Current status of adoption of no-till farming in the world and some of its main benefits

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Abstract: In 1999 no-tillage farming, synonymous of zero tillage farming or conservation agriculture, was adopted on about 45 million ha world wide, growing to 72 million ha in 2003 and to 111 million ha in 2009, corresponding to an growth rate of 6 million ha per annum. Fastest adoption rates have been experienced in South America where some countries are using no-tillage farming on about 70% of the total cultivated area. Opposite to countries like the USA where often fields under no-tillage farming are tilled every now and then, more than two thirds of the area under no-tillage systems in South America is permanently not tilled; in other words once adopted, the soil is never tilled again. The spread of no-tillage systems on more than 110 million ha world-wide shows the great adaptability of the systems to all kinds of climates, soils and cropping conditions. No-tillage is now being practiced from the artic circle over the tropics to about 50º latitude south, from sea level to 3,000 m altitude, from extremely rainy areas with 2,500 mm a year to extremely dry conditions with 250 mm a year. No-till farming offers a way of optimizing productivity and ecosystem services, offering a wide range of economic, environmental and social benefits to the producer and to the society. At the same time, no-till farming is enabling agriculture to respond to some of the global challenges associated with climate change, land and environmental degradation, and increasing cost of food, energy and production inputs. The wide recognition of no-till farming as a truly sustainable system should ensure the spread of the no-till technology and the associated practices of organic soil cover and crop rotation, as soon as the barriers to its adoption have been overcome, to areas where adoption is currently still low. The widespread adoption globally also shows that no-tillage farming cannot any more be considered a temporary fashion or a craze; instead largely through farmers' own effort, the system has established itself as a farming practice and a different way of thinking about sustainable agro-ecosystem management that can no longer be ignored by scientists, academics, extension workers, farmers at large as well as equipment and machine manufacturers and politicians.

Keywords: world-wide no-till adoption, zero tillage adoption, conservation agriculture, soil health, climate change, ecosystem services

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1 Introduction

The rapid expansion of the area under no-tillage/zero tillage from 45 million ha in 1999 to 111 million ha in 2009 shows the increasing interest that this technology is having among farmers[1,2,3]. The superiority of this

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No-tillage has even allowed expansion of agriculture to marginal soils in terms of rainfall or fertility (e.g. Australia, Argentina). All crops can be produced adequately in the no-tillage system and to the authors knowledge there has not yet been found a single crop that would not grow and produce under this system, including root and tuber crops. The wide range of conditions where the no-tillage system is working successfully all around the world, its economic, social and environmental advantages as well as the recognition as a truly sustainable farming system should ensure the expansion of this technology, as soon as the barriers for its adoption have been overcome, to areas where adoption is still low. The main barriers to its adoption continue to be, knowledge on how to do it (know how), mindset (tradition, prejudice), inadequate policies as commodity based subsidies (EU, US), availability of adequate machines (many countries of the world, especially countries like China with small landholdings and high yield-levels) and availability of suitable herbicides to facilitate weed management (especially in developing countries)[6]. These barriers must be overcome not only by farmers but also by scientists, researchers, extension workers, university professors, politicians and all stakeholders involved in the farming industry if a greater adoption is aimed to be achieved[7]. The widespread adoption of no-tillage under a great range of different ecological and socioeconomic conditions on more than a 110 million ha world-wide shows, that the system can be made to work and function under extremely varied conditions. The faster adoption of this sustainable production system should be encouraged in order to reverse the process of soil degradation into a process of rehabilitating or building up its health, fertility and productive capacity. No-tillage technologies have a great potential to increase organic matter content of the soil and sequester carbon while building and maintaining good soil structure and health compared to intensive tillage systems that does exactly the opposite[2,4,5].

This paper provides an overview of the adoption and spread of no-till farming in the world and outlines some of the main benefits that can be harnessed by farmers and the society at large from practicing it.

2 Methods of gathering information about adoption and spread

There are only few countries around the world that conduct surveys and have statistics on the adoption of no-tillage therefore the adoption numbers presented in this paper are based on estimates. To get reliable estimates on the adoption of no-tillage the authors have consulted qualified informants in the different countries which are listed below in Table 1. For data in the US the authors consulted CTIC (Conservation Technology Information Center); for Brazil, FEBRAPDP, the Brazilian Federation of No-till into Crop Residues Farmers Associations; for Argentina, AAPRESID, the Argentinean Association of no-till farmers; for Canada, the Soil Conservation Council of Canada, and so on. In some cases, well informed and reliable individuals and/or institutions have provided the information. Whenever needed information has been cross checked with cooperatives, government agencies, experts and reliable informants. Attention was paid not to include doubtful information avoiding inflated data. We have to admit that the real numbers could be somewhat higher or lower, but our intention was to have an approximate estimate of how much no-tillage farming is practiced around the world.

Farmers who practice rotational tillage, (e.g., tilling every third or fourth year) are not excluded at this stage. But we have excluded those farmers who practice no-tillage for one crop and regularly plow or till the soil for the following crop. We are aware, that this means excluding millions of hectares from our estimates as in many regions of the world production systems are used that include no-tillage in one season and intensive tillage in the next season. There are about five million ha of no-tillage being practiced this way in the Indo-Gangetic-Plains in a rice-wheat rotation, where wheat is the no-tilled crop. Direct seeding is also excluded from our estimates. Direct seeding is defined for the purpose of this paper as a system where machines are used that are able to seed directly into the stubble of the previous crop, i.e. into unprepared ground, but because of the design of the seeding equipment produces high soil disturbance at seeding to prepare a “seedbed” in one pass, so that most of the soil surface and sometimes even the soil profile is tilled and disturbed. There are probably millions of hectares under this system in Russia and countries of the former Soviet Union. Ukraine claims to have about 1.1 million ha under this system according to Neonila Martiniuk[1]. Also in Kazakhstan the area reported by the Ministry of Agriculture under conservation technologies, including high disturbance conservation tillage, is more than 2 million ha.

To avoid double counting of hectares under no-tillage in the case of countries were double cropping is practiced, for the purpose of this publication only the net area under no-tillage is counted. In our understanding this distinction is important to be able to quantify the real number of hectares under Sustainable Conservation Agriculture. The area seeded under no-till in countries like Brazil, Argentina, Paraguay, New Zealand and others where double cropping is intensively used, would probably increase by at least 50% if the number of no-till seeded hectares were to be counted.

3 Clear concept of no-tillage terminology

As the understanding of no-tillage (synonymous of zero tillage) often varies so it is necessary to have a common understanding of what no-tillage means. Unfortunately, no-tillage is often regarded as a technology where seeds are put into the soil without tillage, not taking into consideration that this is a completely different system. This adds complexity to no-tillage research because not only one factor, tillage, but a whole set of factors have to be changed. Different seeding equipment to cut through the residues of previous crops is necessary; and weed and pest management as well as fertilization and selection of crop varieties need to be adapted to meet system requirements.

For the purpose of gathering information about the development and the area under no-till for this paper we have asked our informants to apply the definition by Phillips and Young[8] (with minor modifications), which seems to be the most widely accepted. “No-tillage is defined as a system of planting (seeding) crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil tillage is done”. Permanent or continuous no-tillage should be aimed at, rather than not tilling in one season and tilling in the other, or occasionally not tilling the soil. The soil should remain permanently covered with crop residues from previous cash crops or green manure cover crops, and most of these residues will remain undisturbed on the soil surface after seeding. Crop rotation and cover crops are essential elements that need to be applied in the no-till system.

This is in accordance with the widely used concept of Conservation Agriculture (CA) which is based on three principles applied simultaneously in practice[2,3,5]:

1. Continuous minimum mechanical soil disturbance (no-tillage and direct seeding with minimum soil disturbance)

2. Permanent organic soil cover (retention of adequate levels of crop residues on soil surface including from cover crops to protect and feed the soil, develop surface mulch)

3. Diversification of crop species grown in sequence or association (crop rotations and mixtures to help moderate possible weed, disease and pest problems, generate biomass, fix atmospheric nitrogen and serve as nutrient pumps)

FAO has worked for many years in the promotion of Conservation Agriculture in many countries of the world. Especially working across different language and cultural barriers it is very important to use an agreed terminology, since many of the commonly terms used for tillage operations, have different meanings for different people. For this reason the term Conservation Agriculture was defined in the way specified above. A typology of terms based on tillage intensity as well as their impact on soil quality is provided in[2].

