WHY NO-TILLAGE?

95 Million hectares under No-tillage world wide can't be wrong!
Since 1987 the technology has experienced a 59 fold increase
in Latin America from 670,000 ha to 40.6 million ha in the year 2004
against a 5.6 increase in the USA.

The most important reasons why farmers change to this new farming system are:

- Less work
- More money
- Erosion control, environmentally friendly
- Improvement of the quality of life

"The only thing that improved the quality of my life more than no-till was electricity."
Barbara Francis
wife of a no till farmer from Ohio
Said on 2/5/97 at a CTIC Meeting in Kansas City, Mo.

BENEFITS

Benefits of high residue farming

Conservation tillage systems offer numerous benefits that intensive tillage systems cannot match. These advantages have been summarized as follows:

1. Reduced labor requirements
2. Time savings
3. Reduced machinery wear
4. Fuel savings
5. Improved long-term productivity
6. Improved surface water quality
7. Reduced soil erosion
8. Greater soil moisture retention
9. Improved water infiltration
10. Decreased soil compaction
11. Improved soil tilth
12. More wildlife
13. Reduced release of carbon gases
14. Reduced air pollution

The laws of diminishing yields in the tropics
R. Derpsch, M. Florentin & K. Moriya

In nature there are laws that rule the diminishing productivity of soils, which have to be taken into account in agricultural and livestock production. Those who disrespect these laws are promoting the degradation of soils and the loss of soil productivity. To respect these laws is indispensable if we aim to obtain a sustainable agricultural production.

1. Any agricultural or livestock production system that contributes to constantly reduce organic matter content of the soil is not sustainable and results in poor soils and farmers.
2. Under tropical and subtropical conditions intensive and repeated tillage will generally mineralize (reduce) organic matter at rates greater than possibilities of reposition. This results in a decreasing organic matter content of the soil and diminishing crop yields over time.
3. High rainfall and wind intensities prevailing in the tropics and subtropics are generally associated under intensive and repeated tillage, with soil loss rates (due to wind or water erosion) greater than natural soil regeneration. This results in loss of nutrients and organic matter and in diminishing yields over time.
4. Under tropical and subtropical conditions intensive and repeated tillage will generally damage the soil structure and lead to excessively high soil temperatures. This will have negative effects on root growth, soil flora and fauna (soil biological processes) and on soil moisture resulting in diminishing yields over time.
5. Any agricultural or livestock production system in which important losses of nutrients occur through extraction without reposition (i.e. soil exploitation) through volatilization (i.e. regular burning), and/or through leaching (i.e. fallow periods without crops), is not sustainable and results in poor soils and farmers.

Additionally soil carbon is lost very fast to the atmosphere (as carbon dioxide) after the soil is intensively tilled. This results in unacceptable CO2 emissions into the atmosphere, and instead of carbon being deposited in the soil improving its fertility, tillage contributes to the greenhouse effect and to the global warming of the planet.

**In summary:** The unavoidable negative effects of intensive and repeated soil tillage in the tropics and subtropics on organic matter content, soil erosion, soil structure, soil temperature, soil moisture, water infiltration, soil flora and fauna (soil biological processes) and loss of nutrients, result in chemical, physical and biological soil degradation. This results in diminishing yields over time and in productivity losses of the soil and leads to poor soils and farmers.

As a consequence of the laws of diminishing productivity of tropical soils, sustainability of agricultural or livestock production can not be achieved as long as repeated and intensive soil tillage is performed in the tropics and subtropics. Sustainability also can not be achieved as long as the soil is exploited without reposition of nutrient losses through leaching and/or extractions that occur with harvests, and as long as frequent burning of fields is performed.

In order to maintain and improve soil fertility and achieve a sustainable agriculture in the tropics and subtropics, it is necessary to stop mechanical soil preparation and keep a permanent cover of the soil. At the same time adequate quantities of plant residues should be added to the system (more than 6 t/ha/year of dry matter in semi-arid climates and more than 10 t/ha/year of dry matter in humid climate). It is impossible to achieve a sustainable agriculture and at the same time perform intensive mechanical soil preparation.

No-till with green manure cover crops and crop rotations is the only truly sustainable production system in most forms of agriculture in the tropics and subtropics.
Traditional soil cultivation systems in the tropics and subtropics, with intensive soil tillage, will end in soil degradation and loss of crop productivity. This will result in poverty, exodus of farmers from rural areas, resulting in an increase of city slums and marginal populations, and finally in social conflicts. If we are to offer the farm family a chance to survive on the farm and if sustainable agriculture is to be achieved, than the paradigms of soil use and management must be changed and new farming practices must be implemented. In this paper, the old and new paradigms are presented and the consequences of these two forms of soil management are analysed.

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**OLD PARADIGMS**

- **Soil tillage is necessary to produce a crop**
- Burying of plant residues with tillage implements
- Bare soil for weeks and month
- Soil heating because of direct solar radiation
- Burning crop residues allowed
- Strong emphasis on soil chemical processes
- Chemical pest control, first option
- Green manure cover crops and crop rotations are options
- Soil erosion is accepted as an unavoidable process associated to farming on sloping land (Erosion is caused by excessive rains)

**NEW PARADIGMS**

- **Tillage is not necessary for crop production**
- Crop residues remain on the soil surface as mulch
- Permanent soil cover
- Reduced soil temperatures
- Burning mulch prohibited
- Emphasis on soil biological processes
- Biological pest control, first option
- Green manure cover crops and crop rotations compulsory
- Soil erosion is merely a symptom, that for that area and ecosystem unsuited methods of farming are being used (Erosion is caused by soil mismanagement)

**CONSEQUENCES OF SOIL PREPARATION AND BARE SOIL**

1. Wind- und watererosion are unavoidable
2. Reduced water infiltration into the soil
3. Less available soil moisture
4. Unavoidable reduction in the soil organic matter content; thus reduction of soil quality
5. Soil carbon is lost as carbon dioxide into the

**CONSEQUENCES OF NO- TILLAGE AND PERMANENT SOIL COVER**

1. Wind- und watererosion near zero
2. Increased water infiltration into the soil
3. More available soil moisture
4. Maintenance or increase in the soil organic matter content (enhancement of soil quality)
5. Carbon is sequestered in the soil enhancing
Soil carbon is lost as carbon dioxide into the atmosphere contributing to global warming.

Soil degradation (chemical, physical and biological).

Reduction of crop productivity.

Higher use of fertilisers and higher costs of production.

Survival of the farm family on the farm threatened (lower yields, production without profitability, insufficient monetary income).

Poverty, rural exodus, increase of slums and marginal populations as well as social conflicts.

Carbon is sequestered in the soil enhancing its quality, reducing the threat of global warming.

Soil improvement (chemical, physical and biological).

Crop productivity increased.

Reduced use of fertilisers and lower production costs.

Survival of the farm family on the farm insured through a good profitability and high and sustainable crop production.

Basic needs are satisfied, living standard and quality of life of the farm family are increased.

OFF FARM EFFECTS OF SOIL EROSION

- Sedimentation of rivers, reservoirs, lakes and micro catchments
- Reduced water quality
- Problems in hydroelectric power plants
- Sedimentation of roads
- Higher costs for the government and for society due to off farm effects of soil erosion

OFF FARM EFFECTS OF NEW PRODUCTION SYSTEM

- Reduction of sedimentation of rivers, reservoirs, lakes and micro catchments
- Enhanced water quality
- Less problems for hydroelectric power plants
- Less sedimentation of roads
- Reduction of costs for the government and for society due to off farm effects of soil erosion

RESULT:

Sustainable land use is not possible (ecologically, socially & economically).

Soil resource exploitation.

RESULT:

Sustainable land use ensured (ecologically, socially & economically).

Rational, site-oriented use of the soil.

SUSTAINABILITY

IMPLICATIONS OF NO-TILLAGE VERSUS SOIL PREPARATION ON SUSTAINABILITY OF AGRICULTURAL PRODUCTION

R. Derpsch & K. Moriya:
Sustainable Land Use - Furthering Cooperation Between People and Institutions,

Summary

The key problem of tropical agriculture is the steady decline in soil fertility, which is closely correlated to duration of soil use. This is due primarily to soil erosion and the loss of organic matter associated with conventional tillage practices, that leave the soil bare and unprotected in times of heavy rainfall and heat. The implications of soil preparation on soil erosion and the sustainability of agricultural production was studied with special reference to experience and projects carried out in Paraguay, Brazil and Argentina under tropical and subtropical conditions.
Scientific data show that under tropical and subtropical conditions, tillage generally has a detrimental effect on chemical, physical and biological soil properties. Investigations also show that erosion damage is enhanced when the soil is bare. Water infiltration rates are increased and consequently erosion is reduced when mulch covers the soil in a no-tillage system. Tillage also releases considerable amounts of CO$_2$ into the atmosphere contributing to global warming. In order to achieve sustainable agriculture in the tropics and avoid global warming, soil tillage has to be reduced to a minimum or avoided completely and the soil has to stay as long as possible covered with mulches, sod and growing crops. No- tillage in mulches of previous crops or green manures in combination with adequate crop rotations is the production system of the future if sustainable agriculture is to be achieved.

Keywords: no- tillage, tillage and soil degradation, soil quality, agricultural sustainability, erosion, organic matter, tropical agriculture.

1 Introduction
One of the main factors to be considered in relation to agro- ecological sustainability is the soil, as it is the basis for food production for humanity. Therefore, an effort has to be made to minimise soil erosion so that soil is not transported by runoff to rivers, lakes or to the sea, and to ensure sustainability of food production.

In this paper, sustainable agriculture is defined as establishing high, lasting and economic soil productivity, without damaging the soil and the environment, improving quality of life. Definitions of sustainability that consider only one dimension (i.e. soil fertility) are insufficient. Ecological, social and economic dimensions must always be considered (Hailu and Runge- Metzger, 1993).

The results of exploiting agricultural systems are evident in those regions where the soil is cultivated intensively and continuously, without considering soil degradation caused by soil preparation under hot/ humid conditions. In Central Paraguay, the regions which used to be the granaries of the country and where food used to be produced and exported to Argentina, many soils are so degraded and depleted that it is not possible to obtain economic production of basic products such as maize, cassava and cotton, and are gradually being abandoned. In southern Chile a hilly region close to the city of Concepción named "Cordillera de la Costa", also a granary of the country some 40 or 50 years ago, has suffered such catastrophic erosion that some areas cannot be used even for forestry. In the Andean region of Bolivia and Peru deep erosion gullies are destroying entire landscapes.

Such examples can be found not only in Latin America but world-wide. Rapid depletion of soil fertility and non-sustainable land use particularly in developing countries is both the cause and the consequence of widespread poverty. It is therefore necessary to change actual soil- degrading agricultural systems based on intensive soil preparation which leave the soil bare and unprotected, to sustainable production systems based on permanent soil cover with plant residues and mulches.

Soil is a non- renewable resource and it is available only in limited quantities. Conventional soil tillage that leaves the surface of the soil bare, is one of the major causes of the occurrence of erosion on agricultural land. Highest sediment amounts as well as phosphorus and nitrogen content in the water of the Itaipu dam (shared by Paraguay,
sediment amounts as well as phosphorus and nitrogen content in the water of the Itaipu dam (shared by Paraguay and Brazil), was measured in times of soil preparation for winter and summer crops (Derpsch et al., 1991).

2 The problem of soil degradation
The key problem of conventional agriculture in the tropics is the steady decline in soil fertility, which is closely correlated to duration of soil use (Fig. 1). This is due primarily to soil erosion and the loss of organic matter associated with conventional tillage practices, that leave the soil bare and unprotected in times of heavy rainfall and heat.

![Figure 1: Soil degradation through time in conventional agriculture](Derpsch, R., unpublished)

Despite progress in genetics and breeding, fertilisation, plant protection and management, there is a clear tendency of diminishing yield over time. FAO predicts, that if soil losses continue unchecked the potential rainfed crop production will decline by about 15% in two decades in Africa, about 19% in Southeast Asia, and by more than 41% in Southwest Asia (Kelly, 1983).

The result of soil degradation is not only that farm land has to go out of production, but also that there is an increasing need for more inputs and investments to maintain high levels of productivity. In the United States, 50% of fertiliser needs is applied only to compensate for the losses in soil fertility due to soil degradation. In Zimbabwe, soil nutrient losses by erosion are three times higher than the total quantity of fertilisers applied (Stocking, 1986).

3 Erosion
Occurrence of erosion can be considered the most important factor causing soil degradation. Under the concept of sustainability, the first negative factor in relation to productivity and profitability, and the major aggressor of the environment is soil erosion. Consequently, sustainability can only be achieved if soil erosion is stopped completely.

When agriculture is practised on slopes in undulating topography, and rains of a certain intensity occur, soil preparation especially with disc implements results in bare soil, and this results in water erosion, or in regions of heavy winds in wind erosion.

It is estimated that soil losses in cropland in Latin America reach 10 to 60 t/ha/year (Steiner, 1996; Derpsch et al., 1991). Average soil losses in the State of Paraná, Brazil, where good soil conservation is practised, are as high as 16 t/ha/year. In Paraguay, on 4000 m² plots with 6% and 8% slope on high clay content Oxisols, average soil losses of 21.4 t/ha were measured in conventional soil preparation, while only 633 kg/ha of soil loss were measured in No-tillage (Venialgo, 1996). For the same experiment after extreme precipitations of 186 mm on June 9 and 18, 1995, soil losses of 46.5 t/ha were measured under conventional tillage, as compared to soil losses of only 99 kg/ha under No-tillage (both plots on 8% slopes). This resulted in 470 times higher soil losses when soil was prepared. (Venialgo 1996)

The high losses from agricultural soils have to be compared against the annual rates of soil regeneration that are estimated to be not more than 250 to 500 kg/ha/year. When soil losses are higher than natural soil regeneration rates, sustainable agriculture is not possible.

