# THE NO-TILLAGE REVOLUTION IN SOUTH AMERICA

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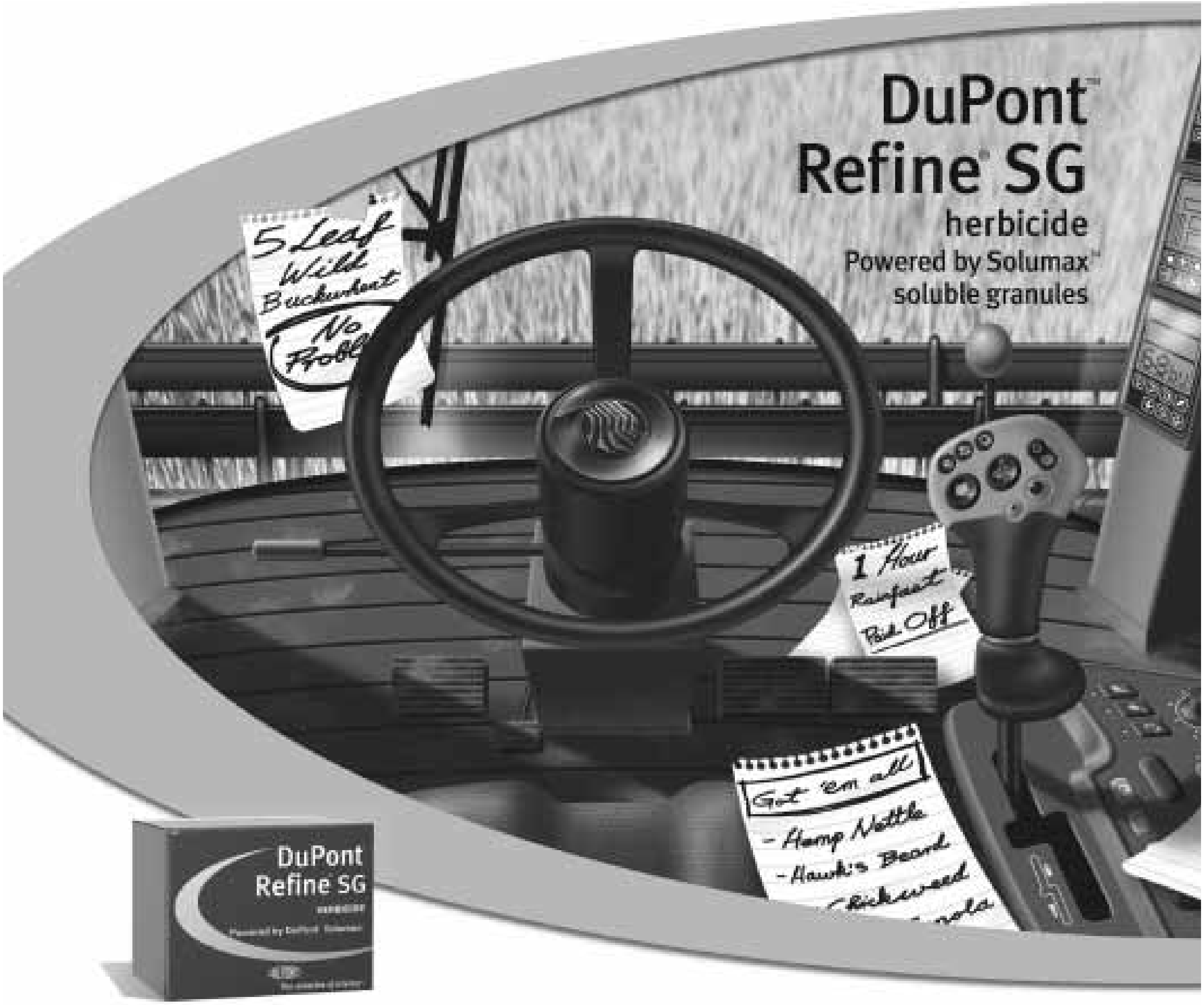
## Abstract

The area under no-tillage has been growing steadily all over the world, but highest rates of adoption have been achieved in South America. The no-tillage technology is now being adopted on more than 95 million ha world wide. Approximately 47% of that area corresponds to South America, 39% to the United States and Canada, 9% to Australia and only 3.9% to the rest of the world. In the MERCOSUR countries (Brazil, Argentina, Paraguay and Uruguay) the area under no-tillage expanded 59 times between 1987 and 2004, from 0.67 to 39.6 million ha, against an expansion of only 5.8 times, from 4.05 to 23.7 million ha in the USA. There are several reasons for the faster growth in South America. Mindset ranks among the most important reasons for a slow change in countries where agriculture is older and deep rooted traditons hinder abandonment of tillage and the plough. Mindset continues to be one of the biggest barriers to no-till adoption not only for farmers, but for researchers and extensionists as well. A paradigm change has to take place in order to accept new and more sustainable production systems that do away with tillage.