4 Development of no-tillage around the world

In 1973/74 no-tillage was used only on 2.8 million ha world wide and 10 years later in 1983/84 the area under this technology had grown to 6.2 million ha with more than 75% of the total area being applied in the United States. By 1996/97 the area under no-till had grown to

38 million ha with the proportion practiced by the United States being reduced to 50% of the total[9] and in 2009 the proportion practiced by the US has fallen to 25%.

Data presented at the 10th ISCO Conference in West Lafayette, Indiana, in 1999, showed a worldwide adoption of the no-tillage technology of 45 million ha[10]. As shown by[11] at the ISTRO Conference in Brisbane, Australia, in 2003 the area had grown to 72 million ha. In the last 10 years the no-tillage technology has expanded at an average rate of 6 million ha per year from 45 to 111 million ha showing the increased interest of farmers in this technology (Table 1).

Table 1 Extent of no-tillage adoption world wide (countries with > 100000 ha)

Country	Area under No-tillage (ha) 2008/2009
USA	26,500,000
Brazil	25,502,000
Argentina	19,719,000
Canada	13,481,000
Australia	17,000,000
Paraguay	2,400,000
China	1,330,000
Kazakhstan	1,200,000
Bolivia	706,000
Uruguay	655,100
Spain	650,000
South Africa	368,000
Venezuela	300,000
France	200,000
Finland	200,000
Chile	180,000
New Zealand	162,000
Colombia	102,000
Ukraine	100,000
Total	**110,755,100**

Source: FAO AQUASTAT 2009[12].

The growth of the area under no-till has been especially rapid in South America where the MERCOSUR countries (Argentina, Brazil, Paraguay and Uruguay) are using the system on about 70% of the total cultivated area. More than two thirds of no-tillage practiced in MERCOSUR is permanently under this system, in other words once started, the soil is never tilled again.

It is well known that only a few countries in the world conduct regular surveys on CA/No-till adoption. The data presented in this paper is mainly based on estimates made by farmer organizations, agro industry, well informed individuals, etc. The authors have been careful to only include data that seems well founded and reliable. Table 4 shows an overview of CA/No-till adoption in those countries that have more than 100,000 ha of the technology being practiced by farmers, and Table 5 shows the area under no-tillage and the percent of adoption by continent.

It is estimated that at present no-tillage is practiced on about 111 million hectares worldwide. As Table 2 shows 46.8% of the technology is practiced in South America, 37.8% is practiced in the United States and Canada, 11.5% in Australia and New Zealand and 3.7% in the rest of the world including Europe, Asia and Africa. The latter are the developing continents in terms of CA/No-till adoption. Despite good and long lasting research in these continents showing positive results for no-tillage, this technology has experienced only small rates of adoption.

Table 2 Area under no-tillage by continent

Continent	Area (ha)	Percent of total (%)
South America	49,579,000	46.8
North America	40,074,000	37.8
Australia & New Zealand	17,162,000	11.5
Asia	2,530,000	2.3
Europe	1,150,000	1.1
Africa	368,000	0.3
World total	115,863,000	100

4.1 Europe including Russia

Europe is considered to be a developing continent in terms of the adoption of Conservation Agriculture[13]. Only Africa has a smaller area under Conservation Agriculture/no-till than Europe. According to [13], "European and national administrations are still not fully convinced that the concept of Conservation Agriculture is the most promising one to meet the requirements of an environmentally friendly farming, capable to meet the needs of the farmers to lower production costs and increase farm income, and to meet the consumer demands for enough and affordable quality food with a minimum impact on natural, non-renewable resources. The reliance of Conservation Agriculture on the use of herbicides and the alleged increased input of herbicides and other chemicals for disease and pest control are the main constraints for the full acceptance of Conservation Agriculture as sustainable crop production concept".

Spain: 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[14].

Spain is the leading country in terms of no-till adoption in Europe. According to AEAC/SV (Spanish Conservation Agriculture Association – Suelos Vivos), 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. Main tree crops in no-tillage system in combination with cover crops are olives and much less apple, orange and almond plantations. Because this report is only based on no-till systems on annual crops we are not including no-tillage practices in tree crops in our global estimates. In total it is reported that Conservation Agriculture is applied on about 10% of arable land in Spain.

France: Long-term experiments with different minimum tillage techniques (including no-tillage) were started by INRA and ITCF in 1970, mainly with cereals[15]. The authors concluded, that a comprehensive range of technical and economic data are 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 Conservation Agriculture/No-till farming. APAD (The French No-till Farmers Association) estimates that no-tillage is practiced on about 200,000 ha in this country. Some farmers have developed superior no-till systems with green manure cover crops and crop rotation which are working very well. The 2008 IAD International Conference on Sustainable Agriculture under the High Patronage of Mr. Nicolas Sarkozy and the following launching of the IAD Charter for Sustainable Agriculture is expected to show results in terms of greater acceptance of CA/No-till practices at all levels and especially at the political level. A greater acceptance of CA/No-till at political level is needed in the EU in order to increase farmer acceptance.

Finland: The adoption of no-tillage technologies was very fast in Finland. According to FINCA (Finnish Conservation Agriculture Association) in less than ten years no-tillage grew from some hundred hectares to 200,000 ha in 2008. 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 Artic Circle in the North (66º N).

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, no-tillage systems as understood by the authors of this paper (see definition above), has 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. Direct Seeding here is a technique were a specially designed machine seeds directly after the harvest of the previous crop into undisturbed soil. This type of machine, which is very widely used in Ukraine, does a virtually complete disturbance of the soil surface in the whole width of the seeding machine because it uses wide tines and often duckfoot openers. For this reason this form of seeding cannot be termed no-tillage and can only be classified as reduced tillage or mulch tillage. 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. As there seems to be a substantial amount of low disturbance no-tillage being practiced in Ukraine the authors of this paper, after carefully balancing information, estimated the area under no-tillage provisionally to be at 100,000 ha.

Switzerland: This country has made remarkable progress in terms of research, development and adoption of no-tillage practices. Research performed in Switzerland over more than ten 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 (no-tillage) is applied on about 12,500 ha in Switzerland and this corresponds to about 3.5% of arable land in this country. The Swiss No-till website offers very useful information on no-tillage in French and German. The No-Till ABC offers straight answers from practitioners to frequently asked questions by farmers.

Germany: Investigations into no-tillage technologies in Germany started in 1966[16]. Intensive and long term research in Germany by Bäumer, Czeratzki, Kahnt and later Teebrügge and Böhrensen, concluded that no-tillage is a viable cultivation system. According to[17], 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, 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 still 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[20]. The quality of his no-tillage operation with crop rotations and cover crops has 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 and adoption is increasing. Some farmers like Alfons Bunk from Rottenburg, Suabia have been using continuous no-till for more than 10 years successfully.

Russia: In Russia no-tillage is often referred under the umbrella term “Resource Saving Technology”. Despite all the efforts made to get at least some information on the area under no-tillage in Russia it has not been possible to obtain realistic numbers for this country. We need to recognize that in this huge country it is difficult at the moment to get reliable data on the area under no-till. On the other hand those people that have closer contact with Russia will know that several machine manufacturers have exported no-till machines to Russia in significant numbers. With the National Foundation for development of Conservation Agriculture (NFDCA), Russia also has an organization promoting conservation agriculture and is part of the European Conservation Agriculture Federation (ECAF). For this reason we believe there is considerable area under no-tillage farming being practiced in this country. We hope to be able to obtain reliable estimates on the area under no-tillage in Russia in the near future.

Compared to other world regions CA development in Europe has been particularly slow, with some few exceptions, such as for example Finland. 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 European union including direct payments to farmers and subsidies for certain comodities, which take the pressure off the farmers for extreme cost savings and discourage the adopton of diversified crop 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 to small import agents. However, also in the EU the environmental pressure is increasing and new European Common Agricultural policy is prepared, which most likely will turn more favourable to CA.

