



Comprehensive inventory and assessment of existing knowledge on sustainable agriculture in the Latin American platform of KASSA

M.F.S. Ribeiro^{1*}, J.E. Denardin^{2a*}, A. Bianchini³, R. Ferreira⁴, C.A. Flores^{2b}, H.J. Kliemann⁵, R.A. Kochhann^{2a}, I.C. Mendes^{2c}, G.M. Miranda¹, L. Montoya^{2d}, N. Nazareno¹, C. Paz⁶, R. Peiretti³, C.N. Pillon^{2b}, E. Scopel^{2e}, F. Skora Neto¹

¹Instituto Agrônomo do Paraná (IAPAR), Rodovia Celso Garcia Cid, km 375, PO Box 481, 86001-970 Londrina, PR, Brazil

^{2a}Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Rodovia BR 285, km 294, PO Box 4561, 99001-970 Passo Fundo, RS, Brazil

^{2b}Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Rodovia BR 392, km 78, PO Box 403, 96001-970 Pelotas, RS, Brazil

^{2c}Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Rodovia BR 020, km 18, PO Box 08223, 73310-970 Planaltina, DF, Brazil

^{2d}Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Estrada da Ribeira, km 111, PO Box 319, 83411-000 Colombo, PR, Brazil

^{2e}Empresa Brasileira de Pesquisa Agropecuária / Centre de coopération Internationale en Recherche Agronomique pour le Développement (EMBRAPA/CIRAD), Rodovia BR 020, km 18, PO Box 08223, 73310-970 Planaltina, DF, Brazil / Avenue Agropolis, 34398 Montpellier, France

³Asociación Argentina de Productores en Siembra Directa (AAPRESID), Paraguay 777, 8th Floor, Of. 4, 2000 Rosario, Argentina

⁴Fundação de Apoio ao Ensino, Pesquisa e Extensão (FAEPE), Campus Histórico da UFLA, PO Box 142, 37200-000 Lavras, MG, Brazil

⁵Universidade Federal de Goiás (UFG), Campus Samambaia (Campus II), PO Box 131, 74001-970 Goiânia, GO, Brazil

⁶Asociación de Productores de Oleaginosas y Trigo (ANAPO), Av. Ovidio Barbery, Esq. Calle Jaime Mendoza, PO Box 2305, Santa Cruz de la Sierra, Bolivia

* Platform Coordinator

Centre de coopération internationale en recherche agronomique pour le développement
Avenue Agropolis, 34398 Montpellier, France

www.cirad.fr

© Cirad 2007

ACKNOWLEDGMENTS

The research reported here has been carried out in the context of KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture) a European Commission – funded project (DG-Research - Contract no. GOCE-CT-2004-505582) under the FP6 programme: “*Integrating and strengthening the European Research Area*”; Thematic priority “Sustainable Development, Global Change and Ecosystems”, Sub-priority “Global Change and ecosystems”.

Disclaimer

This publication reflects only the authors' views. It should not be construed as representing the views of the European Commission. The European Commission is not liable for any use that may be made of the information contained therein.



KASSA has been coordinated by CIRAD.

It worked between 1 September 2004 and 28 February 2006.

The KASSA Consortium assembled 28 contractors from 18 countries.

KASSA has been implemented through four regional "platforms": Europe, the Mediterranean, Asia and Latin America.

<http://kassa.cirad.fr>

Partners of the Latin American platform:

- 29 – IAPAR, Brazil;
- 30 – FAEPE, Brazil;
- 31 – UFG, Brazil;
- 32 – EMBRAPA, Brazil;
- 33 – ANAPO, Bolivia;
- 35 – AAPRESID, Argentina.

Scientific advice has been provided by:

- Michel Griffon (CIRAD, France);
- Ren Wang (IRRI, Philippines);
- Jaromir Kubat (VURV, Czech Republic);
- Roberto Peiretti (AAPRESID, Argentina).

This document is the deliverable D1.4 of the workpackages 1.1 & 2.1

Table of Contents

Concept and practices of Conservation Agriculture.....	1
1 Description of cropping systems design and management.....	2
1.1 Brazil	3
1.1.1 Subtropical area	3
1.1.2 Tropical area	4
1.2 Bolivia	6
1.2.1 Low rainfall zone	7
1.2.2. Medium rainfall zone	7
1.3 Argentina	9
2. Driving forces and constraints to adoption.....	11
2.1 Brazil	11
2.2 Argentina	13
2.3 Bolivia	14
3. Scientific and practical results	15
3.1 Crop yields and stability	15
1.2 Soil characteristics	18
3.3 Weed management	27
3.4 Pests/diseases management	28
3.5 Rainwater efficiency	29
4. Socioeconomic impacts	29
4.1 Small scale Agriculture	29
4.1.1 Labor and machinery requirements	29
4.1.2 Costs and Profitability	30
4.1.3 Multipurpose role of agriculture.....	31
4.2 Large scale agriculture.....	31
5. Environmental impacts	32
5.1 Carbon stratification and sequestration	32
5.2 Nitrogen and nutrient cycling	38
5.3 Erosion mitigation	39
5.4 Pollutants	41
5.4.1 Herbicides.....	41
5.4.3 Nitrate contamination in soils.....	42
5.4.4 Soil and water losses	43
5.5 Soil microbiology	43
6. Conclusions and Proposals	45
6.1 Technical changes.....	45
6.2 Innovation processes.....	45
6.3 Economic, social and cultural aspects	46
6.4 Environmental aspects	46
6.5 Further research needs	46
6.6 Policies	46
References	48

Concept and practices of Conservation Agriculture

Taking into account the wealth of knowledge in terms of research and experiences, participants of the Latin America Platform of the KASSA project consider CA as the main contribution of the platform to KASSA project, being the No-Tillage system an operational tool for CA. In Latin America, this system has been regarded as “Siembra Directa” in the Spanish phone countries and “Plantio Direto” in Brazil.