The following are probably the main factors that induced such a rapid change in South America: 1) Efficient and economic erosion control. 2) Appropriate knowledge was available in the region. 3) Widespread use of cover crops. 4) The same consistent message, positive to no-tillage has generally been voiced by all sectors involved (private and public) without contradictions. 5) No-tillage has been the only conservation agriculture technology recommended to farmers. 6) There has been an aggressive farmer to farmer extension through farmers' associations. 7) Publications with adequate, practical and useful information were made available to farmers and extensionists. 8) Economic evaluations with system approach showed high economic returns of no-tillage, as well as the use of cover crops and crop rotations in the system. 9) There have been no major forces against the system, and finally 10) South American farmers have had to be very competitive in the global market, since there are no subsidies. It is believed that subsidies hamper the creativity of farmers in industrialized countries while South American farmers have to manage cost effective production systems to survive.

Farmers in South America have learned to deal with problems of surface soil acidity, soil compaction, or concentration of phosphorus at the soil surface without needing to till the soil. While more than 85% of South American farmers are applying permanent no-tillage systems, this is only the case with 10 - 12% of farmers in the US. It is becoming evident that the full benefits of a no-till system manifest themselves only after about 20 years of continuous no-till. At the same time it is believed that farmers that apply rotational tillage will never get to harvest the full benefits of the no-till system.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## Introduction

No-tillage is defined in South America 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 is 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 by 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. The quality of the no-till system will be defined by the percentage of soil cover with plant residues, by low disturbance seeding, the years of continuous no-till and by the use of crop rotation and cover crops.

Farmers in South America have learned that almost all advantages of the no-tillage system come from the permanent cover of the soil and only a few from not tilling the soil. Green manure cover crops are used to increase soil cover in an environment where residues decompose quite rapidly. In order to maintain high amounts of crop residues on the soil surface disc seeding systems are more appropriate than tines which clog with heavy residue and cause high soil disturbance covering residues because of soil throw. For this and historical reasons farmers in South America almost exclusively use disc seeding systems.

Control of soil erosion and improving soil quality combined with less work and greater profits are among the main driving forces for no-tillage adoption in South America. In contrast to conventional tillage practices no-tillage is considered to be an environmentally desirable technology with positive effects on water infiltration and erosion control, on soil chemical, physical and biological soil properties, on carbon sequestration, it counteracts soil degradation and desertification and achieves long term sustainability of agricultural production.

## World wide adoption of no-tillage with special reference to South America

One has to be aware that only a few countries in the world conduct surveys on the extent of no-tillage adoption and that in most cases the data is based on estimates made by farmer organizations, agro industry and others. Table 1 shows the estimated area under no-tillage world wide.

It is estimated that in 2005 no-tillage was practiced on more than 95 million hectares world wide. Approximately 47% of the technology is practiced in South America, 39% is practiced in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world, including Europe, Africa and Asia. Despite good and long lasting research in all three continents showing positive results for no-tillage, this technology has only had small rates of adoption in this part of the world.

Since 1999 (when no-tillage was adopted on about 45 million ha) the area has more than doubled to 95 million ha in 2005 and probably will exceed a 100 million ha in 2006.

As can be seen in table 1 there are six countries with more than one million ha of no-tillage being adopted world wide, they are: USA, Brazil, Argentina, Canada, Australia and Paraguay.

Table 1: Extent of no-tillage adoption world wide (Derpsch, 2005)

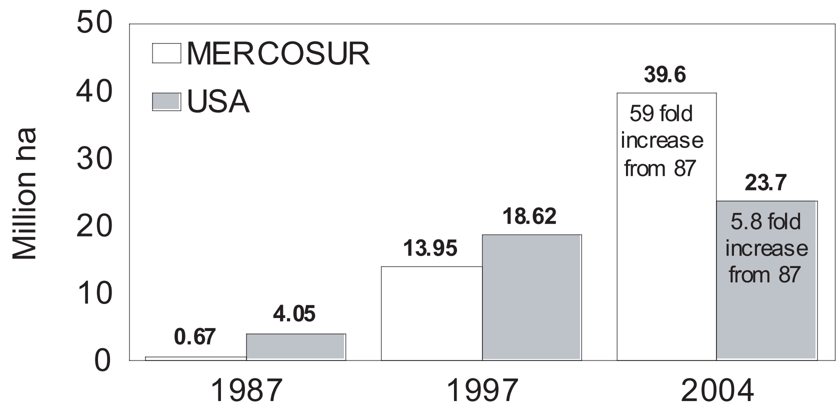
| Country | Area under No-tillage (ha) 2004/2005 |
|---|---|
| USA [1] | 25.304.000 |
| Brazil [2] | 23.600.000 |
| Argentina (*) [3] | 18.269.000 |
| Canada [4] | 12.522.000 |
| Australia [5] | 9.000.000 |
| Paraguay [6] | 1.700.000 |
| Indo-Gangetic-Plains (**) [7] | 1.900.000 |
| Bolivia [8] | 550.000 |
| South Africa [9] | 300.000 |
| Spain [10] | 300.000 |
| Venezuela [11] | 300.000 |
| Uruguay [12] | 263.000 |
| France [13] | 150.000 |
| Chile [14] | 120.000 |
| Colombia [15] | 102.000 |
| China [16] | 100.000 |
| Others (Estimate) | 1.000.000 |
| **Total** | **95.480.000** |

