Frontiers in Conservation Tillage and

Advances in Conservation Practice

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Introduction

When I was invited to present this paper at the ISCO Conference with the title "Frontiers in Conservation Tillage" and analyze this theme from a World perspective I first refused because it is a very difficult task to accomplish. The United States is among the few countries in the world that has yearly statistics on the different forms of conservation tillage. Information in other parts of the world is very scarce or non existent and in most countries statistics on conservation tillage are based on estimates. Also, a problem associated with conservation tillage is its definition. There is confusion in the term conservation as well in the term tillage. When reducing conservation tillage to no-tillage, information is easier to get and for this reason I will concentrate on this praxis, although one must be aware that information still remains unprecise and often was not available in the short time frame to prepare this paper. As most of my working experience with no-tillage has been gained in South America, the organizers of this conference have understanding for the fact that I may concentrate my remarks to this part of the world. It is interesting to note that in the USA no-tillage accounts for only 44% of all cropland hectares planted in conservation tillage in 1998, while in South America no-tillage probably accounts for more than 95% of conservation tillage area. No-tillage is defined in this paper as the planting of crops in previously unprepared soil by opening a narrow slot, trench or band only of sufficient width and depth to obtain proper seed coverage. No other soil preparation is performed (Phillips and Young, 1973). We also refer here to permanent no-tillage rather than not tilling the soil occasionally. It is understood that the soil remains covered by crop residues from previous cash crops or green manure cover crops (GMCC's) and that most of the crop residues remain undisturbed at the soil surface after seeding. As long as this requirement is met shanks can be used to break compacted soil layers below the seed zone. Therefore the term direct seeding, that is also used in translation in South America, is more appropriate than no-tillage unless we use this term in a broader sense. We have to understand that soil carbon and crop residues are key factors for no-tillage to function. We have concentrated too much and too long on not tilling the soil instead of concentrating on crop residues as main tool for management (Wayne Reeves, personal communication 1997).

Control of soil erosion is still one of the main driving forces for no-tillage adoption. No technique yet devised by mankind has been anywhere near as effective at halting soil erosion and making food production truly sustainable as no-tillage (Baker et al., 1996). The long term gains from widespread conversion to no-tillage could be greater than from any other innovation in third world agricultural production. (Warren, 1983).

General situation of no-tillage in the world

The leading countries in the world with the biggest area under no-tillage are the USA with 19.3 million hectares followed by Brazil with 11.2 million ha, Argentina with 7.3 million ha, Canada with about 4.1 million ha, Australia with 1 million ha and Paraguay with 790.000 ha of the technology being practiced by farmers (Table 1). In Paraguay no-tillage was practiced on only 20.000 ha in 1992 and it grew to 790.000 ha in 1999. It is not easy to get information about the spread of no-tillage in Asia, Africa and the East European countries. Admitting that there may be many gaps in information it is estimated that no-tillage is practiced on about_45 million hectares world wide. Approximately 96% of the technology is practiced in the Americas (North and South) and probably less than 4% in the rest of the world. About 52% of no-tillage is practiced in the USA and Canada, 44% in Latin America, 2% in Australia and 2% in the rest of the world, including_Europe, Africa and Asia. There is a very big potential to bring this soil conserving technology to these parts of the world, although limiting climatic and socio-economic factors have to be taken into account. The East European countries seem to have the biggest potential for a fast growth of this technology. In order to overcome the information gaps relating mainly to the East European countries as well as Africa and Asia, the author would welcome any information about the area of no-tillage and conservation tillage being applied in that part of the world.