ECAF (2005) refers to Conservation Agriculture as several practices related to the management of the soil for agrarian uses, altering its composition, structure and natural biodiversity as little as possible and defending it from degradation processes (e.g. soil erosion and compaction). Generally, Conservation Agriculture includes any practice which reduces, changes or eliminates soil tillage and avoids residues burning so as to maintain enough surface residues throughout the year. Key features of Conservation Agriculture include: no ploughing, disking or soil cultivation; crops and cover crop residues stay on the surface; no burning of crop residues; permanent crop and weed residue mulch protects the soil; the closed-nutrient recycling of the forest is replicated; lime and sometimes fertilizers and surface-applied; use of specialized equipment; continuous cropland use and crop rotations and cover crops are used to maximize biological control (FAO, 2001). CA is based on three components – absence of soil tillage, maintenance of soil cover and use of crop rotations – which must be applied simultaneously and have to be considered as more than a simple technique of soil conservation. It has to be regarded as an integrated production system comprised of multiple interrelated processes

For long time conservation agriculture was meant solely as reduction in soil tillage in relation to the conventional tillage system. Consequently, terms as minimum tillage, reduced tillage, zero tillage, or no-tillage were used as an umbrella for conservation tillage due to the reduction in soil tillage.

Presently, conservation agriculture, focused on the crop production systems approach, is defined as a complex of technological processes under a holistic approach aiming at to preserve, improve and conserve natural resources using integrated management of soil, water and biodiversity, compatible with the use of external inputs. This complex of technological processes is considered one of the most notable factors responsible for the improvement of agriculture during the last decade, mainly by involving:

- reduction or elimination of soil disturbance;
- maintenance of crop residues on the soil surface;
- permanent maintenance of soil cover;
- broadening of the biodiversity, through cropping diversified plant species under crop rotation or intercropping and using green manure or cover crops;
- diversifying of crop production systems;
- integrated management of pests;
- controlled traffic of machinery and implements;
- precise use of farming inputs;
- use of complementary conservation agriculture practices to control erosion;
- reduction of the time interval between harvesting and seeding.

Conservation agriculture under this holistic concept has to be seen as system’s approach.

Partial adoption of these processes consequently represents a return to the past scenery, in which conservation agriculture meant reduction in soil tillage.

Conservation agriculture, under this new concept, represents the sustainability of crop production systems, conserving soil, water, air, and biota, as well as, preventing pollution and degradation of the neighboring systems.

In Brazil, conservation agriculture has been intensively used by adoption of the no-till system. In this situation, no-till system is an efficient tool to induce sustainable development of agriculture.

For that reason the no-till system is defined as a complex of technological processes oriented to explore of crop production systems using plant species diversification through crop rotation and/or intercropping, with soil disturbance restricted to the seeding row, maintenance of permanent soil cover, and minimum time interval between harvesting and seeding.

Similarly to the definition of conservation agriculture, the no-till system comprises the complex of technological processes that induces the crop production systems to lower degree of disorder when comparing to other soil management systems, by:

- requiring less farming infrastructure;
- less labor force;
- less fossil energy;
- favoring biological pest control;
- reducing soil erosion;
- improving soil flocculation and aggregation processes;
- improvement of soil structure;
- decrease the organic matter mineralization rate; and
- reduce rate of nutrient cycling, establishing steady state of different growing live organisms.

Thus, no-till system compared with other soil tillage systems, promotes the steady state of the agro-ecosystem, organizing fluxes of entry and exit of energy and product of the system, conserving its own biological potential, giving higher rate of self-organization.

Adoption of no-till system is aimed at to express the genetic potential of species explored by improving the environment and the soil factors, without degrading the natural resources allowing the system to act as a tool for transformation, reorganization and sustainability of the agro-ecosystems. The respect to the life through a constant expectancy to reach a clean agriculture, considers the conservation agriculture and no-till system a real possibility to break the present paradigm.

The Argentinean Report adds the “soil nutrition principle”, understood as a more evolved approach to the crop fertilization issue. This principle takes into account a more systemic approach and considers the interactions among soil chemistry, soil biology, soil organic matter and structural properties, nutrient cycling, rather than just the addition of nutrients to a given crop.

1 Description of cropping systems design and management

Various CA cropping systems under CA were developed in Latin America, which are a function of different agro ecological and socioeconomic conditions found in each country. This report will describe the cropping systems according to these 2 variables.

1.1 Brazil

1.1.1 *Subtropical area*

In family farming systems of the subtropical area, the following crops are found under CA: maize, common beans, tobacco (restricted to sandy soils); Soybeans; wheat, oats and other gramineous adapted to cold climate. The availability of rains all long the year makes possible two, and, depending on the region, three crops per year.

Because of the socio-economic diversity within family farmers, both animal-drawn, tractors and mixed mechanization can be found. Some examples of cropping systems used by family farmers are described below.

Small scale family farmers produce food and cash crops, using animal traction and family labor, as well as low level of inputs. They usually sow summer maize crop with an animal powered no-tillage planter, in a mulch of a black oats (*Avena sativa*) sole cropped of mixed with common vetch (*Vicia sativa*) or hairy vetch (*Vicia villosa*). Other winter cover crop species include forage radish (*Raphanus sativa*) and ryegrass (*Lolium multiflorum*). Prior to planting of the summer crop, the cover crop is managed with burn down herbicides or mechanically, with a knife-roller. Generally, post-emergence herbicides are used for weed control.

Family famers with more availability of capital, produce milk and/or commodities such as maize and Soybeans. They own or hire tractors, and use higher levels of inputs. Summer crops are sown onto the mulch of the last regrowth of black oats or ryegrass cover crop managed through either a knife-roller or a knife-roller combined with herbicide, depending on the amount of Avena residues left and also on weed infestation. The cover crop is grazed several times at the beginning of the winter.