**Source:** 1) John Hassel CTIC, 2005; 2) FEBRAPDP, 2005; 3) AAPRESID, 2004; 4) Dr. Doug McKell, Soil Conserv. Council of Canada, 2004; 5) Bill Crabtree, WANTFA, 2005, 6) MAG – DEAG, Soil Conservation Program, 2005; 7) Dr. Peter Hobbs & Raj Gupta 2005; 8) Carlito Los, 2005, 9) Richard Fowler, 2003; 10) ECAF Homepage, 2005; 11) Rafael E. Perez, 2004; 12) Miguel Carballal AUSID, 2005; 13) ECAF Homepage, 2005; 14) Carlos Crovetto, 2005; 15) Fabio Leiva, 2005; 16) Li Hongwen, 2005;
(*) Preliminary information based on 40% of data collection for 03/04
(**) Includes four countries in South Asia, India, Pakistan, Bangladesh and Nepal

Numbers for China are preliminary and could be greater. In Northern China several hundred thousand ha are used in double cropping wheat and maize. Most maize is no-till seeded, but in the autumn, after maize harvesting, all the fields are ploughed to sow wheat. As this can not be considered to be no-tillage, this area is not included in the above table (Li Hongwen, personal communication 2005).

In the MERCOSUR countries (Brazil, Argentina, Paraguay and Uruguay) the area under no-tillage expanded 59 times between 1987 and 2004, from 0.67 to 39.6 million ha, against an expansion of only 5.8 times, from 4.05 to 23.7 million ha in the USA (Figure 1). This shows that the fastest growth of the no-till technology world wide has been achieved in South America.

Figure 1: Expansion of the area under no-tillage in the USA and Mercosur (Brazil, Argentina, Paraguay, Uruguay) (million hectares)




Among the countries which probably will continue to show the highest adoption rates in the coming years are Brazil and Argentina. The author of this paper and leading no-till experts in the region believe that in less than a decade more than 85% of the cultivated area of these countries will be under no-tillage.

### Reasons why adoption has been so extensive in South America

The reasons why adoption has been so extensive and quick in South America are manifold. As agriculture in South America is relatively young with many areas having been incorporated to agricultural production only in the last thirty or forty years, in general there is not a deep rooted tradition to agriculture in these countries. Also production systems have drastically changed. In Paraná, Brazil, for instance they have changed from coffee plantations to soybean production beginning in the 1970's. Young farmer generations have incorporated new land into production in many regions and are open minded to new technologies. Researchers in general have been open to research and develop the new technologies. Mindset has not hindered adoption as much as it has in countries with a more traditional agriculture like Europe, Japan and even the US and Canada. Brazilian farmers and researcher also soon recognized that no-tillage is a completely new production system and that it is not enough to change the seeding machine in order to be practicing no-tillage. To be successful with the new technology the whole system has to be changed.

According Bieber (2000) „no-till is not a farming practice – it‘s a concept of the mind, If you don‘t believe in it you will fail". In other words if a farmer wants to succeed in the no-tillage system, first his mind has to be willing to accept the change. It appears that this change of mind is easier in societies like South America where agriculture has not so deep rooted traditions as for instance in Europe and Asia.

In Africa the situation is different. Colonial powers at the beginning and aid agencies more recently have instructed farmers to use the plough to grow crops and now the same farmers are told that they should do away with the plough. This is a difficult task for any extension service.

A radical change of mind is necessary to implement the no-tillage technology successfully. This is not only true for farmers but for researchers, extensionists, rural development agents and politicians as well. Mindset continues to be the biggest obstacle to no-till adoption in most parts of the world.

Other factors (besides mindset) that have induced such a rapid change in South America are (Derpsch, 2001).

1) Efficient and economic erosion control under climatic conditions with high erosion and soil degradation potential.

2) Appropriate knowledge was available in the region through research and development as well as farmers' experiences.

3) Widespread use of cover crops for weed suppression (reduction in the use of herbicides), organic matter build up, biological pest control, etc.

4) The same consistent message, positive to no-tillage has generally been voiced by all sectors involved (private and public) without contradictions.

5) No-tillage has been the only conservation agriculture technology recommended to farmers.

6) There has been an aggressive farmer to farmer extension through farmers' associations.

7) Publications with adequate, practical and useful information were made available to farmers and extensionists.

8) Economic evaluations with system approach showed high economic returns of no-tillage, as well as the use of cover crops and crop rotations in the system. Economic returns showed to be immediate and substantial.

9) There have been no major forces against the system, and finally

10) South American farmers have had to be very competitive in the global market, since there are no subsidies. It is believed that subsidies hamper the creativity of farmers in industrialized countries while South American farmers have to mange cost effective production systems to survive.

Disc seeding systems used in South America, which make the benefits of no-tillage appear more intensely and quicker (as compared to tine seeding), may be another reason for the fast growth of no-tillage in this part of the world.

### Productions Systems farmers are using

Because of a great diversity of climates and latitudes there are also a variety of production systems used by farmers in South America. Production systems in the south of Argentina and Brazil are different from production systems in the north. Despite this diversity there is one crop that has grown tremendously in area in South America in the last decades, it is soybeans. Soybean production was incipient in the late 1960's and is now the main crop in many countries, especially in Brazil, Argentina and Paraguay. The main reason for this is that the market for this crop is always guaranteed. Many farmers see soybeans as the most profitable crop and therefore they are quite often planted in monoculture. Double cropping wheat and soybeans is a very popular sequence in South America. This is called a double monoculture because soybeans are seeded each year in summer and wheat each year in winter. Wheat has not always been a very profitable crop in the warmer areas of South America, but newer high yielding varieties are appearing in the market that should be more profitable.