4.2 United States and Canada

United States: First no-tillage experiments in the United States were reported already in the late 1940's. In 1951, K.C Barrons, J.H. Davidson and C.D. Fitzgerald of the Dow Chemical Co., reported on the successful application of no-tillage techniques[18]. Since then the US has been the leading nation in terms of area with no-till adoption. Already in 1996/97 the no-tillage technology was used on 19.4 million ha in this country[19], representing about 50% of world's total at that time.

The United States has been among the few countries that has conducted regular surveys on the area under no-tillage and other forms of Conservation Tillage. Unfortunately these surveys were discontinued in 2004. The data is published at the CTIC homepage (www.conservationinformation.org). The survey shows that by 2004 the area under no-till farming was 25.3 million ha. The surveys were based on the actual area under no-tillage found in the different regions in different years, but it did not consider the number of years a farmer had been not tilling the soil. According to CTIC[20] it was estimated that only about 10 to 12% of the area under no-tillage in the USA was permanently under this system. An amendment to the 2004 figures was done in 2007 which is shown in the CTIC homepage: http://www.conservationinformation.org/?action=members_crm[21]. The CTIC CRM data collection shows the 2007 Amendment to the National Crop Residue Management Survey Summary which is based on 374 Counties in eight States. Here no-tillage appears with 65.48 million acres which is equivalent to 26,493,000 ha. The Amendment also shows that no-till area has increased from 23.2% to 25.5% of total cropland area. Although the percentage of adoption has increased, the numbers still reveal that the majority of farmers in this country are still using conventional intensive or reduced tillage practices. Despite the fact that the growth of the area under no-tillage farming in the US has not been dramatic, a continuous and steady growth could be observed in the last decade (Table 3).

Table 3 Area under no-tillage farming in the United States[20]

Year	Area (million ha.)
1994	15.7
1996	17.3
1998	19.3
2000	21.1
2002	22.4
2004	25.3
2007	26.5

More detailed information under CRM data collection http://www.conservationinformation.org/?action=members_crm.

In the USA the main drive for introducing conservation tillage resulted from the major erosion problems in the past, particularly the dust bowl in the 1930s. Yet, the adoption of Conservation Agriculture, i.e. permanent no-tillage systems, is stagnating in the USA at a fairly low level of adoption. Of the 25% under no-till, probably only half would qualify with a stricter CA criteria as long term no-till. The reasons for this are similar to the ones stated for Europe, namely marked interventions through subsidies discouraging farmers from adoption diversified crop rotations and interest groups lobbying against the adoption of CA for commercial reasons.

Canada: 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 focusing on reduced or zero tillage and chemical fallows, but including factors like 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%[22]. These developments are parallel to the recent increase in the application of Conservation Agriculture in Canada since the year 2000. Canada is actively promoting CA adoption in other countries, such as in China and Ukraine.

Canada is conducting an Agricultural Census every 4 years, the last one being performed in 2006. This Census also includes adoption of no-tillage practices. The regions with highest percentage of adoption of no-tillage are Saskatchewan (60.1%), Alberta (47.8%), Ontario (31.2%), Manitoba (21.3%) and British Columbia (19.0%). According to the Soil Conservation Council of Canada, no-tillage is now practiced on 13.48 million ha in Canada and on average the technology is used on 46.1% of the cropped area[1]. The Soil Conservation Council of Canada informs that in the year 2000 no-tillage was used on 8.8 million ha. This shows an average increase of 780,000 ha per year of no-till adoption in Canada throughout this period. According to Doug McKell[1] the majority of the conventionally tilled land is in the hands of the older and/or smaller farmers who will likely not change their practices. Thus the change in adoption will take place when the land changes hands. The majority of no-tillage in Canada is performed with airseeders that are equipped with hoe-type openers.

4.3 Latin America

Brazil: First no-tillage experiments in Brazil were started in April 1971 at the IPEAME Research Institute (later EMBRAPA), in Londrina, Paraná, by the first author of this paper. The next year Herbert Bartz, the first farmer to try the technology in Latin America, was already introducing the system on his farm. From there it took Brazil almost 20 years to reach the first million ha of no-tillage practice being applied by farmers, but after the first million ha the technology has experienced an exponential growth.

According to FEBRAPDP (The Brazilian Federation of No-till Farmers)[23], in the season 2005/06 there were 25.5 million ha of no-tillage being practiced in this country (Table 4). Brazil continues to be one of the leading countries in the world in terms of adoption of the no-tillage system. The first farmer to use the technology in Brazil started in 1972, ten years after the first farmer in the US was applying no-tillage. In Brazil about 70% of no-tillage is practiced permanently, this means that once started most farmers never till the soil again. While about 90% of farmers in the US practice rotational tillage (several years no-tillage and then they till again) this is the case only with a minority of farmers in Brazil. Most Brazilian farmers and technicians believe that those farmers using rotational tillage will never get to reap the full benefits of the no-tillage system as described in the evolution of a Continuous No-till System[24]. Another aspect where Brazilian farmers are ahead of their peers in the US is in the use of GMCC (green manure cover crops). GMCC are used on millions of hectares in Brazil and many farmers are convinced that they are a must in a sound no-tillage system. FEBRAPD is now concerned about improving the quality of no-tillage and is aiming at certifying the quality of the system to farmers in order to qualify for carbon credits in the future.

Table 4 Area under no-tillage in Brazil [23]

Year	Area (million ha.)
1993/94	3.0
1995/96	5.5
1997/98	11.3
1999/00	14.3
2001/02	18.7
2003/04	21.8
2005/06	25.5

Full set of data from 1972 to 2006 under Area de Plantio Direto at http://www.febrapdp.org.br/port/plantiodireto.html[23].

The quick and steady growth of no-tillage in Brazil was possible because the machine industry engaged early in the production of specialized no-till equipment. Today Brazilian no-till seeding machines are exported all over the world. Brazilian machine manufacturers are not only engaged in producing equipment for motorized mechanization but produce also equipment for animal traction and manual operation. This equipment has been highly appreciated in many developing countries. FAO has played a major role in distributing Brazilian no-till equipment for small farmers throughout the world. The development of this industry in Brazil was possible because there are about 100,000 small farmers using no-till farming systems in this country needing specialized machines. No-tillage in Brazil is almost exclusively performed with disc seeders.

Argentina: First research and farm experiences with no-till started in Argentina in the early 1970's. Several farmers began experimenting with no-till system and then gave up because of the lack of adequate herbicides and machinery which together with 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 1986 of AAPRESID, the Argentinean Association of No-till Farmers based in Rosario. Since 1992 AAPRESID is organizing no-till conferences in August of every year (with simultaneous translation into English) which have been visited by more than 1,000 farmers at the beginning and nowadays exceed 2,000 farmers. Since the founding of AAPRESID, Argentina also experienced an exponential growth in no-till farming.

The advent of the no-tillage technology caused a paradigm shift in Argentina as the idea that tillage was necessary to grow crops was finally abandoned. In Argentina the concept of "arable" soils has been discarded after discovering that soils that cannot be ploughed can be seeded. According to AAPRESID[25] in 2006 there were 19.7 million ha of no-tillage being practiced in this country. With almost 20 million ha under no-tillage, Argentina is among the most successful countries in terms of no-till adoption. The first group of farmers started practicing no-till farming in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned no-till experts from Chile, as well as with Dr. Shirely Phillips and Dr. Grant Thomas from the US. At the beginning, growth in adoption 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 one million ha under no-tillage were reached. Since then adoption has increased year by year thanks to the intensive activities of AAPRESID so that in 2006 about 69% of all cropland in Argentina was under no-tillage farming (Table 5). The main advantages of the no-till system according to AAPRESID[25] is that it is possible to produce without degrading the soil and that soil physical, chemical and biological properties are improved.

The rapid growth of no-tillage in Argentina was possible because no-till seeding equipment manufacturers have responded to the increasing demand in machines. Among the many big and small no-till seeders manufacturers in Argentina there are at least 15 that are in conditions to export their equipment. No-tillage in Argentina is almost exclusively performed with disc seeders.

Table 5 Area under no-tillage in Argentina[25]

Year	Area (million ha.)
1993/94	1.81
1995/96	2.97
1997/98	5.00
1999/00	9.25
2001/02	15.10
2003/04	18.26
2005/06	19.72

More information under Institucional, Siembra Directa at http://www.aapresid.org.ar/institucional_sd.asp[25].

