Development and Current Status of No-till Adoption in the World

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Abstract

In 1999 no-tillage, synonymous of zero tillage, was adopted on about 45 million ha world wide (Derpsch, 2001), growing to 72 million ha in 2003 (Benites, et al., 2003) and to 105 million ha in 2009. Fastest adoption rates have been experienced in South America where some countries are using no-tillage on about 70% of the total cultivated area. Opposite to countries like the USA where often fields under no-tillage are tilled every now and then, more than two thirds of no-tillage practiced in South America is permanently under this system, in other words once started, the soil is never tilled again. The adoption of no-tillage on more than 105 million ha shows the great adaptability of the system 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 3000 m altitude, from extremely rainy areas with 2500 mm a year to extremely dry conditions with 250 mm a year. The wide recognition as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still low as soon as the barriers for its adoption have been overcome. The widespread adoption also shows that no-tillage can not any more be considered a temporary fashion, instead the system has established itself as a technology that can no longer be ignored by scientists, universities, extension workers, farmers as well as machine manufacturers and politicians.

Key words: World wide no-till adoption / zero tillage adoption / conservation agriculture adoption

INTRODUCTION

The rapid expansion of the area under no-tillage / zero tillage from 45 million ha in 1999 to 105 million ha in 2008 shows the increasing interest that this technology is having among farmers. The superiority of this system in relation to unsustainable intensive tillage practices, time, labor and fuel savings as well as higher economic returns are the driving forces for this development. In almost every country there are at least some activities in no-tillage, be it in research or in farmer adoption. No-tillage has expanded to soils and climates earlier thought inadequate for practicing the technology successfully. No-tillage is now being practiced by farmers from the artic circle (e.g. Finland) over the tropics (e.g. Kenya, Uganda), to about 50º latitude South (e.g. Malvinas/Falkland Islands). From sea level in several countries of the world to 3000 m altitude (e.g. Bolivia, Colombia), from extremely dry conditions with 250 mm precipitation a year (e.g. Western Australia), to extremely rainy areas with 2000 mm a year (e.g. Brazil) or 3000 mm a year (e.g. Chile). No-tillage is practiced on all kind of farm sizes from half hectare (e.g. China, Zambia) to hundreds of ha in many countries of the world, to thousands of ha in countries like Australia, Brazil, USA or Kazakhstan. It is practiced on soils that vary from 90% sand (e.g. Australia), to 80% clay (e.g. Brazil's Oxisols and Alfisols). Soils with high clay content in Brazil are extremely sticky but this has not been a hindrance to no-till adoption when appropriate equipment was available. Soils which are extremely sensitive to crusting do not present this problem under no-tillage because the mulch cover avoids the formation of crusts. 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 grown adequately in the no-tillage system and to the authors knowledge there has not yet been found a single crop that would not grow under this system, including root 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 to areas where adoption is still low as soon as the barriers for its adoption have been overcome. 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) and availability of suitable herbicides to facilitate weed management (especially in developing countries). 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. The widespread adoption of no-tillage under a great range of different conditions on more than a 105 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 revert the process of soil degradation into a process of building up its fertility. No-tillage technologies have a great potential to increase organic matter content of the soil and sequester carbon as opposed to intensive tillage systems that constantly reduce the carbon content of the soil.

METHODS OF GATHERING INFORMATION ABOUT ADOPTION

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 consulted qualified informants in the different countries which are listed below table 4. 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 cheeked 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 is practiced around the world.

Farmers that do rotational tillage, (e.g., tilling every third or forth 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 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 (Neonila Martiniuk, personal communication, 2009). 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 real 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 would be counted.

A CLEAR CONCEPT ABOUT NO-TILLAGE TERMINOLOGY IS NEEDED.

As the understanding of no-tillage (synonymous of zero tillage) often varies 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, weed and pest management as well as fertilization and selection of crop varieties need to be adapted to meet the systems 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 (1973) (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) (FAO, 2008) which is based on three principles (FAO, 2009):

1. Continuous minimum mechanical soil disturbance (the minimum soil disturbance necessary to sow the seed)
2. Permanent organic soil cover (retention of adequate levels of crop residues on the soil surface)
3. Diversified crop rotations (to help moderate possible weed, disease and pest problems)

DEVELOPMENT OF NO-TILLAGE IN EUROPE INCLUDING RUSSIA

Europe is the developing continent regarding Conservation Agriculture adoption (Basch, 2005). Only Africa has a smaller area under Conservation Agriculture / no-till than Europe. "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" (Basch, 2005).

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 (Giráldez and González, 1994).