The cultivation of grain crops may include rotation with onion, tomatoes and tobacco. Onion production is basically concentrated on small farms at the State of Santa Catarina. Some cover crops used are *Canavalia ensiformis*, *Crotalaria mucronata*, gray mucuna (*Stizolobium niveum*), and spontaneous vegetation (*Brachiaria* sp and *Digitaria* sp). The implementation of the systems consists of sowing the cover crop (oats, cow pea or even the combination of the two) between maize rows in the beginning of autumn. Maize residues are chopped in May and its mulch is bedded allowing a larger growth of the green covering. At onion transplant time (June to September) the biomass is desiccated with a systemic herbicide and one week after, bedding is done with a knife-roller. Using micro tractors with a kit for minimum cultivation, or fertilizer spreaders of the rotocaster type, the rows where the onion will be transplanted are prepared. With this option, the farmer can have an additional source of income with the maize crop. However, the use of systemic herbicides is necessary. In the initial phase of the crop development it is necessary to do a nitrogen top dressing, as decomposition of residues results in higher demand of N in the soil-plant system. The use of common vetch (*Vicia sativa*) is not compatible due to the planting dates.

As an alternative, summer leguminous species such as mucuna (*Stizolobium niveum*) or *Canavalia ensiformis* can be sown in November or December. With this option, in areas with

frost occurrence, it is possible not to use burn down herbicides, and reduce the use of nitrogen top-dressing. A disadvantage of this option is the non harvest of corn, due to the aggressiveness of the mucuna, that hinders the growth or harvest of the grains of the culture subsequent to the onion.

Tomato can also be found in rotation with maize, which is sown in the summer onto mulch comprised of a mixture of winter cover crops. In the middle of September the biomass is managed with knife-roller, which results in a biomass approximately 5cm thick. The mixture of cover crops should be sown on the maize residues, which makes it possible to have an annual production of straw between 12 and 15 t/ha until the end of the tomato crop cycle.

When tobacco is the main crop, common beans or maize can be sown in rotation so as these crops take advantage of the residual effect of the fertilization of tobacco. Generally farmers use a hand jab planter or an animal-drawn no-tillage planter.

The first experiences of CA for onions took place in Santa Catarina, in the 80's. with the minimum cultivation of the onion. Starting from 2002, producers in São José do Rio Pardo-SP, the main onion center in the state of São Paulo, began to adopt onion planting on mulch, usually corn, using a rotary cultivator to make the furrows for the seedling transplants or a planter adapted with disks to both sow and cut the straw in the definitive place.

CA for perennials: Epagri/ Estação Experimental de Urussanga, Sul de Santa Catarina has been planting black oats (80 kg/ha) associated to hairy and common vetch (25 Kg/ha) in the winter for six years and has been getting good results. The best period to seed is from April 15th - 30th, taking 90 days after emergence to reach the bedding point. The producers can take advantage of the cover seeding operation to incorporate, superficially (2cm), fertilizers and lime, according to the soil analysis recommendation.

Another aspect of the efficiency of the process is that the oat culture can be used as pasture for animals, when it is 20 to 25 cm high. After the cutting of the black oat, a covering fertilizer with cured organic fertilizer or with nitrogen chemical fertilizer (50Kg of urea/ha) should be done.

1.1.2 Tropical area

The direct planting of industrial tomato was tested initially in Guairá-SP. Now, it has been employed in the area of Rio Verde,GO, and Varjão de Minas, MG, under dryness or under irrigation, with the transplanter opening furrows directly in the straw.

Other initiatives in this area are the minimum cultivation of tomato and bell pepper in greenhouses on black oat or corn mulch in Itupeva,SP; the minimum cultivation of cauliflower under organic handling in Teresópolis-RJ; the cultivation of lettuce on black oat mulch cultivated in beds in Piedade, SP; the planting of pumpkins on dry pasture in Brasília, DF; the minimum cultivation of broccoli and cabbage in Lavras-MG; the project named of Direct Vegetable Planting System (DVPS) "Sistema de Plantio Direto de Hortaliças (SPDH)", with the objective of offering alternatives to the tomato monoculture of the, in Caçador, SC. All have been presenting positive and promising results and should get adjustments according to the local reality. With lettuce, cauliflower and one-head broccoli produced in the summer, a significant reduction of disease incidence was observed, be it for the better drainage and for the elimination of the raindrop splash or be it for the thermal regulation that the mulch

promotes, leading to the obtaining of a better quality commercial product. In cultures such as tomato and bell pepper, a higher longevity of the crop in function of the deeper root system is noticed. In cucurbits, such as pumpkins and watermelon, cleaner fruits are obtained by their development on the mulch.

EMBRAPA Hortaliças, from 2003, has presented a pilot project for the direct planting of vegetables. Different covering plants for mulch formation (*Crotalaria juncea*, amaranth, millet, forage sorghum), and levels of the soil covering are being appraised, besides six onion cultures (Baia periforme, Conquista, Serrana, São Paulo, Vale Ouro IPA-11), in a population of 333 thousand plants per hectare, and two industrial tomato cultures (H9553 and H9992), in a population of 30 thousand plants per hectare. The sequence of cultivations that has been made is green corn - covering plants - onion or tomato - green corn - covering plants - tomato or onion. In the first year, the onion productivity obtained under direct planting oscillated between 30.7 and 54.0 t/ha, depending on the mulch and the culture, with an average of 42.9 t/ha. The control produced between 28.8 and 41.2 t/ha, with an average of 36.5 t/ha. As far as classification, under conventional planting 82.4% of bulbs of classes 3 and 4 was obtained, with a larger commercial value, while under direct planting, between 87.9% and 94.1% of bulbs of the same classes. With tomato the average productivity under direct planting systems oscillated being 104.3 and 133.0 t/ha, with an average of 122.3 t/ha, while under conventional planting the average was 102.2 t/ha. With relationship to the mulch level, the best results were observed when having about 6 t/ha. of mulch. Preliminary data indicate that the efficiency of water use, that is, the amount of water necessary to produce one kilogram of tomato, under direct planting systems was superior by up to 80% when compared with the conventional planting.