Recent studies show that soil erosion is a selective process, with the most fertile soil particles taken away. Eroded soil sediments usually contain several times more nutrients than the soils they originated from (Stocking, 1988).

Applied fertilisers are also transported by erosion to streams, rivers, lakes and to the sea, and therefore lost forever. Considering that world phosphate reserves are going to be exhausted in 40 to 50 years (Hoffman et al., 1983), present generations are acting irresponsibly when allowing soil management practices that produce high erosion rates. Even under the assumption that phosphate reserves are going to last much longer, it has to be kept in mind that reserves are finite.
Research has shown, that soil cover is the most important factor that influences water infiltration into the soil, thus reducing runoff and erosion (Mannering and Meyer, 1963).

4 Organic Matter

In the tropics and sub-tropics organic matter content of the soil has an overriding importance in relation to soil fertility. According to Cannel and Hawes (1994), organic matter content of the soil is probably one of the most important characteristics in relation to soil quality, due to its influence on soil physical, chemical and biological properties.

Due to the fact that cation exchange capacity of most tropical soils is very low (Sánchez, 1976), organic matter has a much higher importance to store nutrients in the tropics than in temperate regions. Therefore the efficiency of mineral fertilisers is greatly reduced if at the same time organic matter is not added. On the other hand it is necessary to consider that organic matter is mineralised about five times more rapidly in the tropics than in temperate regions.

Therefore we can state that any agricultural production system that does not add sufficient organic matter and/ or gradually reduces organic matter content of the soil below an adequate level, is not site appropriate, will result in soil degradation and is not sustainable.

4.1 Influence of soil preparation on soil organic matter content and yield:

Soil tillage results in rapid mineralisation of organic matter stored in the soil, liberating nitrogen that will be available for plants. This can lead during a few years to an increase in yield. However, when soil tillage is performed under favourable conditions for mineralisation of organic matter (heat, humidity, good aeration) leaving the soil under fallow (bare), valuable nitrate reserves are lost by lixiviation (washed into deeper soil layers), without crops being able to utilise them.

Once organic matter has been consumed, more nitrogen cannot be liberated and yields of crops remain low. The result is a depleted soil, where the indispensable organic matter is missing.

Many depleted soils of Paraguay and other countries of Latin America are an example of bad land management, with excessive soil tillage resulting in organic matter exhaustion. The long term influence (100 years) of soil preparation on the organic matter content in northeastern United States (temperate climate) is described by Rasmussen and Smiley (1989). In that period a reduction in the organic matter content of the soil from 2.7 to 1.5% could be observed when plant residues were not burned. When 22 t/ ha/ year of manure was applied from 1930 to 1981 only a small increase in the organic matter content of 1.9% to 2.1% was measured. This shows how difficult it is to raise organic matter content of the soil once it has fallen.

Here it is necessary to remember that in tropical climates organic matter reduction is processed much more quickly, and reductions below 1%, sometimes as low as 0.2% can be reached in only one or two decades of intensive soil preparation.

The influence of 20 years of different soil preparation on the organic matter content of the soil in Kentucky, USA, is reported by Thomas (1990)(Table 1).

Table 1:

<table>
<thead>
<tr>
<th>Nitrogen appl./ year</th>
<th>No-tillage</th>
<th>Conventional tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ ha</td>
<td>% Organic Matter</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.10</td>
<td>2.40</td>
</tr>
<tr>
<td>84</td>
<td>4.93</td>
<td>2.53</td>
</tr>
<tr>
<td>168</td>
<td>4.28</td>
<td>2.45</td>
</tr>
<tr>
<td>336</td>
<td>5.40</td>
<td>2.73</td>
</tr>
</tbody>
</table>

These organic matter contents were also reflected on maize yields after 20 years in the same experiment (Thomas, 1990).

Yields of maize without nitrogen were initially much lower in no-tillage than in conventional tillage. The situation changed after 13 years due to organic matter depletion in conventional tillage, and since then yields under no-tillage without nitrogen have been always higher (G. Thomas, 1996, pers. commun.).

5 Influence of no-tillage (NT) on different soil properties
There is enough scientific evidence from warmer areas that shows, that no-tillage has positive effects on chemical, physical and biological soil properties compared to conventional soil preparation (Kochhann, 1996). First, because erosion is drastically reduced, and second, because organic matter levels in the soil are not only maintained, but are increased in this system, and third, because soil temperatures are kept low.

5.1 Influence of NT on chemical soil properties
Compared to conventional tillage, no-tillage has positive effects on the most important chemical properties of the soil. Under no-tillage, higher values of organic matter, nitrogen, phosphorus, potassium, calcium, magnesium and also a higher pH and cation exchange capacity, but lower Al values are measured (Lal, 1976; Lal, 1983; Sidiras and Pavan, 1985; Crovetto, 1996).

5.2 Influence of NT on physical soil properties
Under no-tillage higher infiltration rates have been measured compared to conventional tillage (Roth, 1985), and this results in a drastic reduction of erosion. In no-tillage a higher soil moisture content and lower soil temperatures as well as higher aggregate stability have been measured (Kemper and Derpsch, 1981; Sidiras and Pavan, 1986; Derpsch et al., 1988). At the same time a higher soil density occurs under no-tillage (Lal, 1983; Derpsch, et al., 1991), which is considered negative by many scientists. Despite this fact, higher yields of crops are obtained in Paraguay, Brazil and Argentina with this system, as compared to conventional tillage.

5.3 Influence of NT on biological soil properties
Due to the fact that no mechanical implements are used that destroy the "nests" and channels built by micro-organisms, higher biological activity occurs under the no-tillage system. Also, microorganisms do not die because of famine under this system (as is the case under bare soils in conventional tillage) because they will always find organic substances at the surface to supply them with food. Finally, the more favourable soil moisture and temperature conditions under no-tillage also have a positive effect on micro-organisms of the soil. For these reasons more earthworms, arthropods, (aracina, collemboala, insects), more micro-organisms (rhizobia, bacteria, actinomicetes), and also more fungi and micorrhyza are found under no-tillage as under conventional tillage (Kemper and Derpsch, 1981; Kronen, 1984; Voss and Sidiras, 1985). Despite the fact that chemicals are used to kill weeds, higher biological activity occurs under no-tillage, an indicator of a healthier soil.

5.4 Water quality
Water quality is improved in no-tillage. While drainage water from conventional tillage watersheds are brown in colour and carry a lot of sediments, watersheds in Brazil that have changed to no-tillage have been found to drain clear water even in times of heavy rainfalls.

5.5 Sanitary aspects
Some diseases of crops increase under no-tillage (Igarashi, 1981; Homechin, 1984; Reis, 1985; Reis et al., 1988). For this reason no-tillage should not be practised in monoculture. In general, a well balanced crop rotation with the use of green manure crops is sufficient to neutralise this negative aspect of no-tillage. In relation to pests, no-tillage can have positive or negative effects, and this depends on the specific pest and also on prevailing climatic conditions. In general, the diversity of insects, spiders, etc., increases under the mulched covered soil, where they find more favourable conditions for reproduction. As a result, many useful insects (predators) develop, and this leads to a better biological equilibrium, where pests may be controlled by predators, thus reducing the necessity for chemical pest control.

5.5 Environmental aspects
Intensive soil tillage accelerates organic matter mineralisation and converts plant residues in carbon dioxide, which is liberated into the atmosphere contributing to the green house effect and to global warming. Recent research performed in the USA by USDA/ARS shows that soil carbon is lost very fast - as carbon dioxide - within minutes after the ground is intensively tilled, and the amount is directly related to the intensity of tillage. After 19 days, total losses of carbon from ploughed wheat fields were up to five times higher than for unploughed fields. In fact, the loss of carbon from the soil equalled the amount that had been added by the crop residue left on the field the previous season (Reicosky, 1997). While fossil fuels are the main producer of carbon dioxide, estimates are that the widespread adoption of conservation tillage could offset as much as 16% of world-wide fossil fuel emissions (CTIC, 1996).

Figure 2 (prepared by Reeves, 1995) illustrates the fate of soil carbon considering three hypothesis of adoption of conservation tillage in the USA until the year 2020. In the first hypothesis, in which conservation tillage adoption rates of 1993 (27%) are maintained, and where conventional tillage prevails, almost 200 million tons of carbon are lost to the atmosphere. In the second hypothesis, in which conservation tillage adoption would increase to 57%, some improvement can be observed in relation to the first. In the third hypothesis, when conservation tillage adoption rates would reach 75%
in common with other wetlands, Igdasa greenhouse is a wetland which is rich in aquatic plants and algae. When I was invited to present this paper on "Historical review of no-tillage cultivation of crops" at the 1st IIRCAS Seminar on Soybean Research I thought that I could accept the task since I have had demonstration trials led Harry and Lawrence Young from Herndon, Kentucky, to apply the novel technology on their farm and became one of the first mechanised farmers in the world to use modern no-tillage crop production.

No-tillage trials in Latin America were first started in 1971 by the Instituto de Pesquisas Agropecuarias Meridional, IPEAME, in Londrina, Paraná State, Brazil, in co-operation with a GTZ (German aid) project. This project set up demonstration plots in the farm of Herbert Bartz, a Brazilian farmer of German descent, in Rolandia, Paraná. After seeing the results of these plots, Herbert Bartz induced a change to eliminate tillage by the plough and reduce tillage in his famous book "Plowman's Folly" (1943).


The invention of Paraquat in 1955 and its commercial release in 1961 led the Imperial Chemical Company, ICI, and others, to initiate intensive no-tillage research in the UK, the USA and elsewhere. In 1961 and 1962 demonstration trials were run in several farms in the United States. These demonstration plots led Harry and Lawrence Young from Herndon, Kentucky, to apply the novel technology on their farm and became one of the first mechanised farmers in the world to use modern no-tillage crop production.

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Compared to the Americas, no-tillage practice is much less adopted in Europe, Africa and Asia, and in many countries this soil-conserving sustainable production system is virtually unknown. Despite a wealth of research information generated at IITA, Nigeria, since the seventies, the total area under no-tillage in Africa is still very small.

INTRODUCTION

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. No-tillage is the term used in North America while direct-drilling or zero tillage is used in the United Kingdom and Europe. Aerial seeding is of course the ultimate form of zero tillage.

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EARLY CULTIVATION WITHOUT TILLAGE

No-till and reduced tillage have been used since ancient times by the so called "primitive cultures" for the cultivation of crops, simply because man has not the muscle force to till any significant area of land to a significant depth by hand.
The Incas in the Andes of South America and probably also most indigenous cultures around the world, have used a stick to make a hole in the ground, put seeds in the soil by hand and cover the seeds with the foot. Even today hundreds of thousands of farmers in Central and South America seed their crops using the same technology. Moreover, millions of hectares of land have been (and are today) traditionally sown with a hand jab planter without tilling the soil, after burning, in the shifting cultivation system in Brazil and neighbouring countries, long before the term no-tillage was introduced into the modern vocabulary. The slash mulch or "tapado" system in Central America and Mexico is another example of no-tillage developed by small landholders which has been used for centuries (Thurston, et al., 1994). In this system the seed is thrown after rain on top of the soil underneath a dense stand of Mexican Sunflower (Thithonia diversifolia) or other voluntary (or seeded) vegetation. Then the plants are cut and left on top of the seeds. After a few days the plants dry out and seeds germinate. In this case no tillage is performed at all.

The first possibility of cultivating crops without tillage on large scale farms occurred when 2,4-D, a broadleaf weed killer, was made available to farmers in the 1940s. Later, also Atrazine and Paraquat became available, these being the only herbicides accessible to early farmers engaged in no-tillage agriculture.

**DEVELOPMENT IN EUROPE**

The invention of the herbicide Paraquat in 1955 in the UNITED KINGDOM was the start of modern no-tillage development in Europe and also world-wide. This discovery led the Imperial Chemical Company, ICI, to initiate research without soil tillage. In 1973/74 the area under no-tillage in Great Britain increased to 200,000 ha and 10 years later to 275,000 ha (Table 1), thus the UK had the second largest area under no-tillage in the world after the USA (Derpsch, 1984). Field experiments in England showed that, if well managed, direct-drilling and reduced cultivation could give similar yields of winter cereals to those after ploughing, when straw residues were burnt. However, when restrictions on straw burning were introduced and problems occurred from the build-up of weeds and volunteer cereals many farmers who used these methods resumed the use of the plough and direct drilling almost ceased to be applied (Christian, 1994).