Maize is also an important crop in many areas of South America although it often has market problems, especially in Paraguay. Rotating maize and soybeans in summer and wheat and cover crops in winter is a common practice in many regions. But a two year rotation has shown to be too short to overcome some disease as well as pest and weed problems. Therefore research has introduced longer and more diverse rotations which are now used by many farmers, e.g., a three year rotation starting with black oats (as cover crop) – soybeans; wheat – soybeans; lupins or oilseed radish (as cover crops) maize. Some farmers have decided to use this or similar rotations independently of the price situation of crops. In this rotation the farms are divided in thirds and crops are rotated within the fields. These farmers have had high economic returns because they reap all the benefits of rotations in terms of weed control, nutrients, soil cover, organic matter build up, disease and pest control as well as better use of farm machinery due to better distribution of the work load.

Other crops that are cultivated to some extent are sunflowers, sorghum, rice, beans, among the summer crops and canola, oats and barley among the winter crops. Rotating agricultural crops with several years of pastures has also become very popular in many areas of South America.

### Experiences with cover crops in South America

The use of green manure cover crops (GMCC), crop rotation and permanent no-till are key factors for the unprecedented growth of no-tillage especially in Brazil and Paraguay. Only those farmers that have understood the importance of these practices are obtaining the highest economic benefits from this system. While in some regions of the world farmers concentrate on avoiding tillage, South American farmers have understood that adequate production and management of crop residues are key issues in the no-tillage system. When practiced in monoculture no-tillage is an imperfect and incomplete system, in which diseases, weeds and pests tend to increase and profits tend to decrease. Disease, pest and weed outbreak will oblige farmers at a certain point to abandon monoculture and practice crop rotation Adaptive research in this area is the most important factor to make no-tillage work, that is, take advantage of all the benefits of the system, reduce weed pressure and increase economic returns!

More intense and systematic research with green manure cover crops (GMCC) was started in the late 1970's in Brazil and in the 1990's in Paraguay. This resulted in the identification of more than a dozen species, adequate to the climatic and soil conditions in these countries. Testing included more than a 100 species and some varieties of these same species in Brazil. The following GMCC have been identified and are now available for the use by farmers.

Winter cover crops: Black oats (*Avena strigosa Schreb*), rye (*Secale cereale L.*), triticale (*Tritico-cereale*), oilseed radish (*Raphanus sativus var. Oleiferus Metzg*), white bitter lupins (*Lupinus albus L.*), blue bitter lupins (*Lupinus angustifolius L.)* common vetch (*Vicia* *sativa L.*), hairy vetch (*Vicia villosa Roth*), chick peas (*Lathyrus sativus L.*), sunflower (*Helianthus annuus L.*), ryegrass (*Lollium multiflorum L.*) etc.

Summer cover crops: Millets (*Penisetum americanum L., Sorghum bicolor L,* etc), crotalaria (*Crotalaria juncea L.*), lab-lab (*Dolichos lablab L.*), pigeon pea (*Cajanus cajan L.*).

Even plants that up to now have been considered to be noxious weeds like *Brachiaria plantaginea* are used in the Cerrados of North-Central Brazil as cover crops in the no-tillage system. The Cerrados have only one growing season (winters are dry). Here farmers and researchers have developed production systems where cover crops are established in the late growing season (aerial seeding) or immediately after harvest of cash crops. Cover crops die in the dry season and leave enough biomass for soil cover.

Good knowledge about green and dry matter production and profitability of green manure cover crops, how to fit them into different crop rotations and what residual fertilizer effect we can expect of each GMCC planted before the main cash crops is essential for dissemination of their use. A number of publications have contributed in filling this knowledge gap in South America (Sorrenson and Montoya, 1984; Monegat, 1991; Derpsch, et al., 1991; Derpsch and Calegari, 1992; Calegari et al., 1992). Several publications on the use of cover crops have also appeared in the US in the last decade, i. e., (Cover crops for clean water, W. L. Hargrove, Ed. 1991; Managing Cover Crops Profitably, SAN - SARE, 1998: www.sare.org). There is increasing information on cover crops also in web sites (see www.rolf-derpsch.com).

One of the lessons we have learned in the zero tillage system is that farmers should, if possible, never leave the land in fallow. In general fallow periods will result in weed proliferation, seeding of weeds, reduction of soil cover, soil erosion as well as leaching of nutrients. If instead of leaving the land in fallow for weeks and months farmers seed a cover crop, this will result in reduced weed proliferation, increased soil cover and more biomass returned to the soil, increased organic matter content of the soil, protection of the soil against erosion as well as washing out of nutrients, and will finally improve biological conditions of the soil, leading to higher crop yields.

In dryer climates there is always the concern that green manure cover crops may take moisture out of the soil which is not going to be available for crops. This is and should always be a concern in dryer climates. But there are ways of getting around this problem, e. g., choosing species that use less moisture than others, seeding GMCC at a time there is extra moisture in the soil, managing GMCC at the right time in the right way, not letting them to grow too tall or for a too long period to save moisture, etc.