Large scale farmers in the Cerrados Region

In the Cerrados region of Brazil (central plateaux between 10 and 20°S latitude), the climate is humid with yearly rainfall of 1200 - 2000 mm per year during an 8-10 month period. Diversified CA systems were developed for the large-scale grain producers of this region to replace the inefficient tillage-based Sorghum monoculture system that produced only small quantities of biomass

- CA systems with two annual crops in succession under continuous direct seeding, the second crop playing the role of a 'nutrient pump' (Séguy et al. 2003).
- More recently, CA systems with three crops per year, all under continuous direct seeding, consisting of one commercial crop (Sorghum, rice, maize) followed by cereals (maize, millet, sorghum, Eleusine) intercropped with forage species (from the genera *Brachiaria*, *Stylosanthes* and *Cajanus*, single-cropped or combined) that all function as powerful 'nutrient pumps' producing large amounts of biomass in the dry season which can be grazed or used as green manure (Séguy et al. 2003).

In these last case, the combination 'commercial cereal crop + forage species' following the first commercial crop at the end of the rainy season, uses water substantially deeper than 2 m and has an active photosynthesis later during the dry season. This combination also displays very strong vegetative regrowth after the first rains of the following season or after dry season rain, thus ensuring a complete, permanent covering of the soil. As *Brachiaria sp.* are very efficient forages for cattle, the farmers may choose to convert their area into pasture or to stay

in grain production for the next year. Such systems are frequently used under irrigated conditions or in wetter regions (more than 1500 mm) where it is frequent to have some periods of heavy rains during the first crop cycle recharging deep water reserves. Under such conditions, total annual dry matter production (above and below soil) increased from 4 to 8 t/ha in the initial systems with a single annual crop to an average of around 30 tons/ha in the best CA systems (Séguy et al. 2001).

Under other conditions, natural ecosystems have already served as a model for designing new sustainable cropping systems (Altieri, 2002), but these have generally been perennial cropping systems, involving either trees in agro forestry systems (Eel, 1999) or forage crop systems in natural grassland regions (Soule & Piper, 1992). The main challenge here was to apply these concepts in annual grain production systems.

Crops x livestock integration

In humid tropical conditions the more efficient species for recycling nutrients such as *Brachiaria* and *Stylosanthes* sp. are also good forage species. They can be grown as cover crops towards the end of the rainy season and grazed as soon as at the beginning of the following dry season and even more during the next cycles. Alternate periods between cropping and grazing are possible under different rotation schemes. Moreover, this succession schemes offers the possibility of rehabilitating degraded pastures at basically no installation costs. Such is the case of the newly developed “Santa Fé” cropping system in the Cerrados, which associates a maize crop and a *Brachiaria* pasture (Kluthcouski et al. 2000). *Brachiaria* is made to germinate after the maize either by delaying its planting or by planting it deeper. During the whole maize cycle, *Brachiaria* sp. is shaded by maize plants. At maize harvest however, the pasture is already in place, and grows very quickly over maize residues. Similar types of systems have been devised in southern Brazil, with a rotation of ryegrass used as pasture during winter followed by a Sorghum crop planted directly on the chemically killed pasture.

1.2 Bolivia

CA is being effectively practiced in the humid tropics (Santa Cruz Region) mainly for annual crops. In this region, there are two cropping seasons: the “summer season” from November to December, and the “winter season”, from May to October. Main crops cultivated are Soybeans, rice, maize, sugar cane, cotton, sunflower, sesame and wheat, which comprise a total surface of more than 50% of the total cultivated area of Bolivia. The humid tropics can be classified into 3 main agro ecological regions, according to different rainfall patterns, as described in Figure 1.

Agro ecological zone	Rainfall (mm/year)	Summer/winter crops ratio	Proportion cultivated in the winter (%)
Low rainfall zone	<800	3 x 1 or 1 x 0	0 to 33
Medium rainfall zone	800-1200	2 x 1	50
High rainfall zone	>1200	1 x 1	100

Figure 1 – Main agro ecological zones in the Humid Tropics of Bolivia.

1.2.1 Low rainfall zone

In the summer season, farmers cultivate Soybeans, sesame, sorghum, cotton and sunflower. In the winter, most of the fields are under fallow, however, if there is enough moisture, part of the cropping areas are cultivated with sorghum and/or sunflower (Figure 2).

	Year 1	Year 2	Year 3
Summer ⇒	Soybeans	Soybeans	Soybeans
Winter ⇒		Sorghum	Sorghum
Summer ⇒	Soybeans	Soybeans	Soybeans
Winter ⇒		Sorghum or Sunflower	Sorghum or Sunflower
Summer ⇒	Soybeans	Soybeans	Soybeans
Winter ⇒		Fallow	Fallow
Summer ⇒	Sunflower	Sunflower	Sunflower
Winter ⇒		Fallow	Fallow
Summer ⇒	Sorghum	Sorghum	Sorghum
Winter ⇒		Sunflower or Sorghum	Sunflower or Sorghum

Figure 2 – Crop rotations practiced in the low rainfall zone.

The low rainfall distribution in the winter results in low weeds incidence in the fallow areas. In this situation, the spontaneous vegetation is managed with knife-roller associated to herbicides prior to planting, in order to avoid re-seeding of weeds.

In general, there is no use of chemical fertilizers. Weed management in CA areas is based on spraying of 2 to 2,5 l/ha of glyphosate associated to 0,5 l/ha of 2,4-D. Soil diseases incidence (*Macrophomina*, *Rhizoctonia*, etc.) is more frequent in soybeans.

1.2.2. Medium rainfall zone

Main crops crown in the summer season are Soybeans, maize, cotton and some sorghum and sesame. In winter, parts of the fields are allocated to sorghum, sunflower and wheat, while another part of the fields are left for fallow. Figure 3 illustrates the most frequent combination of crops in this region.

As in the low rainfall zone, the low rainfall distribution in the winter results in low weeds incidence in the fallow area. In this situation, the use of the knife-roller once is enough to manage the biomass. If the rains are more frequent, the knife-roller is used two times. In this agro ecological zone, forage sorghum is being used as cover crop.

In general, no chemical fertilizer is used. For weed control, glyphosate (2 to 2,5 l/ha) and 2,4-D are applied prior to planting. Diseases incidence (*Macrophomina*, *Rhizoctonia*, etc.) occur mainly in soybeans.