Table 1: Total area under No-tillage in different countries (hectares)

COUNTRY	2000/ 2001
U.S.A.	21.120.000 [1)]
Brazil	13.470.000 [2)]
Argentina	9.250.000 [3)]
Australia	8.640.000 [4)]
Canada	4.080.000 [5)]
Paraguay	960.000 [6)]
México	650.000 [7)]
Bolivia	350.000 [8)]
Venezuela	150.000 [9)]
Chile	100.000 [10)]
Colombia	70.000 [11)]
Uruguay	50.000[12)]
Others	1.000.000[13)]

Total	**59.890.000 ..**

Quelle: 1) Dan Towery, CTIC, 2001; 2) FEBRAPDP, 2000; 3) AAPRESID, 2000; 4) Bill Crabtree, WANTFA; 5) Hebblethwaite, CTIC, 1997; 6) MAG - GTZ Soil Conservation Project, 1999; 7) Ramón Claverán, CENAPROS, 1999; 8) Carlito Los, 2000; 9)Carlos Bravo, 2000; 10) Carlos Crovetto, 1999; 11) Roberto Tisnes, Armenia, 1999; 12) AUSID, 1999; 13) Schätzungen.

Remark: Some data on the area under No-tillage in Canada shows 6.7 million ha in that country. These numbers do allow for fall tillage with high soil disturbance. When applying the term no-tillage more strictly (low disturbance and no fall tillage) then the area is only 4.08 million ha for Canada.

Although the biggest area under No-tillage is found in the USA, in this country the technology is applied only on 16,3% of the total cultivated area, against 21% in Brazil, 32% in Argentina and 52% in Paraguay. In relation to the total cultivated area, Paraguay has the highest adoption rate of no-tillage in the world (Figure 1).

A study of the potential use of no-tillage in Africa has been made by GTZ in 1998. The study concludes, that no-tillage ensures optimum soil protection and is therefore the system of choice for those regions where sufficient biomass can be produced to provide all-year-round ground cover. The ecological constraining factors for spreading no-tillage in this continent are: low precipitation with low biomass production, short growing seasons, sandy soils with tendency to compaction and soils at risk of waterlogging. The socio-economic constraining factors are: strong demand for crop residues as forage for livestock, uncertain land use rights, poorly developed infrastructure (market, credit, extension service), distinct market preference for one crop (e.g. maize), and high demand on the farm management. The study also concludes, that in regions and under conditions where no-tillage is not possible, the second best choice is minimum tillage (GTZ, 1998).

While no-tillage was researched in the USA already in the 1940's and more intensively in the late 1950's, and in Europe in the 1960's and 1970's, it was not until 1971 that research on this technology started in Brazil and Latin America (Derpsch, 1998). At first no-tillage was conceived as an efficient technology for soil conservation, since the spread of arable farming had brought about the widespread occurrence of erosion in the southern states of Brazil. With time the technology has evolved to a truly sustainable production system with positive economic, environmental and social consequences.

In the MERCOSUR Countries (Brazil, Argentina, Paraguay and Uruguay) the technology has experienced a twenty fold expansion between 1987 and 1997 against a 4,6 fold increase of the area in the USA in the same period (Figure 2). From 1997 to 1998 the MERCOSUR Countries experienced an expansion of 28% of the area under no-tillage as against 3,7% in the USA. The following may be the main factors that induced such a rapid change in Latin America: 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 tillage 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 are immediate and substantial. 9) There have been no major forces against the system. 10) Latin American farmers have had to be very competitive in the global market, since in general there are no subsidies.

Constraints and limitations for no-tillage adoption in South America and how they have been overcome

Adequate machines

Only in 1975 the first machines for no-tillage were built in Brazil, so many farmers started no-tillage transforming their old equipment. The first machines built in Brazil based on the rotary hoe (Howard Rotacaster) were slow and farmers were very happy when the faster triple disc machines appeared on the local market in 1976. Importing no-tillage machines has been almost impossible in Brazil because of high import taxes. Production in other countries of Latin America (Argentina, Mexico) started much later. Today about 15 industries in Brazil and about 30 in Argentina are building no-tillage equipment.

For small and medium sized mechanized farms we would recommend that farmers buy a no-tillage machine suitable for wide row crops (i. e. soybeans, maize, sorghum, sunflower) and for narrow row machine suitable for wide row crops (i. e. soybeans, maize, sorghum, sunflower) and for narrow row crops (wheat, oats, rye and green manure cover crops in general). Failure in buying a multipurpose machine puts farmers that do not have enough capital to buy two specialized machines in a situation where they cannot plant narrow row crops and therefore they are not able to seed small grains or green manure cover crops and use adequate crop rotations. Leaving the land in fallow during winter time results in high weed infestation and high costs to eliminate these weeds.