Randy Anderson, a weed ecologist from semi arid South Dakota, has reported good results seeding peas (Pisum arvensis) after harvest of the main crop. Peas are killed when they are about 20 cm high. By that time they have produced enough nitrogen and biomass to pay for the operation (personal communication, 2004). This example shows that creativity and finding new ways of crop sequencing add diversity to the system and can lead to unexpected results.

Sorrenson (1984), among others, has clearly shown the economic advantages of using crop rotation and appropriate cover crops in a no-till system. While many people still think that when using GMCC you are adding costs without getting anything back, farmers especially in Brazil and Paraguay have learned that economics of no-tillage can be substantially increased with their use.

In Brazil and Paraguay the use of green manure cover crops has been growing steadily. Black oats for instance are planted on 3.2 million ha only in the States of Paraná and Rio Grande do Sul, Brazil. In Paraguay this cover crop is used on about 300,000 ha. Linked to the spread of cover crops is the use of a "knife roller" to flatten the cover crops. This implement is not very expensive and in many cases can be made locally or by the farmers themselves. The implement can be pulled by medium sized tractors and has contributed markedly in reducing herbicide applications in the no-tillage system. The knife roller has become an essential tool for managing GMCC in Brazil and Paraguay (See pictures and dimension at www.rolf-derpsch.com). If the implement is not available old disc harrows can be used for the same purpose. In this case steel bars are welded on top of the discs of old disc harrows and the implement used in the same way.

When looking at the experiences in South America we of course can not "copy" what is done there. Farming is always site specific, but the principles of using cover crops and crop rotation are valid all over the world. The experiences with these practices from South America are especially interesting for no-till farmers, because they have played a key role in further developing and improving the no-tillage system. We should be aware that some cover crop species adapt to a very wide range of climatic and soil conditions. Several cover crop species used in South America are well adapted to the conditions of northern United States and Canada. We should be aware that "no matter where you farm, there are cover crop species that meet your need" (USDA-ARS, 2002).

According to Michigan state University Extension numerous Ontario farmers use oilseed radish with excellent results. This cover crop can reduce their herbicide rates by up to 50% in spring, it can reduce cist nematode by 80% and holds great potential to reduce nitrate leaching (Eisenbeis, 1994).

## Challenges encountered and innovations adopted

Surface soil acidity and how to incorporate lime under a permanent no-tillage system, phosphorus concentration at the soils surface as well as soil compaction have been some of the main challenges encountered in South America when changing from conventional agriculture to a system where the soil is not disturbed.

**Surface soil acidity**: Often soils in South America **are acidic or contain toxic aluminium**. If this is the case, farmers apply lime the year before starting with no-tillage because this represents the last opportunity for mechanical incorporation. Later lime is applied at the soil surface. The concepts of liming and fertilisation have greatly changed in South America since shifting to the no-tillage system. Experience has shown that most things learned at university about fertilisation and liming should be revised, and instead the new concepts of fertility management in this system need to be applied. The main principle is that farmers should fertilise their soils rather than their crops. Experience has also shown that lime does not need to be incorporated with tillage implements.

Recent research has shown that farmers can apply lime without incorporating as lime moves into deeper soil layers, especially when applied in combination with green manure cover crops. In such cases, farmers should apply a small quantity of lime each year, instead of applying large amounts at once. Miyazawa, et al., (2002), working on a Typic Haplorthox (U.S. Soil Taxonomy) found that "the effect of lime without plant residues was limited to the upper 10 cm profile. Lime with plant residues changed pH, CAex, Mgex and Alex in the soil profile. The efficiency of plant residues on lime mobility followed the order: black oats (*Avena strigosa Schreb*) (most effective) > rye (*Secale cereale L.*) > mucuna (*Mucuna pruriens*) > leucaena (*Leucaena leucocephala L. de Wit)*. Wheat residue had no effect on the mobility of lime".

One important factor that influenced the quick growth of no-tillage in South America is the fact that here virtually nobody believes in the necessity of incorporating lime with tillage implements after no-tillage has been adopted. As said before, surface application of lime in combination with specific cover crops like black oats and/or oilseed radish (*Raphanus sativus Var. Oleíferus Metzg.*) allow the mobility of lime in the soil profile. This is still something of intensive debate in other parts of the world.

**P stratification**: Soils which have been many years under no-tillage show a higher **concentration of phosphorus in the upper soil layer**. This has not been shown to be negative on plant growth and production. The contrary has been the case, since fertilization with phosphorus can be reduced after many years of no-tillage. In no-tillage the upper soil layer in general has high moisture content and low temperatures, allowing roots to grow right to the soil surface under the mulch. Thus, roots show efficient phosphorus uptake in this layer. It is counter productive to try to mix this concentrated phosphorus, placed on the soil surface, into the soil profile with a plough or other tillage implements, because the greater contact of P with the soil particles will in general lead to a strong binding and P fixation in the soil, so that phosphorus is not released for plant use. While in the USA many researchers, extensionists and farmers believe that one has to plough ones in a while to redistribute phosphorus that concentrates on the soil surface after a few years in the no-till system, this is not the case in South America, where farmers have learned that the concentration of this element in the soil surface is not a problem at all for obtaining high yields of crops.