Similar to other countries in South America, farmers in Argentina like to practice permanent no-tillage once they have started with the system. More than 70% of all no-tillage practiced in Argentina is permanently not tilled. 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 when using appropriate cover crops.

Paraguay: Early adopters in Paraguay experienced the same drawbacks as their counterparts in Argentina and Brazil, mainly because of lack of appropriate machines, herbicides and know how. Akinobu Fukami, a Japanese immigrant and president of the Colonia Yguazú cooperative, was the first farmer to successfully apply the technology in Paraguay in 1983. With the support of JICA all farmers of this cooperative were using no-tillage 10 years later. Until 1992 there were only 20,000 ha of no-tillage being practiced by farmers in Paraguay. From 1993 onwards, with the support of a GTZ project, no-tillage expanded massively throughout the country. Whole landscapes have been transformed into country sides where soil tillage practices have disappeared almost completely.

According to the Ministry of Agriculture and Livestock (MAG) and the grain exporting chamber of Paraguay (CAPECO), in tractor mechanized farming systems it is estimated that about 90% of all cropping area is under no-tillage, reaching about 2.4 million ha in 2008. Most farmers apply permanent no-tillage systems. But also in small farmer production systems with animal traction or manual no-till systems, no-tillage practices have increased. It is estimated that about 22,000 small farmers apply no-tillage at least on part of their farms covering about 30,000 ha. The increased interest in small farmer no-till systems has been a result of efforts of the Ministry of Agriculture together with GTZ (German Technical Assistance) and KfW (Kreditanstalt für Wiederaufbau) from Germany that provides grants for buying no-till equipment. Small farmers have been able to successfully grow crops that initially were thought not to be appropriate for no-tillage as for instance cassava (*Manihot utilissima*). Planting cassava under no-tillage in combination with cover crops has resulted in substantial yield increases (sometimes doubling yields) compared to conventional farming systems. Reduction of drudgery (tillage, weed control) and the resulting improvement in the quality of life because of a dignified work are among the main reasons for increased adoption by small farmers.

Bolivia: In 1986, after visiting Brazil and Argentina, the farmer Dr. Jean Landivar started no-tillage on his 2,000 ha farm in the lowlands of Santa Cruz for the cultivation of sorghum, maize and also some soybeans. Research started at about the same time but without positive results. In 1996/97 Bolivia reported 102,000 ha under no-tillage in the lowlands of Santa Cruz, in the east of the country, mainly with soybeans but also maize, rice and some cotton.

Since then no-tillage practices have been increasingly adopted in Bolivia. Main crop under no-tillage is soybeans. According to ANAPO (The soybean and wheat producers association of Bolivia) soybeans under no-tillage have increased from around 240,000 ha (39% adoption) in the year 2000 to 706,000 ha (72% adoption) in the year 2007. The occurrence of wind erosion in conventional tillage systems has been one of the major driving forces for adoption. Also the increased water use efficiency under no-tillage is appreciated by farmers in a region with low and erratic rainfalls.

Uruguay: According to AUSID (Uruguayan No-till Farmers Association), about 82% of cropland, that is 672,000 ha was under no-till systems in the 2006/07 growing season. This is a great progress compared to the 2000/01 season when only 119,000 ha of no-tillage were reported, corresponding to 32% adoption. These numbers have been provided by DIEA (The Statistics Department of the Ministry of Agriculture, Livestock and Fisheries), and reflect the trend that is also seen in the other MERCOSUR countries (Brazil, Argentina, Paraguay and Uruguay). Another interesting fact is that in Uruguay (according to DIEA) 65% of crops are seeded on rented land for which contracts are renewed every year. This hinders the planning of medium term crop rotation and investment strategies. In Uruguay the integration of crop production with livestock is very popular and no-tillage fits very well into the requirements of this mixed production system. Pastures are grown for several years until they show signs of degradation. Then crops are grown for several years according to the needs of the farmers and the market situation. Uruguay also belongs to the countries that have engaged predominantly in permanent no-tillage practices.

Venezuela: Despite repeated efforts to obtain information about the area under no-till in Venezuela it has not been possible to obtain updated data on the progress in the adoption of this technique. Therefore the same numbers are used as in 2005 when no-tillage was applied on 300,000 ha[24].

Chile: No-till pioneer Carlos Crovetto started no-tillage in 1978 and has been using it continuously for 31 years until now in the region of Concepción, Southern Chile. On land with 15% to 18% slope he has virtually eliminated erosion by doing away with tillage and leaving crop residues on the soil surface. Already in 1997, “after 19 years of continuous no-tillage, Carlos Crovetto had added one inch of topsoil, boosted the soil organic matter content from 1.7% to 10.6% in the first 5 cm of soil, improved the bulk density from 1.7 to 1.4 g/cm^3, increased the soil water-holding capacity by more than 100%, increased the phosphate content from 7 to 100 ppm and potash from 200 to 360 ppm in the top 5 cm of soil, improved the soil's cation exchange capacity from 11 to 26 milli-equivalents per 100 g of soil and raised the soil's pH level from 6 to 7"[26].

According to Carlos Crovetto, also author of several books about no-tillage, there are about 180,000 ha of no-tillage being practiced in Chile, which is about 30% of the cropped area in rainfed farming systems. Unfortunately there is a relatively large amount of no-till farmers that have not yet understood the importance of soil cover in this system and burn their cereal residues regularly putting the sustainability of the system at risk. Official research institutions have taken little interest in this technology and have not been willing to study the long term detrimental effect of burning on soil health and yield.

Colombia: In Colombia the area under no-tillage has virtually remained static and no increase in the area under this system has been reported. This has little to do with the merits of this system but more with the political situation of this country and the insecurity in rural areas. According to Fabio Leiva (personal communication, 2008) there are about 100,000 ha under no-tillage in Colombia.

Mexico: In 2001 the estimated area under no-tillage in Mexico was 650,000 ha. However, this estimate was based on the number of no-till drills sold which was multiplied by the average farm size. This method showed to be wrong as it greatly overestimated the area under no-till. A more recent survey stated the adoption of Conservation Agriculture involving no-tillage systems with 22,800 ha[12].

In Latin America, particularly in the South Cone, the conditions for a fast spreading of CA were favourable. First of all there was high environmental pressure due to catastrophic erosion. Secondly, the farmers did not receive any support payments and they had to produce to world market prices without any subsidies on comodities. This was combined with pioneer spirit, a high technology standard and a favourable environment of small equipment manufacturers, who picked up the new trend and became themselves promoters of CA. Yet, also under these conditions with no initial government support it took 20 years before the first million hectare under CA were reached in Brazil.

4.4 Australia and New Zealand

Australia: According to Bill Crabtree, no-tillage Consultant and member of WANTFA (Western Australia No-till Farmers Association)[1], no-tillage is now practiced on about 17 million ha in this country. Overall large increases in no-till adoption have been experienced since 2003 with high levels of growers using no-till to establish crops in 2008. Reduced soil disturbance through no-till and conservation farming methods have led to large increases in profitability, sustainability and environmental impact in the Australian cropping belt[27]. The proportion of growers using at least some no-till is now peaking at levels around 90% in many regions. In regions with relatively low adoption 5 years ago, there have been very rapid increases in adoption, particularly in the period 2003–2006[27]. The adoption of no-till by farmers in Australia varies from 24% in northern New South Wales to 42% in South Australia and 86% in Western Australia. During 2008 the percent of the area under no-tillage is expected to grow to 88% in Western Australia and to 70% in South Australia[28]. Because of the water, time and fuel savings with this technology, as well as the other advantages of the system, no-tillage is expected to continue growing in this country, especially in those States with lower rates of adoption. In northern New South Wales the area under no-tillage is expected to increase from 24% in the year 2000 to 36% in 2010. Overall adoption of no-till in Queensland was approximately 50% with some areas as high as 75%[28].

Because of the water, time and fuel savings with this technology, as well as the other advantages of the system, no-tillage is expected to continue growing in this country. In Australia most farmers use airseeders equipped with narrow knife point openers, although some farmers use disc openers which in the last years seem to gain popularity. Also the use of cover crops is getting popular among no-till farmers. Combining cropping with livestock (generally sheep) is a common practice throughout the country. This often leads to insufficient crop residues left on the soil surface at seeding but more recently the importance of soil cover is increasingly recognized in Australian no-till. Another complementary technology used in Australia on no-tillage farms is controlled traffic farming to avoid soil compaction[29].

