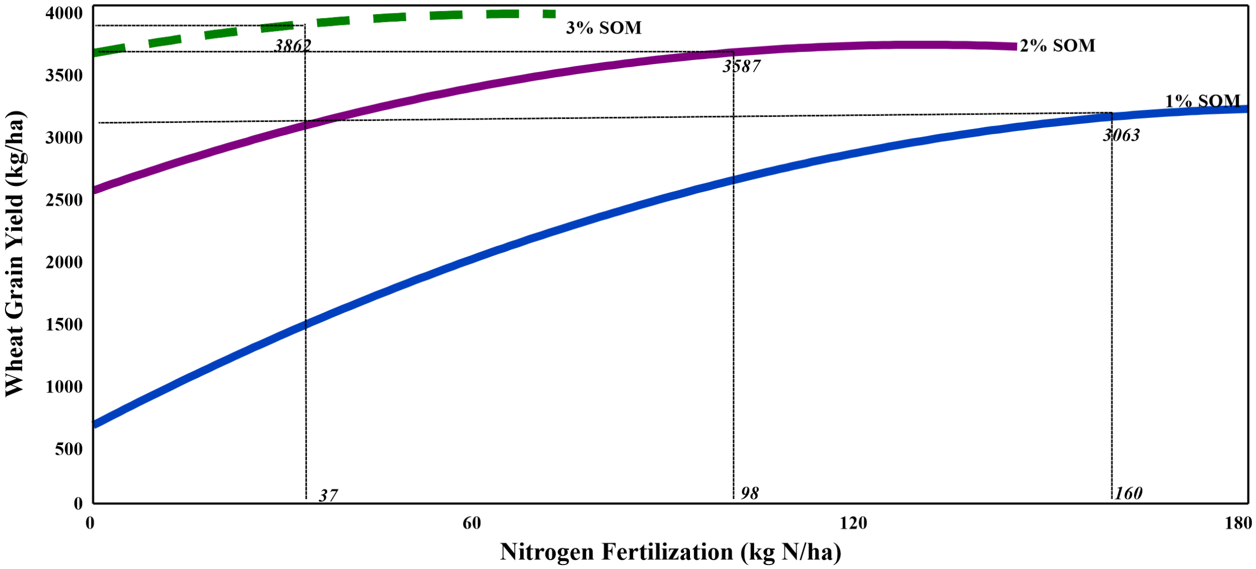

Fig. 4. Yield response to nitrogen fertilization in wheat in Portugal. Values in italic represent the economically optimal N-fertilization rate and the respective yield for the different levels of soil organic matter (SOM) (0-30 cm depth). The dashed green line is the modelled yield response for a SOM level of 3%. In Italic font is the most economic N-fertilization amounts and respective yields (Carvalho *et al*., 2012)

37 kg N ha^{-1}. A crop modelling exercise showed that at 3% soil organic matter content, a yield of 3.5 t ha^{-1} would be achieved without any application of N.

In addition, to maintain and support natural enemies of insect pests and pathogens, a food web must be allowed to establish itself in the fields, and this can only occur naturally if there is a source of decomposing organic matter on the ground surface, including cover crops, upon which to establish a food web, above and below the ground, and to provide habitats for the natural enemies of pests including some weeds (e.g. Hajek, 2004; Khan *et al*., 2016; Kassam *et al*., 2017b).

Evidence of the spread of Conservation Agriculture

The most convincing and solid evidence of the need to move away from conventional tillage agriculture to CA comes from the farmers around the world who have themselves been driving the process of adoption, uptake and innovation. This is despite the fact that relatively little attention and support from national governments and mainstream donors is being directed towards mainstreaming CA.

In 2015/16, the global spread of CA was about 180 M ha of annual cropland (12.5% of global annual cropland), and as mentioned above, since 2008/09 the global area under CA has expanded at an annual rate of over 10 million ha (Kassam *et al*., 2015, 2018). This means that the current area of CA cropland could be about 200 M ha or more. Approximately 50% of the CA area is located in low-income regions and about 50% in the industrialized regions. For historical reasons, the global distribution of CA is uneven because the initial impetus originated in North and South America. From there it has spread to all other continents, including in Asia, Africa and Europe, where considerable expansion in CA area is being recorded since 2008/09 (Jat *et al*. 2014; Kassam *et al*., 2103, 2017b; 2018). In addition, perennial cropping systems such as orchards and plantations in the North and the South are being transformed into CA systems in all continents.

Constraints and Enabling Conditions

Constraints on the adoption and spread of CA practices exist in many countries and have been discussed in the CA literature. (e.g. Gowing and Palmer, 2008; Friedrich and Kassam, 2009; Kassam *et al*., 2009, 2013, 2014a, 2014b; Giller *et al*., 2009, 2015; Powlson *et al*., 2011, 2014; Sumberg and Thompson, 2012; Pittlekow *et al*., 2014; Pannell *et al*., 2014; Kassam and Brammer, 2016).

As discussed in Friedrich and Kassam (2009), Kassam *et al*. (2014a, 2014b) and Kassam and Brammer (2016), the primary constraint to the adoption and spread of CA is the widespread belief that tillage is a necessary part of land preparation for planting. This has led to a lack of policy, research and extension support for CA. In some industrialised countries, such as in Europe, government subsidies on commodities, fuel and equipment discourage the adoption of CA, as does the widespread shift in farming from family farms which practiced diversified cropping and soil-sustaining land husbandry to commercial farms focussed solely on profit maximization (Purseglove, 2015). In many low-income countries, government subsidies on agrochemicals and fuel, and the dominance of commercial agents promoting sales of agrochemicals (often donor supported) can reduce the incentive for farmers to adopt more efficient and sustainable farming practices (Williamson, 2003).