Year 1	Year 2	Year 3
--------	--------	--------

Summer ⇒	Maize		Soybean		Soybean	
Winter ⇒		Sunflower		Sorghum		Wheat Fallow

Summer ⇒	Soybean		Soybean		Soybean	
Winter ⇒		Sunflower Fallow		Sunflower Fallow		Sunflower Fallow

Summer ⇒	Soybean		Soybean		Soybean	
Winter ⇒		Sorghum Fallow		Sorghum Fallow		Sorghum Fallow

Summer ⇒	Soybean		Soybean		Soybean	
Winter ⇒		Sunflower Fallow		Sorghum Fallow		Cover crop (Forage sorghum)

Figure 3 – Crop rotations practiced in the low rainfall zone.

1.2.3 High rainfall zone

Main crops cultivated in the summer are soybeans, rice and maize; in the winter most part of the fields are allocated to soybeans, maize, sorghum and wheat, while part of the lowland areas cultivated with rice are left for fallow. Combinations of crops are illustrated in Figure 4. Farmers from this zone are starting to insert a sorghum crop (early variety) between the harvest of the summer crop (March) and the planting of the winter crop (July), aiming at producing a soil cover and introduce a crop rotation. In general, a burn down herbicide is used for soybean harvest and help for weed management. In some cases, an herbicide application is done prior to planting, in order to avoid re-seeding of weeds and irrigate the soil, and another spraying immediately before planting.

In this zone is very frequent the application of micronutrients via fertilization which are supposed to help the crop development. In this region, there are also some experiences with organic soybeans under no-tillage for exportation. It is estimated that some 2000 ha are under this system, while 1000 are in the transition phase.

	Year 1		Year 2		Year 3	
Summer ⇒	Soybeans		Soybeans		Soybeans	
Winter ⇒		Soybeans		Soybeans		Soybeans
Summer ⇒	Soybeans	Sorghum	Soybeans	Sorghum	Soybeans	Sorghum
Winter ⇒		Soybeans		Soybeans		Soybeans
Summer ⇒	Soybeans		Soybeans		Soybeans	
Winter ⇒		Maize/ Soybeans		Sorghum/ Soybeans		Soybeans
Summer ⇒	Maize/ Soybeans		Soybeans		Soybeans	
Winter ⇒		Soybeans		Soybeans		Soybeans
Summer ⇒	Rice		Soybeans		Soybeans	
Winter ⇒		Soybeans		Soybeans		Soybeans
Summer ⇒	Soybeans		Soybeans		Soybeans	
Winter ⇒		Wheat (Soybeans)		Wheat (Soybeans)		Wheat (Soybeans)

Figure 4 – Crop rotations practiced in the low rainfall zone.

1.3 Argentina

Under the AAPRESID view, the No Till System is understood as the general framework that defined by the contribution of both scientific and empirical knowledge, constitutes a proper scenario to achieve the MOSHPA (Modern Sustainable High Productivity Agriculture) model goals. (Peiretti, 2004).

The No Till system is based on several pillars. Among them, the most important ones are:

- *Absence of soil tillage
- *Soil covered by crop residues
- *Crop Rotation
- *Balanced “Soil Nutrition” as a mean to achieve the proper crop nutrition

The absence of soil tillage is one of the main features (and pillar) of the no till system that establish a clear “Edge Line”, “border line” or “boundary” that separate this from other

conservation farming approaches. The absence of soil tillage and the consecution and maintenance of mulch covering the topsoil and constituted by the crop left over, has a high relevance for a proper No Till system functioning. Both strategies are responsible for the achievement of several system benefits; from the improvement of water management to higher, less variable and sustainable agro-ecosystem productivity. Besides these benefits, No Till significantly helps to reduce the amount and speed of water run-off diminishing the erosion forces (both for water and wind born soil erosion) and at the same time diminishing the sediments and solutes that are regularly carried on water run-off. Also it creates a much more favorable environment on those first millimeters of the soil profile where a large amount of chemical and microbiological activity takes place. The presence of Glyoxalin, a stable protein that is a byproduct of a special type of fungi, is largely enhanced by the no till environment (Wright, 2001). Also she reported a strong correlation between the soil glomalin content and the soil resistance to erosion by means of a higher stability of soil aggregates.

Under the No Till System Principles, crop rotation is understood as more than a sequence of crops. The issue has a great importance for a proper medium and long term agro-ecosystem functioning and improvement. Under this scope, a large number of interactions between rotational and several soil and agro-ecosystem functional characteristics were detected. The importance of Crop Rotation to achieve a better level of sanitation for the functioning of the agro-ecosystem under No Till was discussed by (Carmona, 2003). Also on the same paper the author discuss some of the barrier for higher rotation intensity. The value of crop rotations for a proper No Till System functioning was extensively discussed. On (Peiretti, 1998), among others issues as rotation intensity, yields, economic results and others were discussed. The author concluded reinforcing the principle crop rotation definitely represents one of the pillars of the system.

The generally positive impact and synergy between the cover crops and the No Till benefits were analyzed by (Ruffo, 2003 (a)). He went deeper with the analysis considering different aspects of the possibilities of this technology for the Argentinean agro-ecosystem characteristics and he concluded that cover crops have a large potential to be incorporated to the crop rotation scheme of the Argentinean pampas agriculture and both improve sustainability and profits. However, the necessity to carry out more research on the issue was pointed by the author. (Ruffo, 2003 (b)).

Regarding the “soil nutrition” principle, it should be understood as a more evolved approach to the crop fertilization issue. This principle takes into account a more systemic approach and considers the interactions among soil chemistry, soil biology, soil organic matter and structural properties, nutrient cycling, rather than just the addition of nutrients to a given crop. Some No Till long term studies (Gudelj, 2002) had been carried under this approach. On these sixteen years long term study, crop performance and yields, as well as, several soil fertility indicators were monitored and reported. Two different soil managements were studied; combine tillage (a combination of No Till and reduced tillage) and straight No Till. The experiment was located on a typical Argiudol of the humid part of the Central Pampas Area of Argentina. Besides several other conclusion they stated that the yield for the crops was at least equal for the “Straight No Till” treatment when compared with the one that only No Tilled some of the crops of the rotation. The average yields obtained on both treatments were by far higher than the general average crop yield for the commercial crops developed on the same area that only partially utilize the No Till System Principles but not under the

systemic approach. The results gave an idea of the great potential that the proper utilization of the No Till System Principles has to increase crop yield.