**Soil compaction**: After many years of tillage with the same implements plough pans or heavy disk pans develop. In other cases soils have developed pedogenetic (natural) soil compaction. Starting no-tillage without breaking tillage induced or natural soil compaction will result in poor yields and low profits. Therefore whenever compactions are present they have to be removed before going into the system, unless in-row subsoiling is used while seeding. This type of machine has been developed in Auburn, Alabama, by researchers from USDA (Wayne Reeves, personal communication, 2003). In South America a chisel plough is in general enough to break tillage induced soil compactions.

The question is now what to do if we have practiced no-tillage for several years before somebody tells us that the soil is compacted. Soil compaction in permanent no-tillage is an issue that is discussed repeatedly in South America. Often researchers have a different perception than farmers in looking at this problem. Since researchers have very sophisticated tools to measure compaction and easily demonstrate that soils are more dense under no-tillage than under conventional tillage, we have seen that many researchers see compaction as a very serious problem in the no-tillage system. We are observing that in general scientists and researchers in South America tend to overstate the problem of soil compaction. Farmers in South America measure compaction not in terms of soil density in g/cm3 or in penetration resistance but in terms of crop response and yields. If yields are as good, or better in no-tillage than in conventional tillage, the farmers do not care about a more dense soil. Also farmers measure compaction in terms of penetration of seeding equipment into the soil. If soils are too hard to ensure good penetration to the cutting elements of a no-till seeder than farmers are going to achieve poor germination. But the reason for bad penetration may also be due to poor design or lack of weight of the seeding machine. In clay soils farmers often use a knife point behind the cutting disc coulter to break surface soil compaction and allow better penetration and germination of the seeding equipment.

For the purpose of evaluating farmers perception on the problem of soil compaction, three no-till pioneer farmers from Paraná State, Brazil where interviewed independently in 1997, to express their views on this problem. The interviewed farmers were Herbert Bartz from Rolandia (then 26 years of continuous no-tillage), Nonô Pereira (then 22 years of permanent no-tillage), and Frank Dikstra, both from Ponta Grossa (also 22 years of continuous no-tillage), totalling 70 years of experience. Their soils vary from about 80% clay to about 80% sand. The farmers were unanimous in stating, that they do not perceive compaction as a problem in permanent no-tillage when the system is adequately managed. They also stated that there is no need to till the soil every so often after no-tillage has been established. Finally they said, that the best way to avoid compaction in the no-tillage system is to produce maximum amounts of soil cover, use green manure cover crops and crop rotations, so that roots and biological activity as well as earthworms and insects, etc., loosen the soil resulting in biological soil loosening. Long term no-tillers in general report mellower soils after many years of continuous no-tillage. Good soil cover is also essential to maintain higher moisture levels at the soil surface and this will result in better penetration of cutting elements of the seeding equipment, as well as of roots. Controlled traffic should be aimed at in this system and no heavy trucks allowed indiscriminately in the fields, especially at harvest. Low pressure tyres are also a must.

These **three factors**, lime incorporation, phosphorus redistribution and compaction, are probably the main reasons why farmers in the US till the soil ones in a while in the no-till system. An additional factor is mindset. Often landlords in the US will not lease their farm to a no-tiller because they do not like the "dirty trash" that is left on the soil surface. Thus, the long term benefits of continuous no-till will never happen. Contrary to this, landlords in South America in general will only lease their land to a no-tiller to ensure protection against erosion, avoid soil degradation and maintain soil fertility over time.

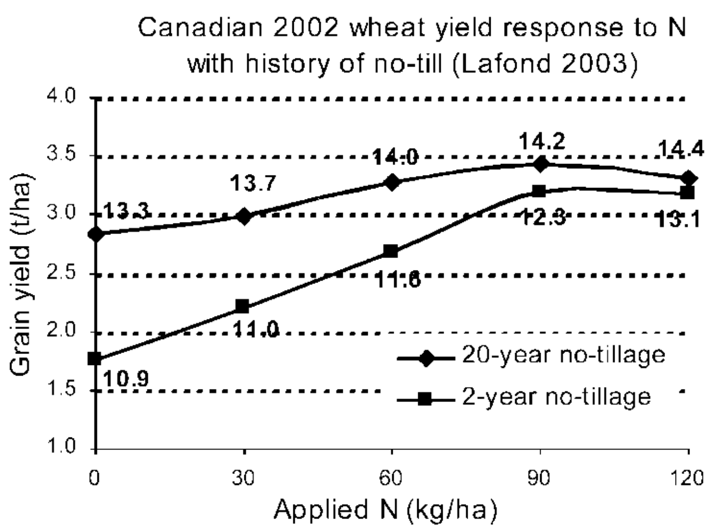
Farmers in Brazil, Argentina or Paraguay would only in exceptional cases consider ploughing or tilling the soil to mix phosphorus in the soil profile, incorporate lime or even loosen soil compaction. The high percentage of permanent no-till (> 85% of all Conservation Agriculture technologies practiced) demonstrates this. In this context one should also remember that in Brazil soils of low pH and high aluminium saturation often occur.