Spain is the leading country in terms of no-till adoption in Europe. According to AEAC/SV (Spanish Conservation Agriculture Association – 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 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 (Boisgontier et al., 1994). 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 Conservation Agriculture/No-till adoption. 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 that 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 mayor 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 this country. About ten no-till seeders 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. They go from less then 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 wish. According to Agrosoyuz (a big 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 they use wide tines and often duckfoot openers. For this reason this form of seeding can not 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 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), expose the soil to erosion under the topography prevailing in this country. According to Swiss No-till http://www.No-till.ch 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-tilllage technologies in Germany started in 1966 (Bäumer, 1970). Intensive and long term research in Germany by Bäumer, Czeratzki, Kahnt and later Teebrügge and Böhrensen, concluded that no-tillage is a viable a cultivation system. According to Tebrügge and Böhrnsen, (1997) no-tillage is a very profitable cultivation system compared to conventional tillage because of the lower machinery costs and lower operating costs. No-tillage decreases the purchase costs, the tractor power requirement, the fuel consumption, the amount of required labour as well as the variable and fixed costs. Since the same crop yields can be achieved by no-tillage compared to plough tillage, on average the profit will increase.

Despite these facts adoption in Germany is still very low. Well informed scientist, farmers and experts

with a thorough understanding of no-till as practiced in most parts of the world coincide, that probably still today there are no more than about 5000 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. http://www.infofarm.de/sn/BetriebSander/index.html 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 boosting fertilizer and fuel prices, erosion problems in some regions and regular droughts in others, the interest in no-tillage is growing steadily and adoption is increasing. Some farmers like Alfons Bunk from Rottenburg, Suabia are 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 was not possible to get realistic numbers for this country. We need to recognize that in this huge country it is difficult 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 with this is part of the European Conservation Agriculture Federation (ECAF). For this reason there should be a considerable area under no-tillage being practiced in this country. We hope to be able to get reliable estimates on the area under no-tillage in Russia in future.

DEVELOPMENT OF NO-TILLAGE IN THE 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 (Phillips and Phillips, 1984). Since than 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 (Hebblethwaite, 1997), representing about 50% of worlds total at that time.

The United States has been among the few countries that 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 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 (2005) 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 (CTIC, 2007). The CTIC CRM data collection shows the 2007 Amendment to the National Crop Residue Management Survey Summary which is based on 374 counties in 8 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 acres have increased from 23.2% to 25.5% of total cropland acres. Although the percentage of adoption has increased the numbers still reveal that the majority of farmers in this country are still using conventional or reduced tillage practices. Despite the fact that the growth of the area under no-tillage in the US was not dramatic, a continuous and steady growth could be observed in the last decade.

Table. 1: Area under no-tillage in the United States (CTIC, 2005/07)

Year	Area (million hectares)
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

Canada 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 cover and crop rotations. As a consequence between 1999 and 2004 the amount of wheat grown in Canada went down by 6.4 %, while the oil crops increased by 48.7 % and pulses by 452.7 %. At the same time the use of fallow went down by 58.7 % (Yuxia Li and Chi Chang, 2007). 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.

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 (Doug McKell, personal communication 2008). 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 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.

DEVELOPMENT OF NO-TILLAGE IN 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 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) (2009) in the season 2005/06 there were 25.5 million ha of no-tillage being practiced in this country. (http://www.febrapdp.org.br) 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 (Derpsch, 2005). 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 ha 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. 2: Area under no-tillage in Brazil (FEBRAPDP, 2009)

Year	Area (million hectares)
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

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 mayor 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 started with the 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 (simultaneous translation into English), which have been visited by more than 1000 farmers at the beginning and nowadays exceed 2000 farmers. Since the founding of AAPRESID also Argentina experienced an exponential growth of the system.

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 do can be seeded. According to AAPRESID (2008) in 2006 there were 19.7 million ha of no-tillage being practiced in this country (http://www.aapresid.org.ar). 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 using no-till in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned no-till experts from Chile, as well as with Dr. Shirely Phillips and Dr. Grant Thomas from the US. At the beginning growth was slow because of lack of experience, knowledge on how to do it, machines and limitations on the availability of herbicides. It took 15 years until 1992/93 when about one million ha under no-tillage were reached. Since then adoption 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. The main advantages of the system according to AAPRESID (2008), 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.

Similar to other countries in South America, farmers in Argentina like to do permanent no-tillage once they have started with the system. More then 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.

Table. 3: Area under no-tillage in Argentina (AAPRESID, 2008)

Year	Area (million hectares)
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

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 on, with the support of a GTZ project, no-tillage expanded massively throughout the country. Whole landscapes have been transformed to country sides where 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 where 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 under small farmers.

Bolivia: In 1986, after visiting Brazil and Argentina, the farmer Dr. Jean Landivar started no-tillage on his 2000 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 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 agriculture and livestock is very popular and no-tillage fits very well into the requirements of this 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 (Derpsch, 2005).

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 eliminating 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 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" (No-till Farmer, 1997).

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 study by CIMMYT showed that the real area is about 50.000 ha.

DEVELOPMENT OF NO-TILLAGE IN AUSTRALIA AND NEW ZEALAND

Australia: According to Bill Crabtree, no-tillage Consultant and member of WANTFA (Western Australia No-till Farmers Association) no-tillage is now practiced on about 12 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 (Llewellyn, et al., 2009). 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 (Llewellyn, et al., 2009). 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 (Flower et al., 2008). 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% (Flower et al., 2008).