2. Driving forces and constraints to adoption

2.1 Brazil

Brazil is known as a country where CA is practiced from small-scale to large-scale farmers. Figures available at the website of the Brazilian Federation of No-Tillage (FEBRAPDP) estimates an area of 21,863 millions ha cultivated under No-Tillage in Brazil for the year 2003/2004. For the agricultural year of 2000/2001, the same source registers a distribution of the cropped area under CA as 55,6% in the subtropical region and 44,4% in the tropical region. However, is only in the subtropical region that CA is practiced by small-scale farmers.

The dissemination of CA in the country started with large-scale farmers from the subtropical region, being the driving forces a result of a combination of technical, agro ecological, socioeconomic and institutional factors. During the 70's the Brazilian agricultural policy encouraged the expansion of the agricultural frontier, the production of commodities such as soybeans and wheat, which replaced activities such as coffee and livestock. These new economic activities were implemented under conventional cultivation, combined to the high erosivity of rains and erodibility of soils, led to serious soil losses. By this time public research and institutions recommended that farmers switch to livestock production (Ekboir, 2001), or to adopt mechanical measures for soil conservation (Borges, 1993). However, depending on the soil type (for instance, shallow and sandy soils of the region of Campos Gerais at the State of Paraná) even mechanical measures were not effective, the production of annual crops was not recommended and supported by official institutions (research, extension and credit) in such erosion-prone areas.

Such situation lead farmers to search for other alternatives, and CA were disseminated as a result of farmers' necessity and innovativeness. Experiences with the no-tillage system at farmer level were then established as an initiative of farmers, supported by research. At the same time, research activities at public research institutions such as IAPAR and EMBRAPA were also established with the financial support of the private sector. The formation of farmers groups supported by technical assistance (private and official), research and the private sector originated innovation networks aiming at the exchange of experiences and up scaling of CA in the subtropical and tropical areas. (Ekboir, 2001; Borges, 1993).

The availability of planting equipment and suitable herbicides are among the main technical factors that contributed to the dissemination of CA in the country (Derpsch, 1999). The machinery industry in Brazil is well developed, and a wide range of equipment – hand operated, animal drawn and motorized – for cover crop/crop residues management, planting and spraying is available.

Institutional arrangements among public and private institutions played a major role for the development of CA in the form of partnerships among public research and extension institutions, agrochemicals companies, agricultural machinery manufacturers, farmers' organizations such as the Friends of the Land Clubs and the Brazilian Federation of No-

Tillage (FEBRAPDP). Rural development projects from the State Government and the National Government were important to provide funds for research, technical assistance and credit for the acquisition of agricultural machinery for small scale farmers. Thanks to a policy of the State of Paraná during the 80's, which was oriented to small-scale farmers, IAPAR started research and development of a no-tillage planter known as Gralha Azul/IAPAR, which was the edge line for the dissemination of CA in southern Brazil.

The transition from conventional systems to CA by small-scale farmers happened at the same time with the adaptation of the system. Agricultural machinery was not yet adapted, and there were many doubts regarding cover crop and weed management. Equipment adaptation was possible due to a strong interaction among research institutions, manufacturers, farmers and technical assistance.

From farmer's perspectives, the main driving forces for the adoption of CA was the savings on the use of machinery (for large-scale farmers), the reduction on labour requirements and drugdery (for small-scale farmers), erosion control and increase in yields and soil fertility.

Main constraints for small-scale farmers are: difficulties in weed control (choice of herbicide and spraying technology), increase in the incidence of pests and higher use of pesticides (Toresan et al., 1999).

An adoption study carried out at the State of Paraná with family farmers (Ribeiro et al., 2006) a range of CA practices was found in this study, some of them incorporating tillage operations which are quite contrary to the CA model. This tends to prove that family farmers adapt and incorporate CA principles into their farming systems not as a rigid package, but according to a series of factors and conditions they face, including agro-ecological (e.g. weeds, soil types), socio-economic (e.g. costs, availability of labour) and knowledge (e.g. existence of certain types of herbicides) ones. The authors also concluded that:

- a) Farmers keep perceiving and using tillage as a useful, economical way of solving problems they face, and especially of correcting periodically problems such as weeds of difficult control and soil compaction which, according to farmers, have a tendency to pop up after several years of continuing no-tillage. From the technical point of view, however, the authors are not yet sure to what extent soil compaction is really taking place or if it is rather a farmeres' perception. There is a need to assess this issue.
- b) Family farmers who have limited resources have bought the idea of investing into cover crops (by purchasing cover crop seed every year). Since most of them do not get direct short-term economic returns from planting cover crops (except for those who use them as forages, as is the case of dairy farmers), this implies that farmers are firmly convinced about the long-term benefits of using cover crops, such as soil conservation and fertility improvement.
- c) Despite the efforts made by research and extension for promoting the diversification of cover crop species and rotations, most family farmers still use a limited range of species and practice rotations with a same crop repeated in successive cycles. This reflects the availability and relative prices of cover crop seeds in the market, as well as the constraints farmers face for diversifying further the rotations they use.
- d) There is a definite need to identify adequate indicators and to assess the sustainability of the different CA practices used by farmers as exemplified in this study, instead of focusing solely on the impact of the "ideal" NT, which is not practiced by most small-scale farmers. Questions such as the maximum frequency of soil disturbance which may be allowed should be answered taking into account not only soil parameters, but also other relevant agronomic and socio-

economic criteria that comprises the overall sustainability of farming systems

2.2 Argentina

The Argentinean No Till adoption process started during the seventies with some small-scale trials within this central area. Later during the eighties the adoption started to grow. AAPRESID (Argentinean No Till Farmers Association) was founded during this period. Since then the No Till area never stops growing and been irradiated to other areas, reaching nowadays more than sixteen millions that account for around sixty percent of the area cropped on the entire country. No Till/CA and an entire new farming model based on the principles of the MOSHPA Model (Modern Sustainable High Productivity Agriculture), (Pirate, 2003) was developed and strongly adopted within that period. In Argentina, The foundation of CAAPAS eleven years ago, (American Confederation of Farmers Organizations for a Sustainable Agriculture), also help to reinforce the No Till adoption process in Argentina as well as in the other country members of the institution.