Adequate herbicides

The first years of no-tillage adoption in South America in the 1970's were especially difficult because the only herbicides available were Paraquat and 2,4-D. Hand hoeing saved many crops from failure at this stage. At the beginning of the 1980's the number of herbicides available for the system had grown to such an extent, that it was difficult to know the properties of each of the many products available on the market. The only people that would give information about the characteristics of the different products were the companies producing them. This made it very difficult for the farmers to recognize and find the products they needed. Two publications written in the early 1980's (now in their 4^{th} edition) helped to overcome this bottleneck and became a milestone in allowing more farmers to adopt the system (Rodrigues and Almeida, 1998; Lorenzi, 1994).

The production and availability of a greater variety of more efficient herbicides together with a greater diversity of more efficient no-tillage seeding equipment in Brazil and Argentina has led to an unprecedented growth of no-tillage in South America.

Mental change

A mental change of farmers, technicians, extensionists and researchers away from soil degrading tillage operations towards sustainable production systems like no-tillage was necessary to obtain changes in attitudes of farmers. <u>As long as the head stays conventional it will be difficult to implement successful no-tillage in practical farming</u>. Through time we have learned, that if the farmer does not make a radical change in his head and mind, he will never bring the technology to work adequately. We found that this is not only true for farmers but for technicians, extensionists and scientists as well. No-tillage is so different from conventional tillage and puts everything upside down, that anybody that wants to have success with the technology has to forget most everything he learned about conventional tillage systems and be prepared to learn all the new aspects of this new production system. We believe that a farmer first has to change his mind before changing his planter

Knowledge

Site specific knowledge of the no-tillage system has most likely been the main limitation to the spread of the system in some countries and regions of Latin America. The biggest change a farmer has to face when moving from conventional to no-tillage is probably weed control. To be able to manage this new situation a farmer has to have a good knowledge especially on herbicides, weeds and application technology.

<u>Herbicides</u>

A comprehensive publication is needed that describes all the products available on the market with all their chemical and toxicological characteristics, amount to be used per hectare as well as listing of the weeds that can be efficiently controlled by each specific product. This is a very necessary information without which not only farmers, but also technicians, extensionists and scientists would have a hard time to make no-tillage work. An example is the publication by Rodrigues and Almeyda (1998) in Brazil, which now is in its 4^{th} edition..

<u>Weeds</u>

Another publication needed is one which describes and shows pictures of the most common weeds for easy identification. A very useful publication in no-tillage that describes common weeds, showing pictures of the adult plant as well as of seeds and seedlings and at the same time shows which herbicides can efficiently control each weed, was published by Lorenzi (1994) and has been an important tool in the hand of farmers and researchers. This publication has also been reedited four times up to now.

<u>Herbicide application technology</u>

The complex calculation of volume of water to be applied per hectare, pressure, nozzle output, tractor velocity, tank capacity and amount of products to be added to apply the recommended rate of a product per unit of area, pose a difficult task not only to farmers but to anybody trying to calibrate a sprayer. We learned, that unless well prepared and easy to handle information is given to the farmer, imperfect calibration will result in poor weed control even if using the best product. Adding to that, in South America it took many years of adaptive research and collection of farmers experience, before we learned that many products work better with less than 100 liters of water per hectare than with more, that in some cases we can reduce significantly the amount of herbicide used by lowering the pH of water to 3.5, that costs and time of application can be greatly reduced by using big spraying tanks

(2000 liter capacity instead of common 600 l tanks) and low volume of water. With time we also learned that light influences the efficiency of some products significantly and that in the tropics farmers have to get up very early to meet spraying requirements of less than 30° C air temperature and more than 60% moisture in the air. In some regions and in the hot season we even have difficulties to meet these conditions at any time of the day. Although isolated information has been published and released every now an then, it was only in 1996 that a more advanced publication on application technology was made available to farmers in Brazil (Fundação ABC, 1996).