In the NETHERLANDS research on minimum and no-tillage started in 1962, aimed at simplification of field work, saving of time and energy and improvement of farm economy. W.A.P. Bakermans and C.T. de Wit of the Institute for Biological and Chemical Research of Agricultural Crops in Wageningen, were among the first scientists to apply the novel technology. Wind and water erosion is not a real incentive for no-tillage practices in this country. From the early experiences, gained in the period 1962-1971, Ouwerkerk and Perdok (1994) concluded that in Dutch arable farming no-tillage is not feasible. Stimulated by successful trials abroad, investigations into direct drilling systems started in GERMANY during 1966 (Bäumer, 1970). Despite intensive and long-term research carried out by Bäumer at the Institute of Plant Production of the University of Goettingen (the early experiments are still under way), by Czeratzki in Braunschweig and by Kahnt at the University of Hohenheim (Kahnt, 1969, 1976) that started in the late sixties, it is estimated that not more than 5,000 ha were under permanent no-tillage in Germany in 1997 (Friedrich Tebrügge, personal communication, 1998). On the other hand occasionally no-tillage is being increasingly practised by farmers in this country. In long-term research (18 years) carried out at the University of Giessen (Tebrügge and Böhrnsen, 1997) the authors concluded that 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. At the same time no-tillage increases the campaign performance so that it is a very powerful cultivation system. On average since the same crop yields can be achieved by no-tillage compared to plough tillage, the profit will increase. On the other hand lower yields can be accepted without any loss of profit in comparison to the conventional system. Based on the calculation of the total process cost, the relative superiority of no-tillage systems could increase further, if the beneficial environmental effects of no-tillage (e.g. less erosion, less pollution by agrochemicals) were taken into account (Tebrügge and Böhrnsen, 1997).

In 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. In PORTUGAL, Carvalho and Basch (1994) concluded that for most of the crops the direct drilling method can be applied.

No-tillage research in SPAIN started in 1982 and 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). In 1996, 500 no-tillage machines were used and it is possible to estimate that the area subjected to direct drilling in Spain amounts 300,000 to 350,000 ha (Gonzáles, et al., 1997). These areas represent only a small proportion (below 5%) of the area under annual crops. Although the references cited mention
no-tillage, it is doubtful that they referred to no-tillage under the proposed definition in this paper. Costa (1996), writes: "It is somewhat disappointing that conservation tillage (no-tillage with 30% of soil covered by crop residues) has received so little public support". Is no-tillage being understood as synonymous of conservation tillage?

First no-tillage trials in ITALY were carried out in 1968, but it is only in the last 5 or 10 years that the technology has experienced a substantial expansion. This is due to the need for reducing crop costs and the greater availability on the Italian market of equipment for sowing on untilled soil, as well as progress in the availability of adequate herbicides. In 1994, it was estimated that this planting system was applied on a surface area well above 30,000 ha for cereals and around 3,000 ha for soybeans (Sartori and Peruzzi, 1994). More recently the no-tillage area has increased to 100,000 ha, i.e. 2% of the agricultural land used for extensive cropping (Sandri and Sartori, 1997).

In BELGIUM Frankinet and Rixhon compared ploughing to direct drilling over a 15 year period from 1967 to 1982. Yields after direct drilling were slightly higher for winter beans, as in the case of winter wheat and spring oats, 15% less for spring barley and maize, and 20% less for sugarbeet (Cannel and Hawes, 1994).

In SWITZERLAND Vez started research on direct drilling in 1967 showing 15% yield increases in winter wheat as compared to ploughing (Cannel and Hawes, 1994).

DEVELOPMENT IN THE UNITED STATES

Research on conservation tillage with early versions of a chisel plough was started in the Great Plains in the 1930s, to alleviate the damage caused by wind erosion, after the occurrence of the famous "dust bowl". Stubble mulch farming was developed in the Great Plains, as a forerunner of no-tillage.

Edward Faulkner's book "Plowman's Folly", first published in 1943, is probably a milestone in the changes in agricultural tillage practices. He questioned the wisdom of ploughing. Some of his statements are: "No one has ever advanced a scientific reason for plowing"; "There is simply no need for plowing in the first instance. And most of the operations that customarily follow the plowing are entirely unnecessary, if the land has not been plowed"; "There is nothing wrong with our soil, except our interference"; "It can be said with considerable truth that the use of the plow has actually destroyed the productiveness of our soils". The statements were questioned by both farmers and researchers, because alternatives to ploughing at that time would not allow farmers to control weeds or plant into the residues. According to the Reader's Digest, "probably no book on agricultural subject has ever prompted so much discussion in the United States, at the time it was written". Five editions were printed in the first year of publishing.


More intensive research on chemical seedbed preparation started in the United States in the early sixties. In 1960, experiments were begun in Virginia, killing bluegrass sod with Paraquat, using Atrazine for residual control and 2,4-D for post-planting cleanup. These experiments were soon repeated in Ohio, Illinois, and Kentucky (Thomas and Blevins, 1996, Blevins et al., 1998).

In 1961 and 1962 demonstration trials were run in several farms in the US. These demonstration plots led Harry and Lawrence Young from Herndon, Kentucky, to apply the new technology on their farm in 1962, and they became one of the first mechanised farmers in the world to use no-tillage crop production. A metal plate at the site remembers the date: "First practice of no-tillage crop production in Kentucky occurred on this farm in 1962. Harry and Lawrence Young of Christian County were among first in nation to experiment with no-tillage techniques which use herbicides in providing seed bed in residue stubble. Conserves soil and water, saves time, labour, fuel and often produces higher crop yields".

Harry Young earned his B.S. and M.S. degrees at the University of Kentucky, and worked for the University before returning to the 500 ha family farm in 1954. He began experimentation with no-tillage on about 1/3 ha in 1962. Soon thousands of visitors went to his farm to learn about the new technology (Phillips and Young, 1973). Other farmers joined Harry Young and his brother later and began testing no-tillage corn production. At this time also machinery manufacturers started developing adequate equipment and in 1966 Allis Chalmers introduced the fluted coulter no-tillage planter. As no-tillage enabled to sow seeds immediately after harvest, soybeans produced by the no-tillage method started to be double-cropped after wheat in 1967 (Phillips and Young, 1973).

Shirley Phillips, one of the pioneer researchers of no-tillage in Lexington, University of Kentucky, wanted to prove that no-tillage was not suitable for adequate crop production. But after seeing the results, he became one of the strongest advocates and most successful propagators of no-tillage, not only in the US, but abroad as well. Because of his commitment to the system and his scientific as well as extension and lecture work, Shirley Phillips can be regarded today as the father of no-tillage technology.

Among the earliest research publications on no-tillage crop production we can cite Moody et al., 1961, Free et al., 1963, Triplett et al., 1963, Triplett et al., 1964, Lillard and Jones, 1964 and Jeater and McLvanny, 1965. A report on a six-year comparison of no-tillage was published by Shear and Mosher
In 1973 Phillips and Young published the book "No-Tillage Farming". This publication was a milestone in no-tillage literature, being the first one of its kind in the world. It led other people to apply and carry out research on the technology and was later translated into Spanish.

The area under no-tillage in the United States experienced a steady growth and increased from 2.2 million ha in 1973/74 to 4.8 million ha in 1983/84 (Table 1) to almost 20 million ha in 1997 (Table 2), but it accounts for only 16% of the total cultivated area of the country.

The new farm laws of 1985 and 1990, which promoted conservation compliance, recognised the vital role of no-tillage as a major means of meeting conservation requirements on highly erodible soils (Thomas and Blevins, 1996) and contributed to a faster adoption of no-tillage.

Despite the impressive increase of no-tillage cultivation in the USA, the expansion has been much slower than anticipated. In 1975 USDA predicted that in the year 2000 about 82% of the planted cropland in the United States could be under conservation tillage and 45% under no-tillage (USDA, 1975, 1985). This prediction may not be realised.

The increase of the no-tillage area in the USA, Canada and the other main countries where no-tillage is applied from 1987 to 1996 is described by Hebblethwaite (1997) from CTIC (Figure 1).

**DEVELOPMENT IN LATIN AMERICA**

**BRAZIL:** The first attempt to apply the no-tillage technology was made by the Faculty of Agronomy of the University of Rio Grande do Sul, in Nào-Me-Toque, in 1969 (Borges, 1993). With the help of USAID a Buffalo no-tillage planter was imported from the USA, and one hectare was subjected to direct drilling with sorghum in the same year. Unfortunately this machine was destroyed by fire putting an end to this early development.

First no-tillage trials in Latin America were started in April 1971 at the Instituto de Pesquisas Agropecuárias Meridional, IPEAME (later EMBRAPA, Empresa Brasileira de Pesquisa Agropecuária), in Londrina, Paraná State, in cooperation with a GTZ (German aid) project (Derpsch, 1984). In this project demonstration plots were set up in the farm of Herbert Bartz, a Brazilian farmer of German descent, in Rolândia, Paraná. After seeing the results of these plots, Herbert Bartz visited the UK and the USA, carried out research on the advances of this technique, visited ICI Fernhurst and Harry Young in Kentucky, bought a no-tillage planter in each country, and started seeding his first soybeans under no-tillage in October 1972. This is how Herbert Bartz became the first farmer to apply the technology in Brazil and Latin America and to use it continuously until the present. Another farmer, that imported an Allis Chalmers no-tillage machine together with Bartz, abandoned the system a few years later, after having problems in controlling weeds. The beginning of no-tillage was not easy in terms of area, since the first machines built in Brazil in 1975/76 based on the rotary hoe (Howard Rotacaster) were slow and the only herbicides available were 2,4-D and Paraqueat. Hand hoeing saved many crops from failure at this stage. Despite the difficulties at the beginning, the area under no-tillage increased from 1,000 ha in 1973/74 to 400,000 ha in 1983/84 (Table 1) and reached 6,500,000 ha in 1996/97 (Table 2). The Federation of No-till Associations in Brazil FEBRAPDP, estimates that in 1998 the area under no-tillage in Brazil had expanded to 8.4 million hectares (Figure 2).

ICI promoted no-tillage in Brazil from the early times with Terry Wiles starting applied research in Rolândia, Paraná in 1972. First experiments in the State of Rio Grande do Sul were started by ICI in 1973. More intensive and systematic research on no-tillage was initiated at IAPAR, Fundação Instituto Agronomico do Paraná, Londrina in 1976, in a co-operative research effort with ICI, resulting in the first comprehensive research publication on no-tillage in Brazil in 1981 (IAPAR, 1981). Another co-operative research project started in 1977 between IAPAR and the German Agency for Technical Cooperation, GTZ, focused on cover crops and crop rotations under no-tillage. The results were published in German in 1988 and later translated into Portuguese (Derpsch et al., 1991). At present, some research institutions of Brazil such as EMBRAPA (CNPTRigo), in Passo Fundo, Rio Grande do Sul, have decided that all their research programs (varieties, rotations, cover crops, etc.) should be carried out in no-tillage and their goal is to achieve (together with the extension service and the private sector) a 100% adoption of this farming system by farmers.

The first National No-till Conference held in Ponta Grossa, Paraná in 1981 was organized by the "Cooperativa Central Agropecuária Campos Gerais". Two other national conferences in 1983 and 1985 at the same site boosted the area under no-tillage in the "Campos Gerais" of Ponta Grossa to about 200,000 ha in 1986, this being the first large region to be subjected completely to the no-tillage practice in Brazil. Here the pioneer work of Frank Dijkstra and Manoel Henrique Pereira (President of the Federation of No-till Farmers FEBRAPDP, from 1992–1998), both farmers and leaders in their community, played a major role in the development and diffusion of this method of farming, not only in Brazil, but in all the Latin American countries and abroad. From here the technology spread mainly to the States of Santa Catarina and Rio Grande do Sul in the South of the country where significant progress has been achieved with the use of cover crops and crop rotations, thus reducing fertiliser and herbicide costs. In the 1990s the largest expansion of no-tillage in Brazil (Figure 2) occurred in the Cerrados (savannas of North Central Brazil with only one growing season per year), due to the economic shift of ANPPO (No-till Association of the Cerrados) which organised the fifth and sixth...
extensive work of APDC (No-till Association of the Cerrados), which organised the fifth and sixth national no-till conference in Goiania and Brasilia in 1997 and 1998, each one with more than 2300 participants.

As more, better and cheaper herbicides appeared on the market in the 1990s, no-tillage became easier to manage and this together with the development of more diverse and better no-tillage seeding machines, has had a tremendous impact on adoption rates by farmers (Figure 2). Among the chemical companies, probably Monsanto has invested more in the diffusion of no-tillage, because of its interest in marketing the herbicide Glyphosate. Among the no-tillage seeding equipment manufacturers, Semeato has been the leading company in developing seeding machines and supporting no-tillage-related activities. In 1985 already, thirteen no-tillage seeding machine manufacturers were on the market in Brazil (Derpsch et al., 1991).

Main crops under no-tillage in Brazil are soybeans, maize, wheat, barley, sorghum, sunflower, beans and green manure cover crops in rainfed agriculture. Irrigated rice is also increasingly being subjected to no-tillage in southern Brazil. About 270,000 ha of irrigated rice (33% of total area) were under no-tillage in the State of Rio Grande do Sul. In the irrigated rice growing area of southwestern Brazil, northwestern Uruguay and eastern Argentina approximately 450,000 ha of irrigated rice were grown under no-tillage in 97/98 (Ivo Mello, personal communication, 1998). Not only traditional crops are now being subjected to no-tillage in this country, but also onions, tomatoes, vegetables, tobacco, etc.

ARGENTINA: First farm experiences with and also research on no-tillage were started in Argentina in 1974. At this time some pioneer farmers began applying no-tillage while looking for a better way to grow soybeans after wheat in a double cropping system (two crops in one year). Several farmers started with the system and then gave up mainly because of the lack of adequate herbicides and machinery which constituted the main constraint for the early adoption of the system. Duperial (ICI) was one of the first private companies to become involved in the diffusion of the system by promoting research activities, meetings and field days. This company also set up a co-operation project with INTA (Instituto Nacional de Tecnologia Agropecuaria) (Marelli, 1995). Among other outputs of this project, a National No-tillage Conference was held at the INTA experiment station Marcos Juarez in 1977 (INTA, 1977). From that time, INTA developed research and extension no-tillage projects targeted at some productive areas of the country. Heri Rosso from Marcos Juarez was one of the first farmers to apply the technology in Argentina in 1978 and is now using it with increasing success. In 1979 the second National No-tillage Conference was held in Rosario, Santa Fe.