Nowadays around 65 % of the total country farmed area is been cropped on this fashion and a great proportion of that can be found on the central areas. In Argentina, definitely the adoption of this new farming system was mostly a farmers' leaded process and to the opinion of several authors it constituted a true technological revolution. (Ekboir, 2003). Those farmers belonging to the large-scale market oriented category play a key role on the process. During the last thirty to forty years, the activity, organizational scheme, farming system etc. utilized by Argentinean farmers of this category, had undergone a deep transformation. The process was highlighted by the strong adoption of No Till/CA principles and also by biotechnology. Also, deep transformation reached the operative organizational area. Nowadays around sixty five percent of the total grain and oilseed production is coming from a "new type farmers" that produce on rented land and contracting for different services of all type to race and harvest the crops. (Ordoñez, 2002). The "custom made modality" developed to fulfill the necessities of the different stages of the farming process, strongly accompanies the Argentinean farming structural reshape.

To promote the adoption of No Till principles, the detection and support of leader proactive farmers was a key factor for success. Farmers to farmer's knowledge transmission were an extremely valuable strategy. At the beginning of the Argentinean No Till adoption process the actions of these types of farmers were of high importance (Rosso, 1992). Under the farmer view, one of the very active AAPRESID members analyzed some of the why's for the need to evolve to a different farming system was considered by (Rosso, 2001). AAPRESID as farmers founded and managed institution, had played a key role on the process and a farmer's proactive and innovative attitude was also of high relevance. (Trucco, 2001).

Even the adoption of No Till in Argentinean begun on the Central Area region very quickly started to be spread to other regions of the country. Following this trend, some leader AAPRESID farmers (Arzeno, 1993) recognized and described the advantages and potential No Till benefits for the North West Region of Argentina where a "new agricultural pole" was been developed.

Among the technical factors, a completely new generation of drillers and planters specially designed to properly operate under the No Tiled Soil condition definitely is a key issue for success at adopting the No Till principles

Also, the industry following the farmers suggestions, invested a considerable amount of time and efforts of all types at developing prototypes of a conceptually entire different drillers and planters. They finally developed and supplied the demand with an appropriate entire new generation, conceptually different drillers and planters. This was also a key issue for the No Till adoption success.

2.3 Bolivia

The development of CA-based technologies started in the 80's, as an initiative of farmers from the eastern lowlands and without support from research institutions. In 1993, ANAPO (the Association of Oilseed Production) asked CIMMYT to support their experiences and the development of no-tillage started as a tool to improve the profitability of the soybean-wheat rotation (Ekboir, 2001). Then two specialized no-till networks emerged: one organized by CIMMYT and comprised by public research institutions, farmer's associations and progressive farmers, and another one organized by Fundacruz (a farmer-founded research foundation), agrochemical companies and farmers (Ekboir, 2001).

The Eastern lowlands and the Andean Valleys of Bolivia are the regions where crop production predominates. While CA is practiced in the Eastern lowlands, no-tillage and minimum tillage is still incipient in the valleys, where small-scale farming predominates. Although the many efforts to promote no-tillage, its adoption is constrained by the following factors:

- Although farmers see the benefits of leaving the biomass on the soil surface, they use crop residues as fodder for their livestock or for shelter, and for selling it for other farmers;
- Lack of capital for investing in machinery
- Communal grazing of the fields after harvesting of cereals
- Cereals are harvested by hand and thrashed away from the field

The Humid Tropics is the region where Conservation Agriculture is more practiced by farmers, mainly for annual crops. From a total of 1,562,00 ha cultivated in this region (Santa Cruz Department), some 818,000 ha are cultivated under no-tillage. Ekboir (2001) points out the following driving forces:

- Save on production costs (especially diesel)
- Possibility of extension of the planting period (from about 3 days) after the first rains to about 12 days

However, this practice predominates for large-scale farmers. Main constraints for the adoption by small and medium-scale farmers are:

- Availability of machinery;
- Religious beliefs in the case of Mennonite farmers

It must be highlighted that CA is not being practiced in its overall concept. Soil tillage was suppressed; however the use of cover crops and crop rotations is still incipient. This has been resulted in soil compaction problems and the formation of soil crusting and high incidence of diseases. The climate conditions of the humid tropics, with high rainfall patterns and high

temperatures results in fast degradation of the biomass.

3. Scientific and practical results

3.1 Crop yields and stability

When starting no-till on a given agro-ecosystem, some benefits can be achieved from the very beginning, even so, the potentially higher and best results shows up after several years of a proper management under no-till. To obtain the most out of no-till, a systemic approach to the agro-ecosystem management should be utilized. Along with no-till, several other management strategies should be applied. A broad conceptual view of no-till, involving an appropriate crop rotation, a good soil coverage, a soil nutrition strategies, etc., constitute some of the key issues to be able to obtain the extra grain yield, and stability of it, that potentially no-till is offering.

The gain in yield, and stability of it, derived from no-till, can be interpreted as the “final product” of a rather complex and interactive process. When an agro-ecosystem is properly managed utilizing the no-till principles, an improvement of the most important components of the agro-ecosystem is achieved. This fact creates a “better production environment” than when properly utilized by removing constraints and maximizing the quality of the management of “manageable production factors” as genetic potential, crop intensity, crop selection, weed and pest management, timing of the farming operations, efficiency of rain and irrigation water use, soil nutrition and crop fertilization strategies, etc., normally leads to the achievement of a higher and less variable yield level. To be successful at this purpose, a systemic approach should be considered. Besides the effect of the individual “production factors”, a revalorization and deep consideration of the “effects of multiple interactions among production factors and among years” should be taken into account at designing the individual crop and the crop rotation strategy for maximum crop yield and minimum variability of yields.