Soils

Many tropical soils are acid or have toxic aluminum. We have been recommending that farmers apply lime the year before entering no-tillage because it is the last opportunity to incorporate it. Newer research results have shown us, that farmers can also apply lime without incorporating, since in the generally very permeable tropical soils with high infiltration rates, lime moves into deeper soil layers. In this case it is recommended that farmers apply small rates of lime each year, instead of applying big amounts only once.

Concepts about liming and fertilization have changed a lot in Latin America after shifting to the no-tillage system. Experience shows us that we have to forget everything we have learned in the University about fertilization and liming and get acquainted with the new concepts in fertility management in this system. Pioneer farmer Nonô Pereira of Ponta Grossa, Paraná, Brazil, together with the soil scientist Joao Carlos Moraes de Sá have developed a system of no-tillage into native pasture, on soils that have a high aluminum saturation, low pH and in general low fertility levels (Farmers spray off the native pasture 3 to 4 months before seeding to ensure a good kill of woody grasses). Despite this fact, farmers applying relatively low amounts of lime on the soil surface and using medium fertilizer levels, can harvest around 3.000 kg/ha soybeans already in the first year. This is probably due to the high organic matter content of these soils, that have never been touched by tillage tools before. Similar experiences are now being made on poor, acid soils and native pasture in Paraguay.

Soil crusting:In general crusting of soils is not a problem in no-tillage. Because the mulch cover avoids the direct impact of the raindrops on the bare soil surface crusts do not develop. We have found, that soils which very badly tend to crusting in conventional tillage do not present crusting problems in no-tillage, as long as the soil is well covered with sufficient plant residues.

It is general knowledge that badly drained soils are not suited for no-tillage. Luckily most tropical soils in South America are well drained and are generally well suited for this technology.

Soil surface roughness

It is obvious, that a no-till seeding machine is not going to work properly if the soil surface is not leveled. In conventional tillage farmers often control their weeds by mechanical cultivation. This tends to leave an undulated soil surface that has to be leveled before entering the no-tillage system. Also if erosion rills or small gullies are present, or if for other reasons a rough surface is left after harvest, we recommend farmers to first level the soil surface before starting no-tillage to avoid seeding problems and bad stands.

Soil compaction

Tillage induced soil compaction inherent of conventional tillage like plow pans or heavy disc harrow pans should be eliminated before entering the system. A chisel plow (in seldom cases a subsoiler) will generally be sufficient in Brazil, Paraguay and Argentina to solve these problems.

Soil compaction in permanent no-tillage is an issue that is discussed over and over again in Latin America. We have found that in general 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 compact 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 Latin America tend to overstate the problem of soil compaction. In contrast to researchers, farmers in Latin America measure compaction not in terms of soil density in g/cm^3 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 farmer does not care about compaction. Also farmers measure compaction in terms of penetration of seeding equipment into the soil. If soils are too hard to give good penetration to the cutting elements of a planter than the farmer is going to have a bad stand.

For the purpose of evaluating farmers perception on the problem of soil compaction, three no-till pioneer farmers from Brazil where interviewed in 1997 to express their views on this problem. The interviewed farmers were Nonô Pereira (22 years of permanent no-tillage), Frank Dikstra (22 years of continuos no-tillage) and Herbert Bartz (26 year of continuous no-tillage), totaling 70 years of experience. Their soils vary from about 80% sand to about 80% clay. The farmers were unanimous in stating, that they do not perceive compaction as a problem in permanent no-tillage (Revista Plantio Direto, 1999). 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. Good soil cover is also essential to maintain higher moisture content on the soil surface and this will result in better penetration of cutting elements of the seeding equipment.

Mulch cover

Permanent soil cover with a thick layer of mulch has been a key factor for having success in the no-tillage system in Latin America. Farmers that have not understood the importance of an adequate mulch cover have not yet understood the system. We aim at having at least 6 and if possible more than 10 tons of dry matter from GMCC's and cash crops per hectare per year. This way we have a good weed suppression, positive effects of mulch on soil moisture and soil temperature, and improve chemical, physical and biological soil fertility. We not only look at the amount of mulch but on distribution as well. Harvesting machines should have a well designed device to spread the mulch evenly over the whole cutting width. Machine manufacturers have seldom understood this requirement of no-tillage, the result being an uneven distribution of plant residues, with excessive mulch in the center and too little or none at the end. This results in poor performance of herbicides and seeding equipment.