In 1986 AAPRESID (Argentine Association of No-till Farmers) was formed, being a milestone in Argentine diffusion of no-tillage technology. In 1992 AAPRESID organised its first national conference “Congreso Nacional de Productores en Siembra Directa” which more than 1000 farmers attend each year. While in 1987/88 not more than 25,000 ha were under no-tillage in Argentina, the technology expanded to 4.4 million hectares in 1996/97. The availability of machines was the main constraint for the early adoption of no-tillage, but today almost 30 different manufacturers from Argentina, and a few from Brazil, are selling no-tillage seeding machines in this country. Soybeans, maize, wheat and other small grains, as well as sorghum and sunflowers are the main crops being subjected to no-tillage in Argentina.

CHILE: Carlos Crovetto is Chile’s no-tillage pioneer. In 1978, he bought an Allis Chalmers planter and planted Chile’s first corn under no-tillage in his Chequen farm near Concepción. Today, Crovetto has virtually eliminated erosion, by leaving about 14,300 kg/ha of corn residues and 6,200 kg/ha of wheat residues on the surface. On land with 15 to 18 percent slope he obtains remarkable yields, such as 19,600 kg/ha irrigated corn and 10,800 kg/ha dryland wheat (No-Till Farmer, 1997). Through 19 years of continuous no-tillage practice Carlos Crovetto has added one inch of topsoil, boosted the organic matter content from 1.7 to 10.6% in the first 5 centimetres of soil, improved the bulk density from 1.7 to 1.4 g/cm³, increased the soil water-holding capacity by more than 100 percent, increased the phosphate content from 7 to 100 ppm and potash from 200 to 360 ppm in the top 5 centimetres of soil, improved the soil’s cation-exchange capacity from 11 to 26 milli-equivalents per 100 grams of soil and raised the soil’s pH levels from 6 to 7 (No-Till Farmer, 1997). As a farmer and researcher, Crovetto is also the author of the book “Rastrojos sobre el suelo” (1992), which was later translated into English with the title “Stubble over the soil” (1996).

First research reports on the no-tillage practice were published by INIA in 1981 (Del Canto and Ormeño, 1981; Martinez and Novoa, 1981). Despite 20 years of successful no-tillage farming in Chile, the system has not expanded to more than about a 100,000 ha in this country, and many farmers still burn the straw and practice no-tillage into ashes. Wheat, oats and rapeseed are the main crops under no-tillage in Chile (approximately 95%), in addition to barley, triticale, lupins, lentils, and maize.

PARAGUAY: Before any research on no-tillage was performed, farmers from the Cooperative Colonias Unidas, in Itapua, in southern Paraguay, applied the new production system in the beginning of the 1980s. Due to the lack of knowledge on how to handle the new technology and because they imported machines of lower quality based on the rotary hoe, as well as due to the lack of appropriate herbicides on the market, the first experiences failed and soon they resumed conventional tillage.
Later, Japanese farmers from Colonia Yguazú, Eastern Paraguay, gave the technology a new try with the backing of the Centro Tecnológico Agropecuario en Paraguay (JICA-CETAPAR). This centre, which was established for extending technical assistance to Japanese immigrant farmers in Paraguay, together with farmers, succeeded in making the system work. Akinobu Fukami, a Japanese immigrant, president of the local co-operative and leader in his community was the first farmer in this country to practice no-tillage successfully and continuously since 1983. With the support of JICA, all the farmers of this co-operative were applying the technology 10 years later and also many farmers in other Japanese colonies. Initial development was slow, and in 1992 only 20,000 ha were under no-tillage in Paraguay. After the Ministry of Agriculture of Paraguay with the assistance of the German Agency for Technical Cooperation, GTZ, initiated a Soil Conservation Project in 1993 that concentrated on no-tillage development and diffusion, the technology expanded rapidly to about 500,000 ha in 1998 (mainly soybeans). About 65% of the soybean-growing farmers in mechanised agriculture were using no-tillage on all or part of their farms in 1998.

**BOLIVIA:** After visiting Brazil and Argentina, Dr. Jean Landivar started no-tillage on his 2000 ha farm in the lowlands of Santa Cruz in 1986 for the cultivation of sorghum and maize and also for some soybeans. Research started at about the same time but without positive results. In the summer of 1996/97 102,000 ha were under no-tillage in Santa Cruz mainly with soybeans but also maize, rice and some cotton. In the winter of 1996, 35,000 ha of wheat (35% of total area) and also sunflowers were sown by applying the no-tillage practice (Patrick Wall, personal communication, 1997).

**MEXICO:** At the end of 1997 about 490,000 ha were under no-tillage in Mexico, 100-200 thousand hectares of which in small landholdings (Ramón Claverán, personal communication, 1997). Other sources indicate that less than 10,000 ha of no-tillage is practiced on small farms in Mexico and Central America (Wall, 1998). This contrasting information is probably due to different definitions of "small farmers".

Most of the other countries in Latin America have started to apply the technology recently, with the no-tillage areas covering less than 100,000 ha.

**CAAPAS:** An important milestone in the development of no-tillage in Latin America was the foundation in 1992 of CAAPAS, the Federation of American No-tillage Associations for Sustainable Agriculture. Victor Trucco was the first president from 1992-1998. At first only Latin American countries joined, but in 1998 CTIC (Conservation Tillage Information Centre) has become a member too.

**DEVELOPMENT IN AFRICA**

Earliest research on no-tillage in Africa was carried out in the late sixties in Ghana (Kannegieter, 1967, 1969, Ofori and Nanday, 1969, Ofori 1973). Research work at the IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria started in 1970 (FAO, 1993). Rattan Lal has been one of the most prominent researchers and prolific writers on this subject at IITA. First publications by Lal were written in 1973 (Lal, 1973 a, b). Forty one of his publications are listed as references in the IITA Monograph N° 2, which summarises 12 years of work at this Institute (Lal, 1983). Other scientists working at national research institutes and universities in Nigeria also started studies on a range of soils in the 1970s to compare the effect of different tillage methods on soil properties, crop growth and yield (Agboola and Fayemi, Aina, Wilkinson, cited by FAO, 1993). Similar studies were also initiated in other African countries including Liberia by Lal and Dinkins, Ivory Coast by Roose and Senegal by Nicou and Chopart (FAO, 1993). Despite the wealth of research information on no-tillage and mulch farming in Africa, the technology has not spread to a great extent among farmers. Also, there is only little information available on the development of no-tillage in this continent. A study on the potential use of no-tillage in Africa conducted by GTZ (GTZ, 1998), indicates, that the technology is already being used to some extent in the following countries: Angola, Benin, Ghana, Ivory Coast, Kenya, Mozambique, Niger, South Africa, Tanzania, Zambia and Zimbabwe. In most countries in Southeast Africa some work on conservation tillage practices (either at research stations or on farms) is being done and no-tillage is practiced successfully in larger farms. The most common crops being used in no-tillage are maize, sorghum, wheat and cotton.

In mechanised farms no-tillage seeding machines are often imported from Brazil, New Zealand or from the USA, but in Zimbabwe there is also a local production. No-tillage seeding equipment for small farms is manufactured in South Africa for experimental purposes and in some cases imported from Brazil. Also hand jab planters are imported from Brazil (GTZ, 1998).

On the other hand according to the Conservation Tillage Handbook in Zimbabwe (Vowles, 1989) many farmers have modified their planters to enable them to plant row crops directly through crop residues with no previous tillage operation. Although experimentation with zero tillage in many cases began with irrigated crops, it is assumed that under dryland conditions the potential benefits of zero tillage are the greatest.

It should also be mentioned, that permanent zero tillage is practiced only in regions with higher rainfall patterns or when irrigation is available. Minimum tillage is used widely and is the most common form...
patterns or when irrigation is available. Minimum tillage is used widely and is the most common form of soil preparation in small farms (1-2ha).

According to GTZ (1998), traditional land tenure, uncontrolled or communal grazing and lack of sufficient soil cover, as well as socio-economic constraints are the major problems in the spreading of no-tillage in Africa. Research and development as well as diffusion strategies have to be directed towards solving these problems before no-tillage becomes an attractive alternative for farmers in this continent. On the other hand labour constraints at the time of seeding in many regions of Africa may be an opportunity for this system to be adopted among farmers.

**DEVELOPMENT IN AUSTRALIA AND NEW ZEALAND**

Before no-tillage of crops was applied, pastures were directly drilled in Australia and New Zealand. In 1964 Plant Protection Ltd and ICI Australia Ltd undertook a joint programme on bipyridyls for crop establishment without tillage in Australia (Barret et al., 1972). First experiments were conducted in the Eastern States (Rowell, 1968). Little information could be obtained on the development of no-tillage in Australia other than that the technology is applied on about 1 million hectares (Hebblethwaite, 1997). Australia has serious erosion problems and this is an important reason why no-tillage is being increasingly used.

In New Zealand, Taylor (1967) from ICI Christchurch, reported that satisfactory yields of winter wheat were obtained by Arnott and Clement in 1962 following the application of chemicals in uncultivated soil. At Massey University in New Zealand many papers have been published in the 1950s and 1960s by M.W. Cross on reseeding, oversowing and overdrilling of pastures. In the 1970s more detailed investigations were conducted on direct drilling of crops (Baker, 1970, Dixon 1972). Intensive research on no-tillage has continued at Massey University until the present. In the book "No-tillage seeding" (Baker et al., 1996), many references of research on direct drilling carried out in New Zealand are listed.

**DEVELOPMENT IN ASIA**

It has been difficult to obtain information on the development of no-tillage in Asia. According to Table 1 no-tillage is being practiced in Japan, Malaysia and Sri Lanka over a limited area. It was reported that conservation tillage is practiced in India, Indonesia, Korea, Philippines, Taiwan and Thailand. More detailed information could be gathered from Japan.

**JAPAN:** (Personal communication by Makie Kokubun, 1998) There have been many studies and experiments on the no-tillage system in Japan, from the viewpoint of soil properties, crop performance and labour cost. The advantages and benefits from this system were in many cases observed in terms of labour cost/time, and sometimes in terms of crop performance. Several types of no-tillage seeding machines have been designed, built and tested by experimental stations and private companies and some of them have been found to be practical. A few machines are ready for commercial sale.

Despite the considerable research efforts for the development of no-tillage, farmers have not been keen to adopt this technology, so that the acreage under this system is statistically negligible in Japan, mainly because soil erosion, which is a strong driving force to introduce no-tillage in South and North America, is not a serious problem in Japan.

Attempts are made to develop the no-tillage system in rice-based cropping systems in paddy fields. In these systems, weed control is performed by water management rather than herbicide application. Similar system was used in rice-pasture cropping systems in Australia.

In some Asian countries where JIRCAS is carrying out collaborative research, the situation is similar to that in Japan. Despite the efforts to confirm the advantages of the no-tillage system, the prevalence among farmers is still at a starting point.

**FINAL REMARKS**

1. Although there were many early attempts to cultivate crops without tillage, modern no-tillage research started in the 1940s and adoption by farmers in the early 1960s.
2. First conceived as an efficient soil conservation method, no-tillage has evolved to an economic and sustainable production system that not only improves soil physical, chemical and biological characteristics, but also improves the environment for all, by reducing the emission of greenhouse gases.
3. The historical development of no-tillage cultivation of crops and the successful application in mechanised farms has been closely related to the following factors:
   - the availability of appropriate knowledge (research results and farmers' experiences)
   - 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 (this has been the basis of successful application especially in Latin America)
ACKNOWLEDGEMENTS

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Table 1. Area under no-tillage in the seventies and eighties (Hectares)

<table>
<thead>
<tr>
<th>Country</th>
<th>1973/74</th>
<th>1983/84</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>2,200,000</td>
<td>4,800,000</td>
</tr>
</tbody>
</table>

http://www.rolf-derpsch.com/notill.htm
United Kingdom & 200,000 & 275,000 \\
France & 50,000 & 50,000 \\
Netherlands & 2,000 & 5,000 \\
Japan, Malaysia, Sri Lanka & 200,000 & 250,000 \\
Australia & 100,000 & 400,000 \\
New Zealand & 75,000 & 75,000 \\
Brazil & 1,000 & 400,000 \\

Source: Various sources, cited in: Derpsch, 1984

Table 2. Total area under no-tillage in different countries in 1996/97 (Hectares)

<table>
<thead>
<tr>
<th>Country</th>
<th>Area under no-tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina 1)</td>
<td>4,400,000</td>
</tr>
<tr>
<td>Brazil 1)</td>
<td>6,500,000</td>
</tr>
<tr>
<td>Canada 1)</td>
<td>6,700,000</td>
</tr>
<tr>
<td>Mexico 2)</td>
<td>490,000</td>
</tr>
<tr>
<td>Paraguay 3)</td>
<td>500,000</td>
</tr>
<tr>
<td>Uruguay + Chile + Bolivia 5)</td>
<td>500,000</td>
</tr>
<tr>
<td>U.S.A. 4)</td>
<td>19,400,000</td>
</tr>
<tr>
<td>Others 5)</td>
<td>460,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>38,700,000</strong></td>
</tr>
<tr>
<td>Australia 1)</td>
<td>1,000,000</td>
</tr>
</tbody>
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ADVANCES

Frontiers in Conservation Tillage and Advances in Conservation Practice

Rolf Derpsch

Introduction

General situation of no-tillage in the world

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

- Adequate machines
- Adequate herbicides
- Mental change
- Knowledge
- Soils
- Mulch cover

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

- Crop rotations and green manure cover crops
- New developments
- Steps in no-tillage adoption

Outlook

Summary

Literature

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)

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>2000/ 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>21.120.000 1)</td>
</tr>
<tr>
<td>Brazil</td>
<td>13.470.000 2)</td>
</tr>
<tr>
<td>Argentina</td>
<td>9.250.000 3)</td>
</tr>
<tr>
<td>Australia</td>
<td>8.640.000 4)</td>
</tr>
<tr>
<td>Canada</td>
<td>4.080.000 5)</td>
</tr>
<tr>
<td>Paraguay</td>
<td>960.000 6)</td>
</tr>
<tr>
<td>México</td>
<td>650.000 7)</td>
</tr>
<tr>
<td>Bolivia</td>
<td>350.000 8)</td>
</tr>
<tr>
<td>Venezuela</td>
<td>150.000 9)</td>
</tr>
<tr>
<td>Chile</td>
<td>100.000 10)</td>
</tr>
<tr>
<td>Colombia</td>
<td>70.000 11)</td>
</tr>
</tbody>
</table>
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 machine built in Brazil based on the water jet technology...
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 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 4th 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. As long as the head stays conventional it will be difficult to implement successful no-tillage in practical farming. 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.