New Zealand: This country is among the first in the world to use and develop the no-tillage technology. At the beginning, pasture renovation without tillage was tried and practiced successfully. Later also annual crops were seeded with the no-tillage system. In the year 1995 only about 4% of the cropped area was under no-tillage and was virtually confined to pastures. According to John Baker[1] there are about 160,000 ha under no-tillage in New Zealand, which corresponds to about 25% of all cropland hectares and includes pasture, forage crops as well as arable crops. Because in this country many farmers use double cropping systems, the total number of hectares seeded each year in no-tillage amounts to around 250,000 ha. But to avoid double counting of hectares under no-tillage, for the purpose of this publication only the net area under no-tillage is counted. The same as in South America, the growth of the area under no-tillage has taken place without subsidies or outside incentives.

4.5 Asia

China: In general an average farmer in China has only about 0.08 ha of farm land and there are 3 to 5 persons on average in each family. Already this fact does not make it easy to estimate the area under no-tillage in China and has to be taken into consideration when putting together numbers on tillage practices. But one thing is certain: the area under Conservation Agriculture (CA) has greatly increased in the last few years in China. Conservation Agriculture is generally termed conservation tillage and includes mulch tillage and no-tillage. Conservation tillage is a term used for land that is not ploughed and where more than 30% cover with plant residues are left on the soil surface. No-tillage makes about 50% of conservation tillage in China and they allow for low disturbance subsoiling or ripping in their no-tillage fields[30]. According to the Conservation Tillage Research Centre (CTRC, headed by the fourth co-author of this paper, Prof Li Hongwen) who has been committed by the Ministry of Agriculture to do a survey on conservation tillage practices every year, by the end of 2008 conservation tillage was being practiced on more than 3 million ha[31]. As no-tillage makes 50% of conservation tillage, this corresponds to 1.33 million ha under no-tillage being practiced in China. The data for no-tillage is conjectured according to CTRC's knowledge and reports from different provinces and is based on talking to farmers and local administrative organizations. In double cropping areas in Northern China, most maize is no till planted, if wheat is not no till planted or minimum tilled planted, the areas are excluded. Beijing has covered more than 85% of its farm land with CA. China State Council has approved the long term plan for CA in China. This plan is made by Ministry of Agriculture and the National Development & Reform Commission, and will promote quick development of CA in China[32]. China had started no-tillage studies since 1960, but the work was not extended and failed. At last, the work was not continued and only taken up again as conservation tillage was studied since 1992 with an ACIAR project, and succeeded.

China is now producing many types of no-till seeders for smaller tractors[33] and has difficulties to cover the high demand. Soil erosion by wind and water as well as water scarcity, low levels of soil organic matter and declining productivity has been among the main driving forces for a rapid adoption of no-tillage in this country[34]. Paradoxically another factor has been the limited labour availability because an increasing amount of young farmers have left for jobs in the cities leaving the older farmers behind. An additional positive element that is now operating in China is that government policy favours the adoption of no-tillage farming.

Kazakhstan: has experienced big changes in land tenure and farming systems in the last decades. No-till adoption has been promoted for some time by CIMMYT and FAO which introduced no-tillage systems in a Conservation Agriculture project from 2002 to 2004. CA has had an explosive development in recent years as a result of farmers' interest, facilitating government policies and an active input supply sector. No-till adoption started from 2004 onwards in the north Provinces (North-Kazakhstan, Kostanai and Akmola) where the highest adoption rates have been registered[1]. A survey in this country showed a total area of adoption in Kazakhstan of 600,000 ha in 2007 and 1.3 million ha in 2008. With this Kazakhstan places itself under the ten countries with the biggest area under no-tillage in the world. The total area not using the plough anymore has even increased more. The official reports by the Ministry of Agriculture count about twice the area reported in this paper, including also technologies with high soil disturbance.

Indo-Gangetic-Plains: The Indo-Gangetic-Plains include four countries in South Asia, India, Pakistan, Nepal and Bangladesh. In 2005 about 1.9 million ha were reported under no-tillage in this region. As was found out later, this refers only to the wheat crop in a double cropping system with rice. For rice, virtually all farmers plough the land or use intensive mechanical tillage practices to puddle the soil. As this cannot be considered to be no-tillage, we are not including the area under no-till wheat in our overview. According to Raj Gupta[1], the area of no-tillage wheat in that region has increased to about 5 million ha with still very few farmers practicing permanent no-tillage systems.

India: The adoption of no-tillage practices by farmers in India has occurred mainly in the rice–wheat double cropping production system and has been adopted primarily for the wheat crop. The main reason is that tillage takes too much time resulting in delayed seeding of the wheat crop after rice. It is well established that for each day of delayed sowing beyond the optimum date wheat yields are reduced by 1 to 1.5%. This timely planting of wheat after rice is critical and that is the reason for the quick uptake of no-tillage wheat. Also, productivity of the rice-wheat system had begun to decline during the nineties (TAC 1992) which led to the Rice–Wheat consortium for Indo-Gangetic-Plains, a systemwide initiative of the CGIAR that involves several National Agricultural Research Centres and has been promoting no-tillage. It is mainly through their efforts that have resulted in the massive uptake of no-tillage wheat in the region. The uptake of the technology was rapid in the north-western states which are relatively better endowed with respect to irrigation, mechanization and where the size of holdings is relatively large (3−4 ha) compared to the eastern region which is less mechanized and where the average land holding is small (1 ha)[1].

Also other efforts have been made to estimate the area under no-tillage. Some estimates on the area under no-till that have been undertaken in the region have been based on the sales of no-till drills and the average coverage per drill. As seen in other countries (e.g., Mexico) this method greatly overestimates the area under no-tillage because the drills are also used in reduced and sometimes even in conventionally tilled fields. For this reason one has to be cautious when alleged areas under no-tillage are mentioned based on the number of sold drills.

North Korea: Since 2002 FAO has been supporting Conservation Agriculture/No-till through a TCP project in the Democratic People’s Republic of Korea (DPRK). The FAO project showed that “no-tillage is a technically viable, sustainable and economic alternative to current crop production practices. After some years the scientific community, the ministry of agriculture and the farmers directly involved in the FAO project have been fully convinced of the economic benefits of crop rotation, no-tillage and straw mulching, which increased yields and reduced inputs. The project demonstrated the value of these CA practices for weed control, soil moisture retention and improvement of soil conditions for crop development[35]. During this period, Korean farmers adopted no-tillage techniques also for rice growing with great success as well as for potatoes, integrating both crops into CA crop rotations with permanent no-tillage. Starting on 3 cooperative farms CA is now practiced on about 30 cooperative farms on an area of about 3,000 ha the limitation being the availability of no-tillage equipment. In Sukchon County, which has been declared CA-model county by the Ministry of Agriculture, the no-tillage rice area in 2008 was 70% of the total rice area (personal communication from the Sukchon County Farm Management Committee).

Turkey: Only recently this country engaged in no-tillage techniques (generally referred to as direct seeding or conservation tillage) mainly at the experiment level by universities and research institutes. Results have been positive for no-tillage compared to minimum and conventional tillage systems in terms of time and energy consumption. Yields of no-tillage have been comparable to other tillage and seeding practices. But research results have not yet reached the farmers. The main reasons for this are, according to Engin Çakir[1].

- There is not enough information available in this field,
- There is lack of know how on how to do no-tillage,
- Some farmers tried no-till but abandoned because of reduced yields,
- There is no government support for conservation agriculture technologies,
- Crop rotation is almost impossible due to low income of the farmers,
- Small sizes of farms (average 6.1 ha) make it difficult to buy a specialized machine,
- No-tillage machines are not available in the market to try.

These problems are common to many developing countries and have to be solved first before any attempt should be made to diffuse no-tillage technologies. Turkey could benefit from the results of no-tillage technologies being applied by GTZ projects under similar conditions in Syria and Lebanon.

4.6 Africa

For the last decade no-tillage has been in a state of intensive promotion in Africa. Reported levels are still low, even where some massive large scale adoption is taking place. Adoption in Africa is in the early stages of building capacities and setting up structures for up scaling[4].