Besides the limiting factors mentioned a farmer also has to learn about the influence of no-tillage on chemical, physical and biological soil properties, its impact on surface water and the environment, on yields and most important on the economics of the system. Several comprehensive publications with research results have been published in the region since 1981, i. e. IAPAR, 1981; Derpsch, et al., 1991; Crovetto, 1996; Panigatti, et al., 1998; etc. Also the proceedings of many conferences held in Argentina, Brazil, Chile and Paraguay are available for detailed information on the performance of the system. In this respect AAPRESID in Argentina and FEBRAPDP in Brazil (the Federations of no-till farmers in both countries), have contributed strongly in the diffusion of site specific knowledge on the system and have helped greatly to spread the technology all over Latin America.

Primary needs associated with the technology's further use and adaptation and constraints to extensive use.

Crop rotations and green manure cover crops

Crop rotation and green manure cover crops (GMCC's) are an essential element in the success story of no-tillage expansion in Latin America. Only those farmers that have understood the importance of these practices are obtaining the highest economic benefits from this system. Cover crops do not cost but will pay. When practiced in monoculture or even in double cropping, i.e. when the same crop or crops are repeated on the same land each year, no-tillage is an imperfect and incomplete system, in which diseases, weeds and pests tend to increase and profits tend to decrease. 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!

Research conducted in southern Brazil shows consistent reductions in weed infestation with crop rotations in no-tillage and conventional tillage (Table 2).

Table 2: Number of weeds per m^3 with and without crop rotation in two tillage systems in Rio Grande do Sul, Brazil (Ruedell, 1990, adapted by Gazziero, 1998)

Occurrence of weeds	With rotation		Without rotation	
	NT	CT	NT	CT
Broad leaved weeds in wheat	36	24	102	167
Narrow leaved weeds in wheat	17	30	41	44
Broad leaved weeds in soybeans	4	20	15	71

NT = No-tillage, CT = Conventional tillage

Good no-till farmers in Latin America see it as good farming practice to use GMCC's and crop

Good no-till farmers in Latin America see it as good farming practice to use GMCC's and crop rotations independently of the price situation of crops. Once farmers have discovered the benefits of these practices they don't want to miss them. Sorrenson (1984), between others, has clearly shown the economic advantages of using crop rotation and the right cover crops. While many people still think that when using GMCC's 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.

Research conducted by Kliewer (1998) in Paraguay has shown, that crop rotation and short term GMCC's can reduce the cost of herbicides drastically to US$ 36,62/ha in the case of Crotalaria juncea (52 days GMCC) and to US$ 37,39 in the case of sunflower (57 days GMCC), as against costs of US$ 107,66 when only herbicides and monoculture were used. Kliewer (unpublished, 1998) also reported soybean yields after black oats of 2600 kg/ha without using any herbicides at all. Weed measurements 96 days after seeding soybeans showed 93 kg/ha of dry matter of weeds/ha after black oats, as against 7390 kg/ha after fallow. In the last case soybeans yielded not more than 780 kg/ha. Using a rotation where long and short term GMCC's or cash crops are seeded as soon as possible after harvesting the previous crop, or after rolling down GMCC's with a knife roller, it was possible not to use herbicides in no-tillage for as much as three years in a row. In some cases when farmers are using crop rotations, only eliminating weeds with a total herbicide before planting is necessary without any herbicide application during the growing season at all. If some weeds escape, the few weeds that develop can be efficiently and economically controlled by hand hoeing because labor is cheap.

Research conducted in Brazil has shown that black oats used as a green manure cover crop before soybeans can increase soybean yield by as much as 63% as compared to soybeans after wheat (Derpsch, et al., 1991).

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. Several publications have contributed in filling this knowledge gap mainly in Brazil (Sorrenson and Montoya, 1984; Monegat, 1991; Derpsch, 1991; Derpsch and Calegari, 1992; Calegari et al., 1992).