**Herbicides**

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 4th edition.

**Weeds**

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.

**Herbicide application technology**

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
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 and 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 de 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/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 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 continuous 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)

<table>
<thead>
<tr>
<th>Occurrence of weeds</th>
<th>With rotation</th>
<th>Without rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>36</td>
<td>102</td>
</tr>
<tr>
<td>CT</td>
<td>24</td>
<td>167</td>
</tr>
<tr>
<td>Broad leaved weeds in wheat</td>
<td></td>
<td></td>
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</tbody>
</table>
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 argued 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).

Lessons learned
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 considered 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 adopt the
under a great variety of conditions worldwide. 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., 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, timeliness, 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 worldwide. 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

PARAGUAY
SOIL CONSERVATION PROJECT (MAG/ GTZ)

ECONOMICS OF NO- TILLAGE AND CROP ROTATIONS
POLICY AND INVESTMENT IMPLICATIONS

FINAL REPORT

FAO Report No: 97/075 ISP-PAR
Date: 1 October 1997

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Justo López Portillo, DIA/ MAG
Mario Núñez, DIA, MAG
July 1997

CONTENTS

SUMMARY AND CONCLUSIONS

(Only the summary and conclusions are presented here)
Please refer to the main author or to the MAG- GTZ Soil Conservation Project for the full report.
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(1) The introduction of soybeans to the southern and eastern parts of Paraguay in the early 1970s, followed by wheat in the mid 1970s, using conventional mechanised soil preparation practices with disc ploughs and harrows, initiated a process of widespread soil degradation and erosion. These have now reached levels that threaten the sustainability of commercial agriculture in Paraguay. However, in the neighbouring Brazilian states of Parana, Santa Catarina and Rio Grande do Sul, cost-effective, no-tillage/ crop rotation technologies, which have important soil conservation characteristics, have been researched and developed in similar agro-ecological zones and are now quite extensively used throughout the central and southern parts of Brazil.

(2) The technique of no-tillage (NT) was first used in Paraguay in the late 1970s. Following a slow start, its adoption by Paraguayan farmers gathered momentum increasing from 20,000 ha in 1991/92 to an impressive 250,000 ha in 1995/96, accounting for about 19% of the land cultivated mechanically.

(3) In 1993, the Ministerio de Agricultura y Ganadería (MAG) and the Deutsche Gesellschaft f"ur Technische Zusammenarbeit (GTZ), started a project aimed at adapting and further disseminating no-
No-till farming in combination with rotations of both cash and green manure crops in the major grain producing departments of Paraguay. Since very little was known about the economics of these technologies in Paraguay, MAG in association with the GTZ, initiated a detailed investigation, the results of which are detailed in this report.

Methodology

(4) Eighteen farmers, representative of the MAG/GTZ project target groups of small, medium and large mechanised farmers in south-eastern Paraguay, were selected for in-depth study on the basis of their representativity and availability of farm records. Most of these farms were in the Itapua and San Pedro departments. Following recommended practice, no-tillage (NT) and crop rotations were being introduced gradually on most of these farms, normally over four to five years. The time series data collected during the study enabled a valid comparison of NT and conventional cultivation (CC) under roughly the same physical and management conditions over several seasons. Interviews were also held with other farmers during the course of the study to canvas their attitudes towards soil erosion and the NT/crop rotation technologies.

(5) Based on the farm data collected during the study, and some secondary data (from farmer cooperatives), two sets of representative crop budgets under CC and NT were prepared, one set for each region. In addition, machinery costs (both fixed and variable) were assembled for each region and crop rotations, which were linked to crop budgets to accommodate residual nutrient effects, were specified. The crop budgets, machinery costs, crop rotations and resource endowments (land, labour and capital) were all combined in models of typical farms for each region, so that the financial and economic impacts of NT and crop rotations could be quantified and compared to CC cropping systems.

(6) The farm models were prepared using universally available spreadsheet software. A subsidiary objective of the study was to make the models accessible to extensionists and farmers through extension programmes. Hence the models were structured to permit easy inputting of variables peculiar to an individual farm such as farm size, capital invested, labour complement, rate of adoption of no-tillage, crop yields, crop and farm input prices, interest rate, etc., so as to assist a farmer to decide on how he should introduce NT on his farm, including the choice of crop rotations.

Discussion and Results

(7) The effectiveness of NT in limiting soil erosion in the humid tropics is well known. Besides substantially reducing soil erosion losses, improving soil chemical, physical and biological properties, raising organic matter content, with consequent beneficial impacts on crop productivity, the cropping season is considerably extended. In Paraguay, conventional tilling of the soil is sensitively weather dependent and normally takes between 30-75 days from harvesting to sowing a subsequent crop. Using NT, this time period is reduced to less than 15 days (the harvester may even be followed immediately by the seeding machine), thus significantly extending the cropping season and providing an opportunity to introduce more crops during the cropping year.

(8) The benefits of introducing green manure crops are also quite well known. Soil erosion losses are further reduced by maintaining soil cover and mulch throughout the year, nutrient recycling and water infiltration are increased, weeds are suppressed, and pest and disease cycles are broken lowering the use of pesticides.

(9) The study has shown that there are a number of additional benefits from adopting NT and crop rotations in place of CC cropping systems. These include: (1) reduced tractor hours and lowered permanent farm labour and machinery costs; (2) savings in fertiliser, insecticide, fungicide and herbicide usage per crop over time in NT compared to CC; and (3) cost savings in NT through eliminating contour terracing and the replanting of crops following heavy rain which is often needed under CC.

(10) Attention is drawn in the report to the fact that the use of NT and crop rotations call for new management skills, particularly, to cost-effectively control weeds. Farmers require a number of years to master these skills, although this period can be significantly reduced through development and extension support oriented by farmers’ interests. The key skills required are: (1) selecting the type and quantity of herbicide used; (2) regulation of sprayer pressure, output, speed and timing of herbicide application; (3) the choice and sequencing of cash and green manure crops in rotations; (4) minimising the time between harvesting and the sowing of a subsequent crop; (5) managing ground cover and crop residues; and (6) using spot spraying with weed-specific herbicides or manual labour, where cost-effective, to control sporadic patches of weeds as opposed to blanket spraying with broad-spectrum herbicides. If these skills are not mastered, inevitably weed infestation increases production...
peanuts and soybeans. If these skills are not mastered, inevitably weed infestation increases, production costs rise, and crop yields may fall, which combine to significantly erode farm profits. Farmers then revert back to CC methods as they attempt to survive for some more time before reaching the inevitable point of having to abandon their land when it is no longer productive and economic to cultivate

(11) Comprehensive, yet practical and user-friendly, farm models were developed during the study to enable detailed quantification of the financial benefits and economic impacts of NT/crop rotations compared to CC cropping practices over 10 years. NT can be introduced over a number of years with the rate of adoption being specified by the user. The recommended practice is to introduce NT over 4 years; normally 10% of the farm in the first year, 40% in the second, 70% in the third and over the whole farm from the fourth year onwards.

(12) Differences in crop yields, as well as per crop fertiliser and herbicide usage (the most significant items of farm costs) were observed on the farms studied under both CC and NT. In general, depending on the crop, yields under CC were following a declining trend, while the reverse was occurring under NT when used in combination with green manure cover crops and crop rotations. Based on detailed analysis of the case study farms, as well as published research data from Parana (analysed by Sorrenson and Montoya, 1989), crop yields under CC decline over a period of about 10 years by between 5%-15% (depending on the crop), while over approximately the same period under NT, they increase between 5%-20% (again depending on the crop). These trends in crop yields were found to impact strongly on farm incomes. Savings in herbicide and fertiliser inputs, per crop, under NT compared to CC, which are partially dependent on the crop rotation being followed, range from 30% to 50%, respectively, over approximately the same period and significantly impact on farm variable costs and profits.

(13) The most commonly used rotations in San Pedro and Itapua, which vary in length from 3 to 5 years, were incorporated in the farm models and are shown below. It can be observed that the number (and range) of crops grown during a cropping year is greater under NT than CC. With NT it is possible to grow soybeans and maize during the main season, as well as out-of-season, and to grow a variety of green manure crops between cash crops to maintain good ground cover on the soil surface to suppress weed growth and to benefit from their residual nutrient effects.

<table>
<thead>
<tr>
<th>Crop Rotaions</th>
<th>San Pedro</th>
<th>Itapua</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT 2. O-S</td>
<td>W-S</td>
<td>OOr-M</td>
</tr>
<tr>
<td>3. W-S</td>
<td>M-S</td>
<td>C-M</td>
</tr>
<tr>
<td>5. O-S</td>
<td>W-S</td>
<td>OOr-GS</td>
</tr>
</tbody>
</table>

CC= conventional cultivation NT= no tillage |designates end of cropping year O= oats S= soybean So= off-season soybeans SF=sunflower M= maize Mo= off-season maize W= wheat OOr= oats and oilseed radish C= crotalaria SG= sorghum OV= oats and vicia

(14) The possibilities of introducing sunflower and maize in Itapua under CC are limited because of the longer growing seasons and extra time required to prepare the soil (wetter, heavier soils compared to the warmer climate and sandy soils of San Pedro).

Farm-level Financial Analysis Results

(15) The financial impacts of NT and crop rotations are analysed in detail by Sorrenson et al (1997). The financial performance of a typical medium-sized farm (45 ha) and a large-sized farm (135 ha) are traced over a period of 10 years for the San Pedro and Itapua regions. Results are outputted from the farm models for the overall farm, but can also be traced separately for each crop and for each crop rotation. Because the farm models are based on a thorough analysis, spanning an number of years of case study farms, the results can be confidently considered as indicative of what is actually being realised in practice by Paraguayan farmers.

(16) Annual income (by crop), variable and fixed costs (by major categories), net farm income, return on capital and annual tractor hours, are calculated for a typical farm. All revenues and costs are expressed in local currency (Guarani – Gs) or United States dollars (US$). The prices used were those prevailing in 1995/96. The same set of prices was used in all years, together with "expected" levels of input/output coefficients, so that financial performance figures reflect the dynamic effects of
San Pedro

(17) The results of the first and tenth years of a typical large farm (135 ha) in San Pedro are detailed in Table A and summarised below. Farm income decreases (from US$ 77,030 to US$ 68,630) under CC in response to declining crop yields which have been built into the model based on research results from Parana, Brazil, and actual farmer experience in San Pedro. Under NT it increases considerably (from US$ 75,010 to US$ 93,760). At the same time farm costs (both variable and fixed costs, the latter exclusive of the cost of NT equipment) are lower under NT compared to CC. Net farm income increases considerably under NT from US$ 8,570 in year 1 to US$ 31,140 in year 10, while under CC it is calculated to decrease from US$ 4,930 to -US$ 3,010. The changes in income and variable costs under NT, between the first and tenth years, reflect increasing crop yields, a higher cropping intensity and savings per crop in fertiliser, herbicide and insecticide. It is significant to note that these results are based on actual farmer experience in San Pedro.

<table>
<thead>
<tr>
<th></th>
<th>FIRST YEAR (US$)</th>
<th>TENTH YEAR (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CC</td>
<td>NT</td>
</tr>
<tr>
<td>Total Farm Income</td>
<td>64,668</td>
<td>63,675</td>
</tr>
<tr>
<td>Total Variable Costs</td>
<td>38,818</td>
<td>36,874</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>18,567</td>
<td>17,229</td>
</tr>
<tr>
<td>Net Farm Income</td>
<td>7,304</td>
<td>9,771</td>
</tr>
</tbody>
</table>

Itapua

(18) The results for a typical large farm (135 ha) in the Itapua region are detailed in Table B and are summarised below. As in San Pedro, the changes in farm income and costs are also based on actual farmer experience in the region. Farm income decreases (from US$ 64,690 to US$ 61,450) while under NT it increases considerably (from US$ 63,670 to US$ 102,860). Farm costs (both variable and fixed costs, the latter exclusive of the cost of NT equipment) increase under NT compared to CC, but these increases are less than the corresponding increases in farm income. Thus, net farm income increases considerably under NT, from US$ 9,770 in year 1 to US$ 33,700 in year 10, while under CC it is calculated to decrease from US$ 7,300 to US$ 1,100.