South Africa: This country has experienced only a modest growth in the area under no-tillage since 2005. Data presented at the III World Congress on Conservation Agriculture in Nairobi in 2005 showed an area of 300,000 ha under no-tillage in South Africa[24]. According to Richard Fowler[1], the area has grown to about 368,000 ha in this country. Although research and practical results have identified that CA techniques can be applied with beneficial outcomes, this obviously has not been communicated in an appropriate form to farmers and technicians. South Africa needs to make bigger efforts to promote and spread no-tillage systems to overcome erosion problems and limited rainfall in many regions. The authors of this paper believe that this country presents excellent conditions for applying no-tillage technologies, e.g., adequate infrastructure, the presence of no-till clubs and government programs to promote Conservation Agriculture adoption, which needs to be better exploited.

Southern and Eastern Africa: Many African Countries, particularly in Southern and Eastern Africa have been exposed to no-tillage systems and CA for the last decade and some of them have included this into their government policies. A number of emergency rehabilitation projects promoted CA in several countries, such as Zambia, Zimbabwe and Swaziland. Conservation Agriculture activities and promotion programmes exist especially in Kenya, Tanzania, Zambia, Zimbabwe, Lesotho, Swaziland, Mozambique and Malawi and CA has also been incorporated into the regional agricultural policies by NEPAD (New Partnership for Africa's Development) and more recently by AGRA (Alliance for a Green Revolution in Africa). So far the area in ha is still small, since most of the promotion is among small farmers, but there is a steadily growing movement involving already far more than 100,000 small scale farmers in the region. A network coordinated by FAO with qualified informants in different countries of Africa has gathered initial information about the application of no-tillage in some countries with following preliminary results: Ghana 30,000 ha; Kenya 15,000 ha; Morocco 4,000 ha; Mozambique 9,000 ha; Sudan 10,000 ha; Tanzania 6,000 ha; Zambia 40,000 ha; Zimbabwe 7,500 ha.

Northern Africa: No-tillage systems have been promoted particularly in Morocco and Tunisia. In Morocco 4,000 ha of no-tillage have been reported. In Tunisia the promotion and development was farmer centred and the area under no-tillage increased from 27 ha on 10 farms in 1999 to nearly 6,000 ha on 78 farms in 2007[36] .

5 Achievable benefits from conservation agriculture

CA represents a fundamental change in the agricultural production system, offering many benefits when practiced correctly. The main benefits are described in the following sections and provide an indication why farmers take up CA as evidenced by its increasing adoption as elaborated later. Due to so many synergistic interactions between the various components of CA practices, all the potential and actual benefits are often not fully understood and adequate explanation for some of the benefits in specific situations are not available. In general, scientific research on CA systems is lagging behind what farmers are discovering and adapting on their own initiative. This is partly because CA is a complex, knowledge intensive system which does not lend itself easily to longer-term scientific scrutiny by the research community that is often driven by short-term reductionist thinking and approaches[37-41].

5.1 CA as a fundamental change in the agricultural production system

Conservation agriculture is a means of reproducing plants and water recurrently and sustainably from landscapes and the soils which cover them. It does this by favouring improvements in the condition of soils as rooting environments. CA is not a single technology, but one or more of a range of technologies that are based on one or more of the three main conservation agriculture principles described in the section above. CA functions best when all three key features are adequately combined together in the field. It is significantly different from conventional tillage agriculture in that, ideally[42,43]:

- It avoids tillage once already-damaged soil has been brought to good physical condition prior to initiating the CA system.
- It maintains a mulch cover of organic matter on the soil surface at all times, for providing both protection to the surface and substrate for the organisms beneath.
- It specifically uses sequences of different crops and cover-crops in multi-year rotations;
- It relies on nitrogen-fixing legumes to provide a significant proportion of that plant nutrient - which is needed for biomass production of crops and cover-crops.

CA also relies on liberating other plant nutrients through biological transformations of organic matter. This can be augmented as necessary by suitable artificial fertilizers in cases of specific nutrient deficiencies; but organic matter also provides micronutrients that may not be available ‘from the bag’.

CA can retain and mimic the soil’s original desirable characteristics (‘forest-floor conditions’) on land being first opened for agricultural use. Throughout the transformation to agricultural production CA can sustain the health of long-opened land which is already in good condition; and it can regenerate that in poor condition[44]. CA is a powerful tool for promoting soil and thus agricultural - sustainability.

The above mentioned multiple effects of CA when fully applied together are illustrated in[5]. By contrast with tillage agriculture, CA can reverse the loss of organic matter, improve and maintain soil porosity and thus prolong the availability of plant-available soil water in times of drought. It can also reduce weed, insect pest and disease incidence by biological means, raise agro-ecological diversity, favour biological nitrogen fixation, and result in both raised and better-stabilised yields accompanied by lowered costs of production. Furthermore, CA is a major opportunity that can be explored and exploited for achieving many of the objectives of the International Conventions on combating desertification, loss of biodiversity, and climate change[45].

Interdependence of the macroscopic benefits from CA and the microscopic features of the soil it has improved:

It is important to recognise that the improvements seen at macro-scale (e.g., yields, erosion-avoidance, water supplies and farm profitability), are underlain and driven by essential features and processes happening at micro-scale in the soil itself.

“Widespread adoption of CA has been demonstrated to be capable of producing “large and demonstrable savings in machinery and energy use, and in carbon emissions, a rise in soil organic matter content and biotic activity, less erosion, increased crop-water availability and thus resilience to drought, improved recharge of aquifers and reduced impact of the apparently increased volatility in weather associated with climate change. It will cut production costs, lead to more reliable harvests and reduce risks especially for small landholders. … ”[4] .

5.2 Higher stable yields and incomes from CA and 'sustainability' as a key attribute

As an effect of CA, the productive potential of soil rises because of improved interactions between the four factors of productivity: (a) physical: better characteristics of porosity for root growth, movement of water and root-respiration gases; (b) chemical: raised CEC gives better capture, release of inherent and applied nutrients: greater control/release of nutrients; (c) biological: more organisms, organic matter and its transformation products; (d) hydrological: more water available.

The combination of above features which raises productive potential makes the soil a better environment than before for the development and functioning of crop-plants' roots. Improvements in the soil's porosity has two major positive effects: (a) a greater proportion of the incident rainfall enters to the soil; (b) the better distribution of pore-spaces of optimum sizes results in a greater proportion of the received water being held at plant-available tensions. Either or both together mean that, after the onset of a rainless period, the plants can continue growth towards harvest - for longer than would previously been the case - before the soil water is exhausted. In addition, increased quantities of soil organic matter result in improved availability, and duration of their release into the soil water, of needed plant nutrients – both those within the organic matter and those applied 'from the bag'. Thus the availability of both water and plant nutrients is extended together. Under these conditions, plants have a better environment in which to express their genetic potentials, whether they have been genetically-engineered or not. Yield differences have been reported in the range 20%−120% between CA systems and tillage systems in Latin America, Africa and Asia[5,50-52].

"Machinery and fuel costs are the most important cost item for larger producers and so the impact of CA on these expenditure items is critical. Most analyses suggest that CA reduces the machinery costs. Zero or minimum tillage means that farmers can use a smaller tractor and make fewer passes over the field. This also results in a lower fuel and repair costs. However, this simple view masks some complexities in making a fair comparison. For example, farmers may see CA as a complement to rather than as a full substitute for their existing practices. If they only partially switch to CA (some fields or in some years), then their machinery costs may rise as they must now provide for two cultivation systems, or they may simply use their existing machinery inefficiently in their CA fields" [49].

No-till, or a reduced proportion of the area needing tillage (e.g., planting basins, or 'zai/tassa/likoti'), requires less input of energy per unit area, per unit output, and lower depreciation-rates of equipment than formerly. It involves lower production costs, thereby increasing the profit margin, at the same time as lessening emissions from burning of tractor-fuel.

Better soil protection by mulch cover minimises both runoff volumes and the scouring of topsoil carrying with it seeds and fertilizers. Such losses represent unnecessary cost, wasted rainwater and wasted energy. Their avoidance increases the margin between profits and costs, which formerly, under tillage agriculture, were accepted as 'normal' expenses to be anticipated.

Systems are less vulnerable to pests, diseases, drought effects because better soil conditions include also greater biotic diversity of potential predators on pests and diseases, while crop rotations break pest build-ups. Here, much of the cost of avoiding or controlling significant attacks is diminished because of it being undertaken by natural predators.