<u>Lessons learned</u>

Possibilities of reducing herbicides costs in no-tillage:

One of the most recent and fruitful lessons we have learned in the no-tillage system is that farmers should, if possible, never leave the land in fallow. In general fallow periods of only a few weeks will result in weed proliferation, seeding of weeds, reduction of soil cover, soil erosion as well as lixiviation of nutrients. If instead of leaving the land in fallow, farmers seed any crop immediately or as soon as possible after harvest of the previous crop, they will reduce weed proliferation, avoid that weeds produce viable seeds, increase soil cover and the biomass returned to the soil, increase organic matter content of the soil, avoid soil erosion as well as washing out of nutrients, and improve biological conditions of the soil. After initiating a more intense and systematic research with GMCC's in the late 1970's, a variety of crops have been identified and are now available for the use by farmers especially in Brazil and Paraguay. Some of the winter cover crops are 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.), vetches (*Vicia sativa* L.), hairy vetch (*Vicia villosa* Roth), chick peas (*Lathyrus sativus* L.), sunflower (*Helinthus annuus* L.), etc. The most commonly used summer cover crops are millets (*Penisetum americanum* L., *Sorghum bicolor* L, etc), crotalaria (*Crotalaria juncea* L.), lab-lab (*Dolichos lablab* L.), and even plants that up to now have been considerded to be noxious weeds like *Brachiaria plantaginea* are used in the Cerrados of North-Central Brazil as cover crops in no-tillage. The Cerrados have only one growing season. Here farmers and researchers have developed production systems where cover crops are established immediately after harvest of the main crop. If cover crops die in the dry season it is not a problem as long as they have produced enough biomass. In Southern Brazil and Paraguay conditions are such, that some cash or GMCC's can be seeded at any time of the year if soil moisture is available.

GMCC's and crop rotation are the key factors for the unprecedented growth of no-tillage especially in Brazil and Paraguay. Linked to the spread of cover crops is the use of a "knife roller" to put the cover crops down to the ground. This implement is not terribly expensive and in many cases can be made locally or by the farmer himself. The implement can be pulled by medium sized tractors or by animal traction and has contributed a lot in reducing herbicide rates in the no-tillage system. The knife roller has become an essential tool for managing GMCC's in many countries of South America. Alternatively steel bars can be welded on top of the discs of disc harrows and the implement used for the same purpose.

New developments

There is great dynamic in the no-tillage system, so farmers should be prepared to learn constantly and be up to date with new developments. New, cheaper and better herbicides and machines appear continually on the market, new cover crops are introduced, new research results on fertilization, liming, varieties, management, diseases and pest control, etc., are constantly produced. We learn that no-tillage potentiates biological pest control, etc, etc. We know that we should learn from organic farmers and introduce aspects of biological farming into the no-tillage system. As new knowledge is generated every day by researchers and farmers, we have learned that we have to keep pace with new developments. We have to be humble and not think that once we have learned everything about the system, nobody can teach us anything new. There is a great challenge for every farmer in being creative to develop the system further in order to save time and labor, improve yields and economic returns, etc.

Finally we have to admit that all over the world farmers adopt technologies because they are economic and are positive to their pockets and seldom because they are environmentally friendly. Therefore an economic evaluation of the system under the different agroecologic and socio-economic conditions is essential to have better arguments for adoption. Of course it is misleading to analyze the results of only one or two cropping seasons. Instead an evaluation of the whole system with all its components has to be made, putting value to timeliness, longer life of tractors and less repair costs in this system, improvement of soil fertility, reduced costs for fertilizers and pesticides, the environmental benefits of the system, etc.

Thorough economic studies with a system approach have been made by Sorrenson and Montoya (1984) in Brazil and again by Sorrenson et al., (1997 and 1998) in Paraguay. The economic evaluation in 1998 in Paraguay was made on small farms of generally less than 20 ha without tractor mechanization. The study concludes that the total economic benefits arising from adoption of the no-tillage technique on 480.000 ha in Paraguay have been calculated to be US$ 941 million (Sorrenson, 1998). The same author claims that "no other farming techniques have been shown to have such a high impact on farmers' incomes, reduce their production costs and risks, and at the same time be environmentally sustainable and generate very considerable net social gains to society"

Steps in no-tillage adoption

All too often we see that some farmers after hearing about no-tillage buy a no-tillage machine. This has led, in many cases, to failure in the application of the technology. Only after acquiring good knowledge about all the components of the system should a farmer buy a no-till planter.