<table>
<thead>
<tr>
<th></th>
<th>FIRST YEAR (US$)</th>
<th>TENTH YEAR (US$)</th>
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<tbody>
<tr>
<td></td>
<td>CC</td>
<td>SD</td>
</tr>
<tr>
<td>Total Farm Income</td>
<td>64,688</td>
<td>63,675</td>
</tr>
<tr>
<td>Total Variable Costs</td>
<td>38,818</td>
<td>36,874</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>18,567</td>
<td>17,229</td>
</tr>
<tr>
<td>Net Farm Income</td>
<td>7,304</td>
<td>9,771</td>
</tr>
</tbody>
</table>

Comparative Summary - San Pedro and Itapua

(19) Highlighted below are the changes between the first and tenth years in net farm income, as well as return on capital and tractor hours, calculated for two representative large farms (135 ha) in San Pedro and Itapua.

<table>
<thead>
<tr>
<th>Farm Model (135 ha) - Net Farm Income US$</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>San Pedro</td>
</tr>
<tr>
<td>First Year</td>
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<tr>
<td>Tenth Year</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Itapua</td>
</tr>
<tr>
<td>First Year</td>
</tr>
<tr>
<td>Tenth Year</td>
</tr>
</tbody>
</table>
(20) All three performance criteria exhibit significant improvements under NT compared to CC in both regions studied. The net farm income figures for NT do not include the purchase cost of a no-tillage drill and auxiliary equipment. These costs can vary largely depending on the type of machinery purchased and whether a farmer opts to buy new or used equipment. Should new machinery be purchased, costs average about US$ 15,000 per farm. Net farm income increases in both regions are expected to be sufficient to pay for the NT equipment within 2 years. Often farmers lower their set-up costs in NT by initially hiring a no-tillage drill, through adapting their conventional drills for no-till, or by purchasing used NT machinery.

(21) The changes in the returns on capital of NT compared to CC are quite impressive. In these calculations allowance is made for the additional investment in NT machinery, costed as new machinery. NT and crop rotations are shown to substantially improve the financial performance of cropping farms in the regions studied, whilst under CC, financial viability becomes seriously threatened within a 10 year time-span.

(22) In both regions, despite increased cropping intensities, total annual tractor hours fall quite sharply by the tenth year in NT compared to CC, with consequential savings in tractor costs and permanent farm labour.

Financial Rates of Returns

(23) Financial rates of return on the marginal investment in NT equipment were calculated over 10 years for medium and large farms in San Pedro and Itapua. It was assumed that new equipment would be purchased. The results are shown below together with average rates of return over the 10 years analysed.

<table>
<thead>
<tr>
<th>Region</th>
<th>Farm Size</th>
<th>Financial Rate of Return(%)</th>
<th>Average Rate of Return(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CC</td>
<td>NT</td>
</tr>
<tr>
<td>San Pedro</td>
<td>Medium (45 ha)</td>
<td>-2.2</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Large (135 ha)</td>
<td>0.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Itapua</td>
<td>Medium (45 ha)</td>
<td>-2.1</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td>Large (135 ha)</td>
<td>1.4</td>
<td>13.7</td>
</tr>
</tbody>
</table>

(24) The adoption of NT and crop rotations is much more attractive financially in both regions for large farmers than medium-sized farmers. The reason for this is because in the farm model analysis, it is assumed that the investment costs in NT equipment would be the same irrespective of farm size.
Therefore, larger-sized farms are able to capitalise on considerable economies of scale. Savings in permanent labour costs are also greater on the larger farms. Nevertheless, NT and crop rotations are still financially attractive for medium-scale farmers.

(25) Small farmers can also benefit considerably from NT and crop rotations. The focus of this study was the mechanised areas where most of the soil erosion is occurring in Paraguay. The study also included an analysis of the benefits a number of small farmers are obtaining from the mechanised NT/crop rotation technologies. These farmers plant 4-5 ha of soybeans through contracting neighbouring farmers with tractors for their cultivation, spraying, sowing and harvesting operations. These farmers, who are conscious of the costs of soil erosion, have adopted new crop rotations and have their soybean crops directly sown. Ignoring the effects of reduced soil erosion, annual cost savings per small farmer, are estimated at about US$ 440.

Risk Analysis

(26) In all 10 years simulated, net farm income on the large farms was higher under NT than CC in both regions (see table below). Risks, defined as the probability of the net farm income falling below zero in any year, are analysed in the report. It is concluded that risks to a farmer lower considerably following the adoption of NT/crop rotations compared to CC cropping. The main reasons for this are: (1) higher and more stable yields in NT compared to CC due to improved soil structure, higher water infiltration and soil moisture retention, and reduced pest and diseases; (2) the impact of lowering farm income when soybean and wheat prices fall is less under NT compared to CC because it is possible to diversify into other cash crops; (3) reduced fuel costs under NT compared to CC and therefore lowered impact of increases in the real price of fuel; (4) over time, lower fertiliser and herbicide costs per crop under NT compared to CC as the impact of green manure crops, and the reduced fallow periods between crops, take effect.

<table>
<thead>
<tr>
<th>Farm Models - Simulated Net Farm Income (US$ per Year)</th>
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<tbody>
<tr>
<td>Year</td>
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<td>1</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
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<td>6</td>
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<td>7</td>
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<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

(27) Situations are rarely encountered in agricultural technology development whereby highly attractive financial returns are accompanied by a lowering of risks. Generally more profitable technologies carry with them concomitantly higher risks, necessitating the weighing-up by farmers of accepting higher profits with higher risks, as opposed to operating on a lower average profit but with lower risks.

Country-level Economic Analysis Results

(28) Farm models of representative medium and large farms for Itapua and San Pedro were used as the building blocks for an ex-ante economic evaluation of a soil conservation participatory R&D, training and extension project proposed in the report. The project, designed to speed-up the rate of successful adoption of NT/crop rotations in south-eastern Paraguay, would support on-farm trials, farmer workshops and seminars, study tours, up to 50 additional extensionists who would be specially trained and dedicated to the project, as well as a project management facility. The main output of the project would be a higher rate of adoption of no-tillage, in combination with financially attractive crop rotations, estimated to increase from the present about 20% of farmers to 60%, 75% and 80% by the 5th, 10th and 20th years respectively with the project. Without the project it is estimated that the rate
35m, 70m and 200m years respectively with the project. Without the project it is estimated that the rate of adoption would increase to 40%, 50% and 55% respectively by the 5th, 10th and 20th years. The direct costs that would be associated with the project over 10 years are estimated at about US$ 20 million. The expected Economic Rate of Return (ERR) over a 20 year period is estimated at 57%. Past research and development costs on NT/ crop rotations have been treated as sunk costs and therefore ignored. In economic prices, the annual incremental crop output valued at farm gate is estimated to rise from US$ 15 million (m), to US$ 32 m and US$ 43 m respectively in the 5th, 10th and 20th years.

**Policy and Investment Implications**

(29) Two important agricultural policy issues arise from this study. The first is an issue concerning extension policy. Because most soil erosion in Paraguay occurs on the mechanised annually cropped areas, it is these areas -- and the medium and large farmers concerned -- which must be the principal target of soil conservation efforts if sustainable agricultural cropping is to be achieved. However, at present Government of Paraguay (GOP) policy does not support any extension efforts directed at mechanised farmers. Instead public extension efforts are focused exclusively on small farmers using animal traction. Before the proposed interventions designed to increase the rate of sustainable adoption of the NT/ crop rotation techniques can be advanced, the GOP will need to readdress its agricultural extension policy. The study suggests that GOP should support extension efforts for the medium and large cropping farmers through the extension services of the farmer co-operatives, since a successful and cost-effective farmer discussion group model already exists in the country, albeit on a very small scale in two farmer co-operatives. Contracting of private sector extension operators to provide specific extension services, within the context of the proposed interventions, should also be considered and also calls for revising existing extension policies.

(30) The second policy issue relates to the methods of soil conservation to be supported by the GOP. There are three basic choices: (1) outdated conventional methods using contour terraces under CC; (2) reduced tillage combined with contour terracing; (3) NT in combination with crop rotations. Sorrenson and Montoya (1989) analysed these options in detail in Paraná, Brazil, and concluded that the third option was by far the most cost-effective. The work reported in this paper confirms that this option is financially attractive to farmers, cost-effective, economic and environmentally sustainable. GOP should make a clear policy choice on which option it wishes to follow so as to avoid inefficient use of resources in soil conservation efforts, including the Binacional Itaipú Soil Conservation Programme with Brazil and the World Bank assisted Natural Resource Management Project initiated in 1996. So far, a clear policy choice has not been taken and considerable confusion exists.

(31) There are a number of investment implications which arise from the study. Aside from the direct costs of the proposed soil conservation participatory R&D, training and extension interventions, estimated at US$ 20 million over 10 years, investment in additional NT equipment is estimated to be about US 7 m per year during the initial years and reducing thereafter. Although there should be sufficient funds to cover farmers’ additional needs for short term finance, there are limited funds available for financing farm machinery over medium terms of 5-7 years. The GOP, through the Banco Nacional de Fomento, should actively pursue with bilateral or international financing agencies, increasing the availability of funds to finance the additional investment which would be needed in NT equipment.

**Conclusions**

(32) Benefits to farmers from the adoption of no-tillage, in combination with sensible crop rotations, could be substantial. However, in order for farmers to realise these benefits, besides adopting NT, they must markedly alter their cropping systems, switching from monocropping practices to diversified crop rotations, including the use of green manure crops. This necessitates the learning and mastering of an array of new crop management skills. It is clear that participatory R&D, training and extension are needed to speed up the learning of these skills. While the suppliers of machinery and pesticides are active in the extension of NT -- aimed at increasing their sales and not farmers’ profits -- farmer co-operatives and farmers deserve to be supported so that the potential benefits to society, which could be captured from these techniques, are optimised.

(33) The study has indicated that investment in public goods over a 10 year period, in the form of participatory R&D, specialist training and extension programmes in no-tillage and crop rotations, would increase the rate of adoption of these technologies and be an economically attractive investment for Paraguay. These efforts should facilitate farmer-led development and private sector extension initiatives. This could be achieved by supporting self-organised groups of no-till farmers either directly, or indirectly through the technical departments of farmer co-operatives. The proposed participatory R&D, extension and training and awareness activities, in combination with substantially increased farm profits, are expected to provide sufficient incentives to encourage most Paraguayan
capping farmers to adopt NT and more diverse crop rotations. These changes in farm production methods are expected to reverse the current trend of declining crop productivity and lead to an economically, ecologically and socially sustainable form of commercial cropping in Paraguay.

(34) The MAG/ GTZ project should be considered as a pilot phase of the proposed participatory R&D/ training/ extension project. The possibility of immediately expanding the MAG/ GTZ activities through the World Bank supported Natural Resources Management Project\(^8\) should be carefully evaluated since it would save valuable time and would provide useful information which could be incorporated in the formulation of the project identified in this report.

<table>
<thead>
<tr>
<th>TABLE A</th>
<th>Farm Model (135 ha) – San Pedro</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
</tr>
<tr>
<td></td>
<td>LC</td>
</tr>
<tr>
<td>INCOME (US$)</td>
<td></td>
</tr>
<tr>
<td>Conventional Cultivation</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>30,458</td>
</tr>
<tr>
<td>Sunflower</td>
<td>13,911</td>
</tr>
<tr>
<td>Maize</td>
<td>16,752</td>
</tr>
<tr>
<td>Wheat</td>
<td>13,911</td>
</tr>
<tr>
<td>No-Tillage</td>
<td></td>
</tr>
<tr>
<td>Soybeans (main season)</td>
<td>5,682</td>
</tr>
<tr>
<td>Maize</td>
<td></td>
</tr>
<tr>
<td>Maize (off-season after sunflower)</td>
<td></td>
</tr>
<tr>
<td>Maize (off-season after soybeans)</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
</tr>
<tr>
<td>TOTAL INCOME</td>
<td>77,031</td>
</tr>
<tr>
<td>VARIABLE COSTS (US$)</td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td>7,507</td>
</tr>
<tr>
<td>Harvesting</td>
<td>2,828</td>
</tr>
<tr>
<td>Freight</td>
<td>2,878</td>
</tr>
<tr>
<td>Seeds</td>
<td>8,164</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>15,800</td>
</tr>
<tr>
<td>Insecticide</td>
<td>3,491</td>
</tr>
<tr>
<td>Fungicide</td>
<td>1,210</td>
</tr>
<tr>
<td>Herbicide</td>
<td>6,169</td>
</tr>
<tr>
<td>Hired Labour</td>
<td>1,550</td>
</tr>
<tr>
<td>Interest</td>
<td>3,886</td>
</tr>
<tr>
<td>TOTAL VARIABLE COSTS</td>
<td>53,484</td>
</tr>
<tr>
<td>FIXED COSTS (US$)</td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td>13,720</td>
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<tr>
<td>Permanent Labour</td>
<td>4,898</td>
</tr>
<tr>
<td>TOTAL FIXED COSTS</td>
<td>18,618</td>
</tr>
<tr>
<td>NET FARM INCOME (US$)</td>
<td>4,929</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>TABLE B</th>
<th>Farm Model (135 ha) – Itapua</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
</tr>
<tr>
<td></td>
<td>CC</td>
</tr>
<tr>
<td>INCOME (US$)</td>
<td></td>
</tr>
<tr>
<td>Conventional Cultivation</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>50,005</td>
</tr>
<tr>
<td>Wheat</td>
<td>14,683</td>
</tr>
<tr>
<td>No-Tillage</td>
<td></td>
</tr>
<tr>
<td>Soybeans (main season)</td>
<td>5,445</td>
</tr>
<tr>
<td>Soybeans (off-season)</td>
<td></td>
</tr>
<tr>
<td>Maize (main season)</td>
<td></td>
</tr>
<tr>
<td>Maize (off-season)</td>
<td></td>
</tr>
<tr>
<td>Sunflower</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
</tr>
<tr>
<td>TOTAL INCOME</td>
<td>64,688</td>
</tr>
<tr>
<td>VARIABLE COSTS (US$)</td>
<td></td>
</tr>
<tr>
<td>Tractor</td>
<td>6,712</td>
</tr>
<tr>
<td>Harvesting</td>
<td>2,105</td>
</tr>
<tr>
<td>Freight</td>
<td>2,921</td>
</tr>
<tr>
<td>Seeds</td>
<td>5,813</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>6,615</td>
</tr>
<tr>
<td>Insecticide</td>
<td>1,163</td>
</tr>
<tr>
<td>Fungicide</td>
<td>1,072</td>
</tr>
</tbody>
</table>
1. Farms were selected on the basis of their representativity in terms of agro-ecological zoning, farm size and soil tillage/cropping systems used. The area of summer crops grown per farm ranged from 18 ha to 350 ha.