As a result, the financial benefits for farmers in Latin America who have adopted CA have been striking[46]. However, these take time to fully materialize. Sorrenson[50] compared the financial profitability of CA on 18 medium and large-sized farms with conventional practice in two regions of Paraguay over ten years. He found that by the tenth year net farm income had risen from the CA farms from under US$10,000 to over US$30,000, while on conventional farms net farm income fell and even turned negative. Medium and large-scale farmers have experienced:

- Less soil erosion, improvements in soil structure and an increase in organic matter content, crop yields and cropping intensities.
- Reduced time between harvesting and sowing crops, allowing more crops to be grown over a 12-month period.
- Decreased tractor hours, farm labour, machinery costs, fertilizer, insecticide, fungicide and herbicide, and cost savings from reduced contour terracing and replanting of crops following heavy rains.
- Lower risks on a whole-farm basis of higher and more stable yields and diversification into her cash crop [51].

Such effects are cumulative over space/area, and accumulate over time from degraded condition to improved stabilised condition, with yields and income rising over time, as in this example of large-scale wheat production under CA in Kazakhstan. Figure 1 shows the development of wheat yields and financial benefits after changing from conventional tillage to no-till agriculture on mechanised farms in northern Kazakhstan. The internal rate of return to investment (IRR) is equal to 28%[52]. Thus, farmers should turn away from the struggle to reach the highest yield. Instead they should struggle for the highest economic yield. Figure 1 indicates that CA can achieve that goal even under the current conditions prevailing in northern Kazakhstan.

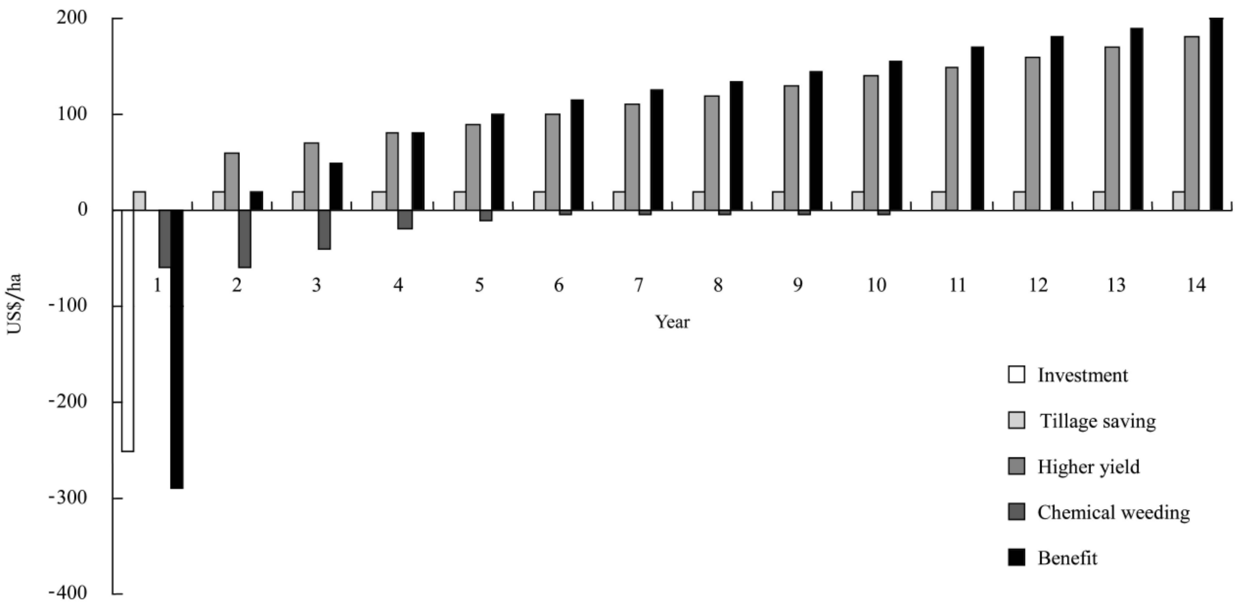

Figure 1 Financial benefits of conservation agriculture in wheat production in northern kazakhstan (IRR = 28%)

Further, in Paraguay, yields under conventional tillage declined 5-15 percent over a period of ten years, while yields from zero-till CA systems increased 5–15 percent. Over the same period, fertilizer and herbicide inputs dropped by an average of 30–50 percent in the CA systems. In Brazil, over a 17-year period, maize and soybean yields increased by 86 and 56 percent respectively, while fertilizer inputs for these crops fell by 30 and 50 percent, respectively. In addition, soil erosion in Brazil decreased from 3.4-8.0 t/ha under conventional tillage to 0.4 t/ha under no-till, and water loss fell from approximately 990 to 170 t/ha[53].

5.3 Climate change adaptation and less vulnerability

Less vulnerability to effects of drought, less erosion, lower soil temperatures, represents a managed adaptation of CA systems to climate-change’s effects of, for example, more intense rainstorms, increased daily ranges of temperatures, and more severe periods of drought. Overall, CA systems have a higher adaptability to climate change because of the higher effective rainfall due to higher infiltration and therefore minimum flooding and soil erosion as well as greater soil moisture holding capacity.

The advantage of CA over tillage agriculture in terms of the duration of plant-available soil moisture is clearly illustrated by the work reported by Derpsch *et al.*[54], which shows that the situation with respect to soil moisture conditions in the rooting zone throughout growing-season under CA is much better than under minimum tillage and under conventional tillage. Stated another way, the crops under the CA system would have continued towards maturity for longer than those in soil with conventional tillage. In addition, the period in which available nutrients can be taken up by plants is also extended, increasing the efficiency of their use. The greater the volume and longer duration of soil moisture's availability to plants (between the soil's Field Capacity and Wilting Point) under CA treatment has significant positive indications for farming stability and profitability. The range of pore sizes which achieve this also implies the presence of larger pores which contribute to through-flow of incident rainwater down to the groundwater[43].

Infiltration rates under well-managed CA are much higher over very extended periods than in TA due to better soil porosity. In Brazil[46], a six-fold difference was measured between infiltration rates under CA (120 mm per hour) and TA (20 mm per hour). CA thus provides a means to maximize effective rainfall and recharge of groundwater as well as reduce risks of floods, due to improved water infiltration. Due to improved growing-season moisture regime and soil storage of water and nutrients, crops under CA are healthier, requiring less fertiliser and pesticides to feed and protect the crop, thus leading to a lowering of contamination of soil, water, food and feed. In addition, in soils of good porosity anoxic zones hardly have time to form in the root zone, thus avoiding problems of the reduction of nitrate to nitrite ions in the soil solution.

Good mulch cover provides 'buffering' of temperatures at soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimising a potential cause of limitation of yields. By protecting the soil surface from direct impact by high-energy raindrops, it prevents surface-sealing and thus maintain soil's infiltration-capacity.

In the continental Europe, Russia and North America region where a significant portion of annual precipitation is in the form of snow fall in the winter, CA provides a way of trapping the snow evenly in the field which may otherwise blow away, and also permitting snow to melt evenly into the soil, thus maximising effective precipitation. In the semi-arid areas of continental Eurasia, one-third or more of the precipitation is not effectively used in tillage systems, forcing farmers to leave land fallow to 'conserve' soil moisture. On the other hand, in CA system, more soil moisture can be conserved than leaving the land as fallow, thus allowing for the introduction of additional crops including cover crops into the system[55,56]. In the tropics and sub-tropics, similar evidence of adaptability to climate change and to rainfall variability has been reported[47,48].

5.4 Reduced greenhouse gas emissions

No-till farming also, and most importantly, reduces the unnecessarily-rapid oxidation of organic matter to CO_2 which is induced by tillage. Together with addition of mulch as a result of saving crop residues *in situ*, there is a reversal from net loss to net gain of carbon in the soil, and the commencement of long-term processes of carbon sequestration[57].

Making use of crop residues, in addition to the direct exudation of carbon by roots into the rhyzosphere, represents the retention of much of the atmospheric C captured by the plants and retained above the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown, (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration. Tillage however results in rapid oxidation to CO2 and loss to the atmosphere. Expanded across a wide area, CA has potential to slow/reverse rate of emissions of CO2 and other 'greenhouse' gases by agriculture.