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.

New Zealand: This country is among the first countries 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 (personal communication, 2008) 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 real 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.

DEVELOPMENT OF NO-TILLAGE IN ASIA

China: In general an average a farmer in China only works about 0.08 ha 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 this country and has to be taken into consideration when putting together numbers on tillage practices. But one thing is certain, the area under Conservation Agriculture has greatly increased in the last 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. According to Li Hongwen from the Conservation Tillage Research Centre (personal communication, 2008) 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 is practiced on about 2.66 million ha. As no-tillage makes 50% of conservation tillage he informs that there are 1.33 million ha under no-tillage being practiced in China. The data for no-tillage is conjectured according to their knowledge and reports from different provinces and is based on talking to farmers and local administrative organizations. China is now producing many types of no-till seeders for smaller tractors and has difficulties to cover the high demand. Soil erosion by wind and water as well as scarce water, low levels of organic matter and declining productivity has been among the main driving forces for a quick adoption of no-tillage in this country. Paradoxically another factor has been limited labour availability because an increasing amount of young farmers have left for jobs in the cities leaving the older farmers behind.

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. According to Mekhlis Suleimenov (personal communication 2008) no-till adoption started from 2004 on in the north Provinces (North-Kazakhstan, Kostanai and Akmola), were the highest adoption rates have been registered. 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 tillage practices. As this can not be, in our view, termed no-tillage, we are not including it in our overview. According to Raj Gupta (personal communication,

2008), 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. The Rice – Wheat consortium for Indo-Gangetic-Plains, an initiative of CGIAR that involves several National Agricultural Research Centres has been promoting no-tillage and it is mainly 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) (Inder Pal Abrol, personal communication, 2008).

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 some times 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" (FAO, 2007). 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: (Engin Çakir, personal communication 2009).

- 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.

DEVELOPMENT OF NO-TILLAGE IN 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 (FAO 2008a).

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 (Derpsch, 2005). According to Richard Fowler (personal communication, 2008) 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 need 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 6000 ha on 78 farms in 2007 (Baccouri,2008).

EXTENT OF CA / NO-TILLAGE ADOPTION WORLD WIDE

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 (Derpsch, 1998) 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 world wide adoption of the no-tillage technology of 45 million ha (Derpsch, 2001). As shown by Benites, et al (2003) 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 106 million ha showing the increased interest of farmers in this technology (Table 4).

Table 4: Extent of No-tillage Adoption World Wide (countries with > 100.000 ha)

Country	Area under No-tillage (ha) 2007/2008
USA [1]	26.593.000
Brazil [2]	25.502.000
Argentina [3]	19.719.000
Canada [4]	13.481.000
Australia [5]	12.000.000
Paraguay [6]	2.400.000
China [7]	1.330.000
Kazakhstan [8]	1.200.000
Bolivia [9]	706.000
Uruguay [10]	672.000
Spain [11]	650.000
South Africa [12]	368.000
Venezuela [13]	300.000
France [14]	200.000
Finland [15]	200.000
Chile [16]	180.000
New Zealand [17]	162.000
Colombia [18]	100.000
Ukraine [19]	100.000
Russia [20]	?
Others (Estimate)	1.000.000
Total	**105.863.000**

Source: Derpsch, R. and Friedrich, T., 2009

Information provided by: 1) CTIC, 2007; 2) FEBRAPDP, 2005/06; 3) AAPRESID, 2006; 4) Dr. Doug McKell, Soil Conserv. Council of Canada, 2006; 5) Bill Crabtree, 2008; 6) MAG & CAPECO, 2008; 7) Li Hongwen, 2008; 8) Mekhlis Suleimenov, 2007; 9) ANAPO, Bolivia, 2007; 10)) Miguel Carballal AUSID, 2007; 11) Emilio González-Sánchez, AEAC/SV, 2008; 12) Richard Fowler, 2008; 13) Rafael E. Perez, 2004; 14) APAD, 2008; 15) Timo Rouhianinen, FINCA, 2008; 16) Carlos Crovetto, 2008; 17) John Baker, 2008; 18) Fabio Leiva, 2008; 19) Estimate by the authors.

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 106 million hectares world wide. As table 5 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. 5: Area under No-tillage by continent

Continent	Area (hectares)	Percent of total
South America	49.579.000	46.8
North America	40.074.000	37.8
Australia & New Zealand	12.162.000	11.5
Asia	2.530.000	2.3
Europe	1.150.000	1.1
Africa	368.000	0.3
World total	**105.863.000**	**100%**

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" (Huggins and Reganold, 2008).

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.

Farmers, researchers and extensionists need to reflect on the benefits of no-till farming systems (AAPRESID, 2008).

- 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 over reduced and conventional 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 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 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**.

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