### Long term benefits of a no-tillage system.

While about 70% of South American farmers are applying permanent no-tillage systems, this is only the case with 10 - 12% of farmers in the US. Under a situation of rotational tillage the soil is always in transition and will never leave the initial phase so that farmers will never get to experience the full benefits of the system.

Research and farmers experience has demonstrated the long term benefits of a no-tillage system. Research conducted by Lafond (personal comm., 2005, see figure 1) has shown, that after 20 years of continuous no-tillage with full stubble retention higher yields can be obtained in comparison with a short term (2-year) no-tillage system. With no nitrogen application, yields of about 1.75 t/ha were obtained in a 2-year no-tillage situation compared to 2.8 t/ha obtained after 20 year no-tillage. Moreover the protein content of the grain was much higher in the long term no-tillage. This is important for farmers in Canada, as they get penalized when the protein content of the grain is below 14%.

**Figure 1:**



It certainly would not have been possible to obtain these results if residues were sold, burned or eaten by animals. This graph is helpful in understanding how to get no-tillage to a higher level and to better comprehend the graph below.

**Figure 2:**

## Evolution Scale of the No-tillage System

(Sá, University of Ponta Grossa, Brazil, 2004).

| Initial Phase | Transition Phase | Consolidation | Maintenance |
|---|---|---|---|
| Rebuild aggregates<br><br>Low OM<br><br>Low crop Residues<br><br>Reestablish microbial biomass<br><br>> N | Increase soil density<br><br>Start incr. of crop residue<br><br>Start incr. in OM<br><br>Start incr. P<br><br>Imob. N ≥ Min. | High crop residues<br><br>High C<br><br>> CEC<br><br>> $H_2O$<br><br>Imob. N < Min.<br><br>> Nutrient cycling | High accum of crop res.<br><br>Continuous N & C flux<br><br>Very high C<br><br>> $H_2O$<br><br>> High nutr. cycling<br><br>Less N and P use |
| **0 -5** | **5 - 10** | **10 - 20** | **> 20** |

**Time (Years of continuous No-till or Zero-till systems)**
(Full stubble retention permanent no-till system)

This graph illustrates the evolution of a long term no-till system.

In the initial phase (0 – 5 years) the soil starts rebuilding aggregates and measurable changes in the carbon content of the soil are not expected. Crop residues are low and N needs to be added to the system.

In the transition phase (5 – 10 years) an increase in soil density is observed. The amount of crop residues as well carbon and phosphorus content start to increase.

In the consolidation phase (10 – 20 years) higher amounts of crop residues as well as higher carbon contents are achieved, a higher cation exchange capacity and water holding capacity is measured. Greater nutrient cycling is observed.

It is only in the maintenance phase (> 20 years) that the ideal situation with the maximum benefits for the soil is achieved and less fertilizer is needed.

Any tillage performed in the phases 2 - 4 means a return to the initial phase. Tilling the soil ones in a while means that the soil is in constant transition and farmers will never get to see the full benefits of the system. Farmers practicing a no-till system without full stubble retention, i.e. letting animals graze their fields, baling and/or selling the residues and/or burning the residues, will probably never leave the initial phase. If fields are well managed leaving a reasonable amount of soil cover, farmers eventually may start entering the transition phase.

It is estimated that farmers using a tine seeding system, even when practicing no-tillage with full stubble retention, will only reach the transition phase and perhaps just those that manage to handle higher amounts of residues and have a higher biomass yield may start entering the consolidation phase.

Practicing adequate crop rotations and using green manure cover crops once in a while will help in reaching the maintenance phase.

It is the opinion of the author of this paper that only with disc seeders, full stubble retention and adequate crop rotations, will it be possible to reach the maintenance phase, reaping the full benefits of a no-till (zero tillage) system.

### Constraints and limitations for no-tillage adoption in South America

The constraints and limitations for no-tillage adoption in South America and how they have been overcome have been extensively described by Derpsch (2001). Therefore they are only going to be briefly mentioned here. In the early days of no-tillage the main constraints to adoption of the technology were:

- Adequate machines
- Adequate herbicides
- Knowledge about herbicides, herbicide application technology and weeds
- Knowledge about soils, liming and fertilization, soil crusting, soil compaction
- Mulch cover, the use of green manure cover crops and crop rotations.
- Mental change

The constraints related to these issues have been in general overcome in South America. Adequate machines and herbicides are now available in the leading no-tillage countries. Also knowledge is now available world wide, although the difficulty in agriculture is that we need to adapt this knowledge to local conditions. Adaptive research and technology development done by skilled people in a systems approach is necessary to advance in the application of no-tillage in a site appropriate way. One of the biggest barriers to this technology still seems to be the mental change necessary to believe in the system, which is a prerequisite to make it work.

"Curiously, in Brazil the resistance of researcher, academics and extensionists to change was much greater than that of farmers. In economic terms the farmer saw immediate benefits over and above the cost of change, while the professionals saw high costs in the effort of change and no foreseeable economic benefits accruing for the extra effort" (Landers, 2001).

### Quality No-tillage

Seeding without tillage does not necessarily mean no-tillage seeding. Poor quality no-tillage, that can hardly be called as such, is often practiced by farmers in many parts of the world. High soil disturbance at seeding, low percentage of soil cover, monoculture and rotational tillage characterize poor quality no-tillage. Quality standards have therefore to be developed.