There are some critical factors that should be considered before starting no-tillage. Therefore we recommend the following to farmers:

1. Improve your knowledge about all aspects of the system but especially in weed control
2. Analyze your soil and if necessary incorporate lime and correct nutrient deficiencies
3. Avoid soils with bad drainage
4. Level the soil surface if this is rough for any reason
5. Eliminate soil compaction using chisel plows or subsoilers
6. Produce the highest amount possible of mulch cover
7. Buy a no-till machine
8. Start on only 10% of your farm to gain experience
9. Use crop rotations and green manure cover crop to get the full benefits of the system
10. Be prepared to learn constantly and be up to date with new developments

Outlook

- Knowledge and information is the main constraint to no-tillage adoption in most countries. Information has to be relevant, actual, locally appropriate, true and useful in order to generate impact among farmers.
- The first step before changing to the no-tillage system should be that farmers, researchers, technicians and extensionists improve their knowledge about all aspects of the system.
- The superiority of the no-tillage system over conventional tillage has generally been proven under a great variety of conditions world wide. It is necessary now, to develop and adapt the system locally and make sure that the technology works under the special environmental and socio-economic conditions of each specific site.
- We need to learn which soils are not suited or have limitations for applying the system and how we can overcome those limitations.
- We also need to learn what other limitations to adoption exist under local conditions (i. e.

We also need to learn what other limitations to adoption exist under local conditions (i. e. machines, herbicides, adequate crop rotations, adequate green manure cover crops, knowledge) and also be aware of socio-economic constraints and find ways to overcome those limitations.

- The attitude "it doesn't work" is not helpful to solve problems in no-tillage! If we are aware of the fact that no-tillage is the only truly sustainable production system in extensive agriculture in the tropics and subtropics, than we will have to find ways to overcome the problems and limitations.
- We should not be concerned with lower yields in the no-tillage system as long as we have higher profits.
- Erosion control, improvement of chemical, physical and biological soil conditions, lower machinery costs, reduced labor and tractor hours, timelines, higher economic returns and other benefits of the system will guarantee a steady growth of permanent no-tillage in most regions of the world.

Summary

The leading countries in the world with the biggest area under no-tillage are the USA with 19.3 million ha followed by Brazil with 11.2 million ha, Argentina with 7.3 million ha, Canada with about 4.1 million ha, Australia with 1 million ha and Paraguay with 790.000 ha of the technology being practiced by farmers. Although the biggest area under No-tillage is found in the USA, in this country the technology is applied only on 16,3% of the total cultivated area, against 21% in Brazil, 32% in Argentina and 52% in Paraguay. In relation to the total cultivated area, Paraguay has the highest adoption rate of no-tillage in the world Admitting that there may be many gaps in information it is estimated that no-tillage is practiced on about 45 million hectares world wide. Approximately 96% of the technology is practiced in the Americas (North and South), about 2% in Australia and only about 2% in the rest of the world, including Europe, Africa and Asia. There is a very big potential to bring this soil conserving technology to these parts of the world, although limiting socio-economic factors have to be taken into account.

The historical development of no-tillage crop production and the successful application in mechanized farms in Latin America, has been closely related to: the availability of appropriate knowledge under different agro-ecological and socio-economic conditions; the availability of a variety of efficient low-cost herbicides; the availability of appropriate machines at adequate prices; the practice of adequate crop rotations including green manure cover crops and most important, a mental change of farmers, technicians, extensionists and researchers away from soil degrading tillage operations to a truly sustainable production system in agriculture.

The practice of adequate crop rotations including green manure cover crops is probably the main factor of successful and widespread adoption of the technology in many regions of Latin America. Experience has shown that green manure cover crops do not cost, they will pay. The study of the economic implication of these practices has shown, that economic returns of no-tillage could be substantially increased by the use of crop rotations and green manure cover crops.

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Table of Contents

Top