2. In the San Pedro region, land can be abandoned in as few as 5-7 years after having been cleared of virgin forest for cropping. In Itapua, the period before abandonment may be as short as 8-10 years.

3. According to Kelly (1983), it is estimated that if soil erosion continues unchecked, yield declines of 15% in Africa, and 19% and 41% in Southeast and Southwest Asia respectively, are expected in the period 1980-2000.

4. Over 17 years (1977-1995) yield increases have been reported in Parana in NT of 86% in maize and 56% in soybeans, at the same time fertiliser inputs have been reduced 30% and 50% in maize and soybeans respectively (F. Dijkstra, pers. comm.).

5. A separate set of prices was used for San Pedro and Itapua.

6. The impact of price and climatic variation on farm financial performance under NT and CC are addressed in the report.

7. The second phase of the MAG/GTZ project which commenced in 1996 includes a component designed to assist small farmers to introduce NT and crop rotations onto their farms using animal traction. A study of the financial and economic implications of NT and crop rotations on small farms is planned as part of the second phase.

8. This project, despite clear objectives and concepts, distinctly lacks specification on how these will be translated into pragmatic soil conservation activities on farms.

CONTENTS

SUMMARY AND CONCLUSIONS

(Only the summary, conclusions and recommendations are presented here)
No- till was introduced on tractor- mechanised medium and large farms in Paraguay in 1990. By 1997 some 480,000 ha, 51% of the total cultivated area in Paraguay, was no- tilled. The total economic benefits arising from this spectacular adoption of the technique are enormous. Their magnitude can be appreciated from the US$941 million that has been calculated for the year 1997. This estimate includes the savings in lost nutrients in the soil that was saved from erosion on the no- tilled areas, plus the costs saved in reduced tractor hours, less fuel and lowered inputs of fertiliser.

In comparison to the meteoric rise of no- till on tractor- mechanised farms, no- till has hardly reached small farms. While the number of small farms in Paraguay total almost 248,000 and occupy 1.5 million ha, the area of no-till on small farms has been estimated at only 4,500 ha. This area includes areas occasionally no- tilled. The area permanently no- tilled on small farms is likely to be less than 2,000 ha involving no more than 150 farmers.

It is estimated that 1.2 million people live on small farms, 80% of whom live below the poverty line. Rural poverty has been increasing and small farm families have been suffering from declining incomes and deteriorating levels of nutrition and health. As a consequence, urban drift has been escalating. The urban population, as a percentage of the total Paraguayan population, increased from 37% in 1972 to 50% in 1992. A root cause of urban drift is undoubtedly declining productivity due to soil erosion and soil degradation and diminishing farm incomes. It is most unfortunate and ironic that many of the small farmer families who abandon their farms in search of a better life in fact face worsening conditions. Most end up living in and around cities in impoverished slum areas.

Despite the worsening situation faced by small farmers, and the significant number who have been abandoning their farms and moving into urban areas, they still make a major contribution to the Paraguayan economy. While small farmers occupy only 6% of the country's agricultural area they still generate 35% of the sector's output. This is a major contribution to the economy since the agricultural sector is the backbone of the Paraguayan economy generating 26% of the economy's Gross Domestic Product, 90% of all exports and employs 37% of the workforce.

**Edelira and San Pedro**

The report documents detailed case studies of seven farms in two representative regions of the country where most experience has been built- up with no- till on small farms - Edelira and San Pedro. Farms studied were selected as being representative of most small farms and varied in size from 5- 20 ha. In Edelira farmers had 5 or 6 years of experience with no- till and in San Pedro the two no- till adopters had only 2 years of no- till experience. The performance of these farms before the adoption of no- till, i.e. when the farms were conventionally cultivated, were compared to their performance after the adoption of no- till. Two farms which have not adopted no- till, one in each region, were also analysed in- depth to provide a further check on the current performance of conventional cultivation systems. In addition detailed analysis was carried out of five typical farms in Paraguay considered representative of small farms on an estimated 367,400 ha of extremely degraded soils of Central Paraguay.

This study shows that the yields of cotton, soybeans, tobacco and maize, important income earning
crops for small farmers, have been falling rapidly in unsustainable conventional cultivation systems. These systems enter an ever increasing downward spiral of diminishing yields and incomes and inevitably reach a point where farmers are forced to abandon their farms.

Soil fertility and organic matter levels rise rapidly when no-till and green manure crops are introduced immediately raising significantly farm incomes. Under conventional cultivation, in most cases small farmers do not use any fertiliser, very little if any manure and generally no soil conservation measures are taken. Due to significant soil erosion, high quantities of soil nutrients and organic matter are lost. In the opinions of the no-till adopter farmers’, crop yields immediately improve under no-till. Crop yield data are provided in the report for each of the case study farms. These clearly illustrate trends of declining yields under conventional cultivation and immediately increasing yields after the adoption of green manure crops and no-till. An example of the dramatically quick response to the introduction of no-till and mucuna is the introduction of tobacco on the two no-till farms studied in San Pedro. In the second year of using no-till, tobacco has been reintroduced into these farming systems. A highly profitable crop demanding higher levels of fertility, previously tobacco was only viable to grow for one or two years after the felling of forest on newly cropped land. This is a sign that soil fertility has rapidly recuperated.

The study shows that crop production costs fall substantially after the adoption of no-till. Not only are soil preparation costs saved, but farm labour requirements fall and the cost of weeding in most instances also lowers. On one of the farms studied in Edelira, soil preparation for soybeans costed US$59/ha accounting for 24% of the total production costs. These costs were eliminated under no-till. On the same farm, substantial savings (US$76/ha) in the costs of weeding were realised under no-till compared to conventional cultivation and annual farm labour requirements fell from 300 person-days to 239 person-days.

The study clearly demonstrates that the financial performance of conventional cultivation systems is poor and that in contrast no-till offers an almost instantaneous and dramatic improvement. Not only do crop incomes rise but crop production costs are significantly reduced. The order of magnitudes are illustrated below. Conventional systems are calculated to be marginally economic when all factors of production, including family labour, are costed at market rates. In distinct contrast, the farming systems where no-till and green manure crops have been introduced have shown a dramatic improvement.

### Summary Farming System Results for Edelira

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Bruno</th>
<th>Mendoza</th>
<th>Florencio</th>
<th>Victor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Area</td>
<td>Hectares</td>
<td>20</td>
<td>9,2</td>
<td>18</td>
<td>19,6</td>
</tr>
<tr>
<td>- Labour</td>
<td>Person-</td>
<td>381</td>
<td>181</td>
<td>300</td>
<td>379</td>
</tr>
<tr>
<td>- Net Farm Income</td>
<td>day US$</td>
<td>567</td>
<td>1,960</td>
<td>2,844</td>
<td>2,905</td>
</tr>
<tr>
<td>- Return to Labour</td>
<td>US$/ dia</td>
<td>1,49</td>
<td>10,85</td>
<td>9,47</td>
<td>7,66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Bruno</th>
<th>Mendoza</th>
<th>Florencio</th>
<th>Victor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Area</td>
<td>Hectares</td>
<td>20</td>
<td>9,2</td>
<td>18</td>
<td>19,5</td>
</tr>
<tr>
<td>- Labour</td>
<td>Person-</td>
<td>0</td>
<td>132</td>
<td>239</td>
<td>350</td>
</tr>
<tr>
<td>- Net Farm Income</td>
<td>day US$</td>
<td>0</td>
<td>3,184</td>
<td>3,853</td>
<td>5,778</td>
</tr>
<tr>
<td>- Return to Labour</td>
<td>US$/ dia</td>
<td>0</td>
<td>24,15</td>
<td>16,14</td>
<td>16,52</td>
</tr>
<tr>
<td>Incremental Net Farm Income</td>
<td>US$</td>
<td>0</td>
<td>1,224</td>
<td>1,008</td>
<td>2,873</td>
</tr>
<tr>
<td>% Increase in Net Farm Income</td>
<td>%</td>
<td>0</td>
<td>62</td>
<td>35</td>
<td>99</td>
</tr>
</tbody>
</table>

While the conventional farming case study (Sr. Bruno) currently has a net farm income of less than US$600 and a return to labour of less than US$1.50 per day, all three farms where no-till has been adopted have net farm incomes between about US$3,200 and US$5,800 with returns to labour from US$16 to US$24 per day. This is an impressive improvement over the farm that is still conventionally cultivated where the poor performance of the farm is primarily due to its heavy reliance on soybeans. Not only does it have a low yield (average 2,500 kg/ha) but the farmer also receives a relatively low price for his crop from a local soybean trader (12%- 15% below what the local farmer co-operative Colonias Unidas pays). He also pays a high rate of interest for credit borrowed from the trader (5% per month = 60% per annum) which significantly raises his costs of production. This farmer is caught in a proverbial vicious cycle of dependency on his local trader - a common occurrence amongst small farmers.
The results of the no-till adopters are equally impressive when they are compared to the past performance of these farms when they were conventionally tilled. The increases in net farm incomes have been between 35% and 99%.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Farmer</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CONVENTIONAL CULTIVATION</strong></td>
<td></td>
<td></td>
<td>Augustin</td>
<td>Lucas</td>
</tr>
<tr>
<td>Farm Area</td>
<td>Hectares</td>
<td>20</td>
<td>9.2</td>
<td>18</td>
</tr>
<tr>
<td>- Labour</td>
<td>Person-</td>
<td>183</td>
<td>164</td>
<td>163</td>
</tr>
<tr>
<td>- Net Farm Income</td>
<td>day US$</td>
<td>1.416</td>
<td>571</td>
<td>1.448</td>
</tr>
<tr>
<td>- Return to Labour</td>
<td>US$/dia</td>
<td>7.74</td>
<td>3.49</td>
<td>8.88</td>
</tr>
<tr>
<td><strong>NO-TILL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Area</td>
<td>Hectares</td>
<td>20</td>
<td>9.2</td>
<td>18</td>
</tr>
<tr>
<td>- Labour</td>
<td>Person-</td>
<td>0</td>
<td>154</td>
<td>171</td>
</tr>
<tr>
<td>- Net Farm Income</td>
<td>day US$</td>
<td>0</td>
<td>1.919</td>
<td>2.538</td>
</tr>
<tr>
<td>- Return to Labour</td>
<td>US$/dia</td>
<td>0</td>
<td>12.46</td>
<td>14.84</td>
</tr>
<tr>
<td>Incremental Net Farm Income</td>
<td>US$</td>
<td>0</td>
<td>1.348</td>
<td>1.090</td>
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<tr>
<td>% Increase in Net Farm Income</td>
<td>%</td>
<td>0</td>
<td>236</td>
<td>75</td>
</tr>
</tbody>
</table>

The current net farm income on the conventionally cultivated farm of Sr. Agustin is US$1,416, which is about comparable to the net farm incomes (on a per hectare basis) earned on the other two farms when they were conventionally cultivated. What is particularly impressive is how the net farm incomes and returns to labour have increased only 2 years after the introduction of no-till, particularly on the small 5-hectare farm.

Farmers in Edelira and San Pedro have been receiving readily available high-level technical assistance, initial stocks of green manure crop seeds and free no-till machinery and equipment. All farmers interviewed acknowledge the need for continuous technical assistance. However, the detailed analyses carried out in the study suggest that even if farmers were to pay themselves for the initial seeds of green manure crops and for the machinery/equipment in small groups of 3-4 farmers per group, these technologies would still be highly profitable for them. The study therefore shows that no-till would have a high economic pay-off to the state and is financially attractive to small farmers.

Before a significant number of small farmers can adopt no-till, they will need access to competent technical assistance and long-term credit at affordable rates to purchase a minimum of equipment and machinery. Depending on what equipment and machinery are purchased, costs per farmer would vary from about US$800-US$3,000 for a group of three farmers and from US$600 to US$2,200 for a group of four farmers. At the current interest rate charged by the CAH of 17.5% interest per annum, loans of at least 6-7 years duration would be needed.