Practical constraints to the adoption and spread of CA include: a lack of appropriate machinery and equipment in the early years of CA adoption; weed competition; non-availability or high cost of herbicides in some remote interior areas of Africa; and inadequate availability of soil-protective mulches in semi-arid climates with a longer dry season where crop biomass has other competing uses such as for livestock feed (FAO, 2009; Kassam and Brammer, 2016; Lalani *et al*., 2017; Kassam *et al*, 2017b; Sims *et al*., 2018). However, there are many examples from different parts of the world to show that farmers, including smallholders, are able to increase biomass production with CA and even substantially increase livestock carrying capacity, including in semi-arid areas (Landers, 2007; Owenya *et al.*, 2011; Lalani *et al.*, 2018).

On severely degraded land, switching from conventional tillage systems to stable CA systems can take several years to build up soil organic matter, soil health and system resilience (Sá, 2004). Large areas of tropical soils are severely degraded, as are large areas of soils in industrialised countries. The potentially slow pace of transformation of farming systems needs to be recognised by scientists, development agencies and programmes, and by farmers (Kassam *et al.*, 2013; Kassam and Brammer, 2016).

However, the above notwithstanding, exemplary progress has been enabled in many countries in the South and the North by the implementation of appropriate mechanization strategies for smallholders and larger-scale farmers working collaboratively together, backed by positive policy and institutional support. Additional critical ingredients to overcome constraints have included the promotion of: CA champions, individuals and institutions; CA farmer organizations; CA service providers; strong and mutually beneficial relationship between CA farmers and agricultural industries; reliable and affordable markets along the value chains; and support from CA research, education and extension. Thus, overall, the necessary and sufficient conditions for CA adoption and spread are becoming increasingly understood by stakeholders, and farmers continue to be at the leading edge of the global transformation of conventional tillage agriculture to CA by overcoming context-specific constraints with locally adapted STI in all continents. Indeed, globally there is already some 40 years of reliable empirical and scientific knowledge on constraints and how they are being overcome by farmers, smallholders and larger-scale farmers, in all major agroecologies in all continents (FAO, 2011, 2016; Kassam *et al.*, 2013, 2014a, 2014b, 2015, 2018).

Conclusions and Policy Implications

As national economies expand and diversify, more people become integrated into the economy and are able to access food. However, for those whose livelihoods continue to depend on agriculture to feed themselves and the rest of the world population, the challenge for agriculture is to produce the needed food and raw material for industry with minimum harm to the environment and the society, and to produce it with maximum efficiency and resilience against abiotic and biotic stresses, including those arising from climate change. There is growing empirical and scientific evidence worldwide that the future global supplies of food and agricultural raw materials can be assured sustainably at much lower environmental and economic cost by shifting from conventional tillage-based to CA-based food and agriculture systems.

The achievement of this goal will require effective national and global policy and institutional support (including research and education). However, agriculture systems, whether they are deemed ecologically sustainable or not, are responding to the demands and pressures placed upon it by the food system, industry, government and the economy as a whole. The main political and economic drivers of the prevailing food, feed and agro-industrial systems continue to push the supporting agriculture system further down the intrusive, technology-oriented non-ecological path. These structural forces need to be overcome if CA is to become the dominant agricultural paradigm.

CA offers an opportunity to establish multi-functional agriculture with much greater crop and land potentials in agricultural land use systems to underpin the effective implementation of the food and agriculture related SDGs. Modern tillage agriculture has become unfit for purpose and cannot be relied upon. CA offers an alternative approach to sustainable agriculture, an agriculture that can deliver 'more with less' resources, rehabilitate degraded lands and ecosystem services, and mitigate future land, water and environmental degradation. It is unlikely that national and global food security goals, embedded in the SDGs, can be achieved sustainably without CA. Nor is it possible to achieve high output and sustain an efficient and resilient agriculture without CA. Modern tillage agriculture, with its heavy reliance on high application rates of expensive purchased inputs, is sub-optimal in terms of factor and total productivities and is not climate-smart. Consequently, the current agriculture paradigm is unsuitable for delivering the SDGs related to pro-poor development and poverty alleviation as well as for those aimed at protecting the environment and delivering ecosystem services.

CA has proved to be a far better option in all continents and land-based agro-ecologies. In recent years, it is fashionable to discuss and argue about the need for all nations to develop 'climate-smart' agriculture. We believe that such agriculture, as part of the SDGs, cannot be achieved unless CA is placed at the core of national food and agriculture development strategies. We further believe that such CA-based strategies will also contribute effectively to the achievement of the goals of the three international conventions namely: climate change, desertification, and biodiversity that are an integral part of the SDGs.

Every effort needs to be made by all stakeholders to transform tillage agriculture to CA so that maximum impact could be made through meeting SDGs. More specifically, policy action should focus on the following areas as elaborated in Kassam *et al*. (2014):

- Strengthening government capacity to support the adoption and spread of CA through updating agricultural policies, reforming or ideally removing perverse commodity support programmes, and instituting policy reforms, especially in Asia, parts of Latin America and the Caribbean, Africa and Europe
- Developing an enabling policy environment for private sector participation in developing and supporting the promotion of CA
- Advocating for initial government support to increase farmers' access to appropriate farm equipment for CA
- Developing large scale programmes that would offer payments to CA farmers for harnessing ecosystem services e.g. carbon sequestration, watershed services and control of soil erosion
- Including CA in all new agriculture development projects as the foundation of sustainable production intensification
- Funding universities and research centres to undertake innovative practical research to tackle soil and agronomic challenges
- Revising universities' agriculture curricula to include CA as an alternative and sustainable way of farming and providing agricultural universities and schools with relevant literature and publications about CA in the local language.

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