Studies in southern Brazil show an increase in carbon in the soil under conservation agriculture. According to Testa *et al.*[58], soil carbon content increased by 47 percent in the maize-lablab system, and by 116 percent in the maize-castor bean system, compared to the fallow-maize cropping system which was taken as a reference. Although exceptions have been reported, generally there is an increase in soil carbon content under CA systems as shown by the analysis of global coverage by West and Post[59]. In systems where nitrogen was applied as a fertilizer, the carbon contents increased even more. Baker *et al.*[60] found that crop rotation systems in CA accumulated about 11 t/ha of carbon after nine years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 t/ha per year of CO_2[51].

With CA, reduced use of tractors and other powered farm equipment results in lesser emissions of exhaust gases. Up to 70% in fuel savings have been reported[4]. CA systems can also help reduce the emissions for other relevant green house gases, such as methane and nitrous oxides, if combined with other complementary techniques. Both methane and nitrous oxide emissions result from poorly aerated soils, for example from permanently flooded rice paddies, or from severely compacted soils, or from heavy poorly drained soils. CA improves the internal drainage of soils and the aeration and avoids anaerobic areas in the soil profile, provided soil compactions through heavy machinery traffic are avoided and the irrigation water management is adequate. Technical solutions are available for both.

In most agricultural soils biogenic formation of nitrous oxide is enhanced by an increase in available mineral N which, in turn increases the rates of aerobic microbial nitrification of ammonia into nitrates and anaerobic microbial reduction (denitrification) of nitrate into nitrogen. Addition of fertilizer N, therefore, directly results in extra nitrous oxide formation as an intermediate in the reaction sequence of both processes which leaks from microbial cells into the atmosphere[61]. In addition, mineral N inputs may lead to indirect formation of nitrous oxide after N leaching or runoff, or following gaseous losses and consecutive deposition of nitrous oxide and ammonia. CA generally reduces the need for mineral N by some 30 to 50%, and enhances nitrogen factor productivity. Also, nitrogen leaching and nitrogen runoff is minimal under CA systems. Thus overall, CA has the potential to lower nitrous oxide emissions[62] and even mitigate most or all of all the other GHG emissions as reported by Robertson *et al.*[63] for the mid-west USA and Metay *et al.*[64] for the Cerrado soil in Brazil. However, the potential for such results applying generally to the moist and cool UK conditions have been challenged by Bhogal *et al.*[65] and questions have been raised over their validity due to the depth of soil sampled, particularly for nitrous oxide emissions and the overall balance of GHG emissions (expressed on a carbon dioxide (CO_2-C) equivalent basis).

5.5 Better ecosystem functioning and services

Societies everywhere benefit from a multitude of resources and processes that are supplied by nature. Collectively they are known as ecosystem services because there is a demand for these natural assets and processes by human beings for their survival and well-being. These ecosystem services include products such as clean drinking water, edible and non-edible biological products, and processes that decompose and transform organic matter. Five categories of services are recognised -- *provisioning* such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; *cultural*, such as spiritual and recreational benefits; and *preserving*, which includes guarding against uncertainty through the maintenance of biodiversity.

Greater quantities of cleaner water and increased biological nitrogen fixation:

CA's benefits from ecosystem services derive from improved soil conditions – air-space, water, nutrition – in the soil volume explored by plants' roots. The improvement in the porosity of the soil is effected by the actions of the soil biota – such as microscopic bacteria, fungi, small insects, worms etc. - which are present in greater abundance the soil under CA. The mulch on the surface protects against the compacting and erosive effects of heavy rain, damps-down wide temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface.

When the effects, seen on a square meter of a field surface, are reproduced across enough farms in a contiguous micro-catchment within a landscape, and beyond, the ecosystem services provided-such as clean water, sequestration of carbon, avoidance of erosion and runoff - all become more apparent. The benefits of more water infiltrating into the ground beyond the depth of plant roots is perceptible in terms of more-regular stream-flow from groundwater through the year, and/or more reliable yields from wells, boreholes. The benefits of carbon-capture become apparent in terms of the darkening colour and more crumbly 'feel' of the soil, accompanied by improvements in crop growth, plus less erosion and hence less deposition of sediment downstream in streambeds, blocking bridges etc.

Legumes in CA rotations provide increased *in-situ* availability of nitrogen, as the essential plant nutrient for producing biomass, diminishing the need for large amounts of applied nitrogenous fertilizers. Also, there is increasing evidence of significant amount of 'liquid carbon' being deposited into the soil through root exudation into the rhizosphere.

Society gains from CA on both large and small farms by:

- much-diminished erosion and runoff,
- less downstream sedimentation and flood-damage to infrastructure;
- better recharge of groundwater, more regular stream-flow throughout the year, and the drying of wells and boreholes less frequent.
- cleaner civic water supplies with reduced costs of treatment for urban/domestic use;
- increased stability of food supplies due to greater resilience of crops in the face of climatic drought;
- better nutrition and health of rural populations, with less call on curative health services.

Protection and better use of agrobiodiversity:

The addition of soil organic carbon also clearly represents the incremental development of the soil from the surface downwards, by contrast with its depletion under tillage agriculture.

In CA systems, the mixtures, sequences and rotations of crops encourages agro-biodiversity because each crop will attract different overlapping spectra of micro-organisms. The optimisation of the populations, range of species and effects of the soil-inhabiting biota is encouraged by the recycling of crop residues and other organic matter which provides the substrate for their metabolism. Rotations of crops inhibit the build-up of weeds, insect pests and pathogens by interrupting their life-cycles, making them more vulnerable to natural predator species, and contributing development inhibiting allelochemicals.

Above-ground the same crop mixtures, sequences and rotations provide mixed habitats for insects, mammals, birds, without undue mechanical disturbance during the year. Under CA, increased biodiversity from both soil organisms' proliferation as well as from the wider range of crops favours a broader range of insect pollinators.

6 Concluding remarks

"The age-old practice of turning the soil before planting a new crop is a leading cause of farmland degradation. Tillage is a root cause of agricultural land degradation - one of the most serious environmental problems world wide – which poses a threat to food production and rural livelihoods"[66].

With increasing awareness that sustainability of agricultural production is a must if sustainable development at national and global level is to be achieved, Conservation Agriculture/No-tillage systems will continue to grow world wide. But for sustained growth to take place the main barriers to no-till adoption need to be overcome.

- Mindset (tradition, prejudice)
- Knowledge on how to do it (know how).
- Availability of adequate machines
- Availability of adequate herbicides
- Adequate policies to promote adoption

These barriers must be overcome by politicians, public administrators, farmers, researchers, extension agents and university professors. With adequate policies to promote Conservation Agriculture/No-till, it is possible to obtain what is called the triple bottom line, economic, social and environmental sustainability, while at the same time improving soil health and increasing production[6,7].

Farmers, researchers and extensionists need to reflect on the benefits of no-till farming systems [29].

- 96% less erosion

- 66% reduction in fuel consumption
- Reduced CO_2 emissions
- Enhanced water quality
- Higher biological activity
- Increased soil fertility
- Enhanced production stability and yields
- Incorporation of new areas into production
- Lower production costs

Recognizing the multiple benefits of no-tillage farming over reduced and conventional tillage-based farming systems should foster research and development efforts in order to overcome the bottlenecks of the system and help extensionists in diffusing the technology so that farmers can have a sound basis for practical application.

The wide recognition of Conservation Agriculture as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The widespread adoption of no-tillage system[1,2] shows that this way of farming can not any longer be considered a temporary fashion. Instead, this farming system has established itself as a technology that can no longer be ignored by politicians, scientists, universities, extension workers, farmers as well as machine manufacturers and other agriculture related industries.

No tillage and Conservation Agriculture has initially been developed as farming methods to reduce erosion. It has been proven that with CA the erosion rates can be brought to levels below the soil formation, which makes the system in the long term sustainable. A review of human history and the fate of human civilizations through the millennia of human development on earth have shown that the survival of civilizations has directly been linked to the way they treated their soils. Each decline of a civilization was accompanied with significant soil erosion events, which still today can be geomorphologically been proven[67]. With this the adoption of no-tillage and CA is becoming a question of the long term survival of human civilization in the way we know it today.

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