Paraguari

Paraguari was selected as representative areas of extremely degraded soils in Central Paraguay. No-till has not yet reached small farmers on these poorly degraded soils.

The likely financial impact of a proposed MAG-GTZ fertility restoration programme, and the introduction of no-till and green manure crops, were evaluated in the study for a 5-hectare model farm. The data on which this model is based was obtained by studying in detail five typical farms in Paraguari and Ybycui. The farm model analysis also incorporated the results of 11 pilot parcelas which were installed on small farms by the MAG-GTZ Soil Conservation Project in 1997. The proposed fertility recuperation interventions involve restoring the fertility on 1 hectare of a farm over three years. The results are shown for a scenario in which 75% of the costs of the technical inputs of lime, seed and fertiliser in the first year are subsidised. Such a policy would be necessary for the programme to be financially viable and acceptable to small farmers. A projection is also made of the likely financial performance of the farm if soil fertility was restored and no-till was adopted over the total cultivated area of 3.75 ha. It would probably take a typical small farmer from 9-12 years to reach this stage. The results are also impressive as can be seen in the table below. The net farm income is estimated to rise substantially from minus US$176 to positive US$298 while labour reduces slightly from 126 to 118 person-days.
The Paraguari results indicate that for a model 5-hectare farm under conventional cultivation the system is uneconomic when all factors of production are costed at market rates. The main reason for this is the very low crop yields realised on the extremely degraded soils where cotton yields average 800 kg/ha, mandioca 8 t/ha and maiz colorado 600 kg/ha. Farmers continue to farm under such circumstances minimising their production costs. In the majority of cases no fertiliser or pesticide inputs are ever purchased. They use their own seed and rely on family labour which they do not have to pay for, although of course both have opportunity costs. In many instances farmers own their own work oxen, or they hire these from neighbouring farmers and pay for this in production or through their own labour.

The study also explores the capability of a typical small farmer to service loan commitments. A typical farmer would need to borrow between US$400 to US$500 to finance the cost of two matracas, a small 2,000 kg maize silo, as well as 25% of the cost of the technical inputs required in the first year and 100% of those required in the second year. The study shows that this would be financially feasible providing a loan for at least 4 years was provided, interest was charged at the current CAH rate of 17.5% and interest only was charged in the first year and principal was repaid in equal annual instalments for the remaining three years. It would be necessary however, to incorporate loan repayment delay and loan write-off clauses to cover possible crop failures due to circumstances beyond the control of the farmer, such as severe drought or pest attack, to eliminate the risk of financial ruin.

The results for Paraguari indicate that, investment in fertiliser and high green-mass producing green manure crops, and the introduction of no-till/ green manure crops, on small farms in the extremely degraded soil zones of Central Paraguari would be highly economic to the nation and to the small farmers.

A Proposed Programme for the Restoration of Soil Fertility in Central Paraguay

A 4-year first phase programme proposed for recuperating soil fertility on the extremely degraded soils of Central Paraguay is detailed in the report. The first phase would consist of four components: (1) 250 farm demonstration plots; (2) machinery and equipment; (3) extension; (4) technical assistance. The costs of this programme have been have been calculated at about US$1.1 million inclusive of price contingencies. Government of Paraguay would need to contribute about 60%. Farmers’ labour contributions are estimated to total about US$180,000, equivalent to 19% of the programme costs. A line of credit for participating farmers would total about 21%. Including the credit portion of the project costs means that farmers’ will pay 40% of the total programme costs. The project would need specialist technical support, which it is assumed will be provided free of charge by GTZ to the Government of Paraguay.

During the course of the project 25 extensionists would be trained extensively in the techniques of no-till, crop rotations, participatory on-farm development and in assisting farmers to organise the operation and maintenance of manual and animal traction no-till machinery. These extensionists would be dedicated full-time to the programme and would work directly with 250 small farmers.

Through the planned extension activities, involving national congresses and local symposia and field days, contact would be made with at least 2,000 other small farmers. In addition training courses...
Days: Contact would be made with at least 2,500 other small farmers. In addition training courses funded through the programme at the DEAG Training Centre in San Lorenzo would be an integral part of the extension activities. These training courses are designed to widen the impact of the programme beyond the extensionists and small farmers directly involved. An additional 60 extensionists and 240 leader small farmers would be trained in the basic principles of soil conservation and the restoration of soil fertility on the extremely degraded soils, in no-till and green manure crops. They would be selected from other parts of Central Paraguay where soils are extremely degraded. This would provide an opportunity for them to learn from the first phase field experiences and to help set the stage for a subsequent second-phase expanded programme.

**Immediate Government Support**

Because it will be imperative for the successful adoption of no-till and crop rotations that well trained competent extension services and long-term credit are accessible to small farmers, as a next step the study strongly advises that Government immediately support two pilot programmes. The first should be the first phase programme proposed in this report for the restoration of soil fertility in Central Paraguay summarised above. The second should be a small farmer no-till/crop rotation expansion programme in Itapua and San Pedro which would focus on building-up technical capacity for ensuring the necessary extension services and long-term credit are built up in these regions. It is recommended that these services should be supported through the local farmer co-operatives that exist in these regions.

This report has specified the resource requirements and institutional arrangements for the first proposal. There is a need to specify these for the second programme. While this was outside of the scope of the study, the report does provide considerable data and analysis on which a detailed proposal could be formulated.

**Conclusions**

1. The study has shown that no-till and crop rotations are sustainable and are much more profitable to small farmers than conventional unsustainable cultivation cropping systems.

2. Clearly the technology of no-till/green manure crops/crop rotations works just as well for small farmers as it does for medium and large mechanised farmers. Potentially huge economic, environmental and social benefits could be realised if this technology could reach a substantial numbers of small farmers in Paraguay. However, while this technology can be extended relatively easily to medium and large farmers who have the resources to easily access them, it will be much more difficult to extend them to small farmers. This is because small farmers do not have the resources to access them, especially technical assistance and credit.

3. To raise the rate of adoption of the technology will require important policy and institutional reforms and considerable Government financial support. Nevertheless the extent of the social, economic and environmental benefits that will arise from this technology adoption will justify the very considerable resources and efforts that will be required. Small farm families will be the major beneficiaries, a target group well worthy of this assistance. However, it would also be economic to society. Not only will it potentially halt urban drift with its heavy social costs, it would at the same time substantially reduce the currently high costs to the state of soil erosion.

4. It is concluded that no-till and crop rotations constitute a technological revolution for small farmers. Never before has the senior author analysed such an impressive technology for small farmers in more than twenty years of extensive experience analysing small farm systems in South America, Africa and Asia. To the authors’ knowledge, 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. To realise these private and social benefits will be a major challenge that will call for considerable effort and dedicated support.

5. The report highlights that to achieve greater spread of the technique considerable policy reform, capacity building and institutional strengthening will be required. Support will be required for this from the Government of Paraguay and international organisations particularly on two fronts: (1) **small farmer technical and organisational support** which will be indispensable for the successful introduction/adaptation of no-till technologies on small farms and to enable small farmers to organise themselves so that they can capitalise on these. This support has important policy implications - who will provide the services and the linkages that will need to be defined between DFAG/ DIA/ farmer co-operatives/ NGOs? (2) **credit and institutional support**
between 1980, dry-farming co-operatives NGOs. (c) credit and institutional support needed to provide sustainable lines of credit for small farmers and to strengthen linkages between small farmers/farmer co-operatives/banks to make this work.

6. Due to the complexity of the situation a step-by-step process is called for. As an immediate step the two pilot programmes are highly recommended for testing and developing the mechanisms which will be needed to realise a significant spread of these technologies amongst Paraguayan small farmers. Should these programmes be successfully implemented, the stage would be soundly set for an expansion of no-till on small farms in Paraguay. Any attempts at expanding no-till on small farms in Paraguay, before the policy and institutional reforms and other pre-requisites recommended in the report are soundly in place, would not be advisable as it would lead undoubtedly to costly misuses of scarce resources.

RECOMMENDATIONS

Throughout this report a number of specific recommendations have been made. The more important general recommendations arising from this study are highlighted below.

Enormous socio-economic and environmental benefits could be obtained from the restoration of the fertility of extremely degraded soils and from the substitution of conventional cultivation systems with crop rotations and no-till. Unlike medium and large farmers who have the technical and financial capacity to realise a lot of these benefits themselves, small farmers will require a lot of publicly-funded help if they too are to benefit from these technologies. Government support in the following areas is strongly recommended since it will be essential and fully justified on socio-economic and environmental grounds:

1. **Provide an on-farm research and development support service to enable small farmers to successfully introduce no-till and green manure crops on their farms.** The providers of this service would need to be MAG. Government would need to train a small number of DIA and DEAG personnel for this since this capability does not exist at present. Technical assistance would be needed to build up capacity within these institutions to competently provide the level of service that would be needed.

2. **Support a specific extension programme aimed at the expansion of no-till and crop rotation techniques as rapidly and cost-effectively as possible.** Specific training for this would be part of this programme and would need to be implemented by DEAG. The extension personnel to be trained to provide the extension service would be Government employees as well as employees of the private sector, especially farmer co-operatives and NGOs. Wherever feasible and cost-effective, private sector extension service providers should be contracted by Government to provide the necessary extension services. It will be imperative that Government funds this extension programme for at least the medium-term and possibly over the longer term (5-10 years). This is because the adoption and spread of these technologies will be much slower and more complex amongst small farmers than it is among medium and large mechanised farmers.

3. **Ensure that long-term credit is available for small holders to:** (a) purchase individually the necessary technical inputs of seeds, fertilisers, matracas and grain storage silos, etc; and (b) to purchase in small groups manual and animal traction no-till machinery imported into Paraguay mostly from Brazil. In the case of extremely degraded soils, there will be a need for a specific line of credit and separate programme to fund the initial inputs required to bolster the levels of fertility to more normal levels. Loans for up to 4 years would be needed for this. In the case of (b), loans of from 5-7 years would be needed. It is recommended that the CAH, and wherever possible farmer co-operatives, would be the most appropriate institutions to administer these lines of credit. Such credit would need to be subject to normal financial viability criteria and be made available only to farmers who are supported by the recommended on-farm development and extension services. Loan repayment assistance clauses in the case of recuperation of soil fertility, to cover the risk of crop failures, are recommended.

4. **Ensure lines of short-term credit, subject to the normal financial viability criteria, are available to small farmers to purchase seeds, fertiliser and pesticides that would be needed to successfully establish no-till and green manure crops.**

5. **Although outside the scope of the study, it is recommended that Government urgently overhaul its policies for assisting small farmers so that there is a coherency and consistency in the policies of the different institutions.** There is also an urgent need for major institutional restructuring of State credit institutions to reduce the current drain on limited Government resources caused by the enormously high costs of administering credit to farmers.
there is need now to move beyond purely technical aspects of no-till and green manure crops in small farming systems. It is now known that technically no-till and green manure crops work well under small farm conditions. Not only have they been well accepted by the few small farmers who have had the opportunity to use them, but it is now known from the findings of this study that they are highly profitable for small farmers. However, while there is a need to continue this technical work along the lines recommended above, there is an urgent need now to ensure that farmers can get access to trained and competent extension services as well as the seeds of green manure crops and the necessary machinery and equipment. Up to now these have been provided without any charge to a very small number of farmers through MAG-DEAG with the assistance of GTZ.

Emphasis needs to be placed now on:

1. providing funds for the training and functioning of the needed extension services;
2. developing sustainable seed production of green manure crops;
3. ensuring small farmers get access to affordable credit to buy the necessary no-till equipment and to organise themselves to operate and maintain this equipment.

It is recommended that pilot projects be initiated in Itapua with the Colonias Co-operative and in San Pedro with the Small Farmer Co-operative there. A number of groups of small farmers should be formed (3-4 per group) and assisted to access credit. These co-operatives can act as intermediaries to prepare investment plans to present to banks (CAH possibly BNF) and to administer the loan repayments. Short-term technical assistance is recommended to build up capacity in these two co-operatives for this.

For the immediate future, two specific programmes are highly recommended:

1. A programme for the recuperation of soil fertility and the introduction of no-till/crop rotations in Central Paraguay with activities focused in the Departments of Paraguari, Corillera and Caaguazu;

These immediate programmes are recommended now to prevent spreading limited manpower resources too thinly, since the institutional capacity to implement them is very limited, and to ensure that there will be measurable impacts. From these programmes, important experiences and lessons will provide a sound foundation for expanding later cost-effectively into other parts of Paraguay and institutional capacity will have increased through these initial programmes.

A limited number of simple crop variety and fertiliser trials on-farms should be an integral part of these immediate programmes. This is because there are absolutely no crop yield data, under small farm conditions in Paraguay, of the main crop varieties at differing levels of fertiliser and for alternative crop rotations incorporating residual nutrients of green manure crops. It is imperative that these data be generated as soon as possible so that farmers can rationally decide on what crop varieties, levels of fertiliser and green manure crop/crop rotations, best suit their needs. This development work, which should be practically based on-farms, should be part of the soil conservation efforts of DEAG, but will need to be done in close association with DIA. It will be imperative that trials are kept simple yet comprehensive enough to be meaningful. Emphasis would be placed on farmer participation/farmer acceptability of the options tested and on economic analysis of data rather than statistical analysis.