It has become clear that keeping the soil permanently covered and maximizing biomass production for each location is essential to obtain the maximum benefits from the No-till system. No-tillage without plant residues on the soil surface will result in poor crop development and yields below those obtained in conventional tillage. Research conducted by Wall (1999) with several tillage treatments in a low rainfall area of Bolivia, shows that "in all seasons the highest yields were obtained from the plots with no-tillage and crop residue retention, and the lowest yields from the plots with no-tillage and no residues". Other experiments conducted on degraded soils in the region of Cochabamba, Bolivia (Wall, 1999) also showed that "grain yields at all sites and in all years have been directly related to the amount of ground cover applied after the previous harvest. Consistently the lowest yields were obtained in no-tillage with no residues".

We should therefore remember that almost all the benefits of the no-tillage system come from the permanent cover of the soil and only very few ones from not tilling the soil. In other words it is not the absence of tillage, but mainly the presence of crop residues on the soil surface that results in a better performance of no-tillage in comparison to conventional tillage system. Management practices should consequently be directed towards maximizing biomass production for a certain location (adequate fertilization, weed as well as pest and disease control, high biomass producing species and cultivars, etc.).

***Criteria to determine the quality of no-tillage***

1. The percentage of soil cover with plant residues specially after seeding.
2. The amount of soil disturbance while seeding.
3. The number of years in continuous no-tillage without tillage of any kind.
4. The use of diversified crop rotations and the inclusion of cover crops.

Full stubble retention, the use of disc seeders, able to cut through high amounts of crop residues causing little soil disturbance, the number of years under permanent no-tillage and the inclusion of cover crops in rotation systems are the basis for a high quality, sustainable no-till systems. Quality no-tillage is essential to reap the full benefits of this system and experience the benefits more rapidly.

***Other criteria to determine the quality of no-tillage***

- Zero erosion
- Monitoring and correcting soil pH and aiming at a balanced nutrient status
- Enhancement of biological soil tillage (roots of crops, soil animals)
- Controlled traffic and use of low pressure tires
- Use of integrated and if possible biological pest control
- Quality no-tillage aims at achieving a sustainable production system (economically, socially and ecologically).

In relation to the percentage of soil cover the following table is suggested:

| SOIL COVER % | QUALITY OF NO-TILLAGE |
|---|---|
| 0 a 5% | The worst quality, almost bare soil (crop residues are burned, exported or eaten by animals) |
| 5 a 30% | Very low quality no-tillage (crop residues are partially buried or exported). |
| 30 a 60% | Low quality no-tillage (insufficient crop residues to control wind or water erosion). |
| 60 a 80 % | Fairly good quality no-tillage (sufficient crop residues to control wind erosion) |
| 80 a 100% | High quality no-tillage (sufficient crop residues to control wind and water erosion; high water infiltration rates are achieved; significant increase of soil moisture; efficient control of weeds) |

## Organic matter as an indicator of the quality of the system

Any agricultural or livestock production system that contributes to constantly reducing the organic matter content of the soil is not sustainable and results in poor soils and farmers. Soil organic matter is the most important element that indicates fertility of a soil. Low values of organic matter mean low fertility while the same soil with high values is a more fertile soil, where higher crop yields can be obtained. Conventional or intensive soil tillage is the typical management praxis which results in degradation of organic matter and in emissions of carbon dioxide into the atmosphere. No-tillage on the contrary results in sequestering carbon from the atmosphere and increasing carbon content of the soil.

Long term no-till experiments in a corn soybean rotation conducted from 1962 to 2003 at Wooster Ohio, USA, showed a steady increase of the carbon content of the soil in the no-tillage system but a steady decrease in conventional tillage. The C pool in the topsoil was greater under no-tillage (6.75 kg/m2) than for plough tillage (5.56 kg/m2) (Mestelan, et al., 2006). At Wooster carbon content of the soil increased steadily in no-tillage from 13 to 27 g/kg while it decreased steadily in conventional tillage from 13 to less than 10 g/kg during the 44 year period of the experiment (Warren Dick, personal communication, 2006).

Management practices that are directed to obtain maximum amounts possible of crop residues for a specific location (crop rotations including if possible corn, cover crops, fertilization of crops, etc), will enhance carbon content of the soil and increase yields of crops.

A positive balance between inputs and outputs has always to be aimed at. Inputs are achieved by additions of carbon through plant residues. Outputs are achieved by any type of tillage. Incorporation of seeds of black oats as a cover crop is sometimes done in South America with a light disc harrow. In this case it has been demonstrated that the total loss of carbon due to the use of the disc harrow is 0.90 t/ha, while the return of carbon from the cover crop residues is only 0.52 t/ha (Sá et al., 2006). This is a clear negative balance. Also soybean monoculture or double cropping wheat/soybeans has a negative balance because the amount of carbon added (3 – 4,5 t/ha/year in Brazil) is insufficient to sustain the system. Therefore, high biomass producing crops such as corn should be part of a rotation. According to Sá (2006) additions of more than 8 t/ha/year of carbon from plant residues (shoots and roots) are needed in Brazil to maintain a stable equilibrium and ensure the sustainability of the system.

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