Crop yield increases at the “farm level” were somehow extensively reported however the decrease of the “among years yield variability” will require of long term, comparative well designed experiments that are not commonly found. Even so, the report of empirical observations derived from “paired crops” managed under conventional tilled and no tilled condition, clearly shows the advantages of no-till regarding the final crop yield and the decrease of variability.

Crop productivity, in a general way, is the parameter more relevant to farmers when evaluating soil management systems. Past experiences indicate in years of rain shortage the higher productivity is obtained under no-till system while during years of normal rain distribution the productivity did not differ among agricultural management systems. During the first years of adoption of no-till system especially under degraded soil the productivity of cultivated species is normally lower than the obtained under systems that use intensive soil disturbance. This behavior, certainly, is associated to the evolution of the global soil fertility promoted by no-till system, which as the time passes, tends to promote improvement in soil quality and to stabilize crop productivity (ANAPO, 2004).

Various authors have shown that the intercalated rotation of crops from different plant families such as grasses, leguminous, cruciferous, etc. can increase the competitiveness and economic viability of agricultural production systems (Derpsch and Calegari, 1992; Santos,

1992; and Santos et al., 1993). Crop diversification produces varying amounts of crop residue, reduces soil losses, recycles nutrients, interferes with pathogen cycles, eliminates weeds, extends the rooting system of plants to different depths and improves nutrient absorption as well as ensures the best use of labor and equipment and the sustainability of agricultural activity.

In subtropical areas of Brazil, although species diversification was known to be a technological solution for the control of necrotrophic pathogens of wheat (Reis, 1991), associated with the production of green manure for the recovery of soil structure (Denardin, 1997), it was the no-till system that popularized crop rotation as one of the essential features of the conservation agriculture which arose in the middle of the 1980's.

Crop rotation and no-till system has contributed to the stability of the profits produced by both summer crops such as soybean and maize (Derpsch et al., 1991; Ruedell, 1995; Santos and Tonet, 1997; and Santos et al., 1997) and winter crops such as barley and wheat (Santos et al., 1995; Sacred et al., 1996; Sacred et al., 1998; Sacred et al., 1999; and Santos and Reis, 2001), especially in the subtropical areas of Brazil where the climate is unstable. Mundstock (2004) stated that increase of maize productivity is closely related to, among other factors, improvement of soil till such as no-till system, rational use of fertilizers, increased planting density and use of selective pre-emergence and post-emergence herbicides. In fact, maize is the main crop that sustains no-till system because in the most frequently used production models it is the crop that contributes most to straw production and also has the highest root volume. Before the introduction no-till system maize productivity was less than six tons per hectare but now the best no-till system produce an average of ten tons per hectare (Uma Revolução, 2002).

Diaz-Zorita (2002), while comparing different rotations, had reported an increase of crop yields under no-till for the southwest part of Buenos Aires Province where the soils are of relatively high sand content. Also for that rotation that contains the higher proportion of corn and wheat the organic matter content was higher than on those that have lower participation of these crops. The same trend was observed while comparing the no-till treatments against the chisel plow one. The organic matter content was higher for the no-till one.

The response of different annual grain crops varies with different soil tillage systems. The productivity of crops has been consistently higher under no-till system compared to conventional tillage (Ruedell, 1995). Calegari et al. (1992), Muzilli et al. (1994), and Hernani et al. (1997) observed that yield of maize, soybean, and wheat cultivated under no-tillage system was 17% higher than cultivated under conventional tillage. Long term trials by Santos et al. (2000, 2001, 2003a, 2003b, 2004) and Santos and Tomm (2003) have shown the following: no-till system produce higher yields than conventional system; crop rotation increases and stabilizes yield more than continuous cropping; no-till system plus crop rotation results in better energy conversion and energy balance than conventional tillage and continuous cropping; and no-till system combined with crop rotation is more lucrative and results in less risk as compared to conventional tillage and continuous cropping. Santos and Tomm (2003) emphasize that the higher productivity observed in the no-till system may be related to the improvement of total soil fertility manifested in higher levels of organic matter, phosphorous and potassium than those occurring in conventionally tilled soils. Santos et al. (2000) state that the higher wheat yields produced under crop rotation are due to the fact that when rotation is used the severity of necrotrophic disease is reduced by up to 50%, while in a

later study, Santos et al. (2003a) showed that no-till system combined with crop rotation are more energy efficient, produce higher grain yields, and result in the input of higher nitrogen levels from cover plants and lower energy consumption than non-rotated conventional systems. Santos et al. (2004) credit the greater profitability and the smaller risk of no-till system plus crop rotation are due to the increase in gross revenue, in economies in labor, fuel, and lubricant costs and maintaining and depreciation costs of the agricultural machinery.

For a thirteen years period under continuous agriculture comparing two basic management no-till and combined till, a mixed management combining reduced till and no-till, in the central pampas areas, the yield evolution as well as the evolution of several soil fertility indicators were reported by Ghio (1999). The results show a yield benefit for the straight no-till treatment as well as an improvement on some soil fertility indicators. The conclusion is that the system pillars are: no-till, soil fertilization, and crop rotation. Within a no-till environment, other studies were directed to evaluate the interaction between crop yield and stability of it with crop rotation. (Phailé, 2003).

In Bolivia, after ten years of trials the association of no-till system and crop rotation has proportioned yield increases around 500 kg/ha when comparing with continuous wheat/soybean. The yield increase for maize has being in the order of 1,100 kg/ha and 1,600 kg/ha, respectively, compared to conventional tillage and minimum tillage. Paz (1999) states that soil fertilization and chisel plowing did not affected crop productivity of soybean, maize, wheat, and sunflower. However, it is clear that the soybean crop when cultivated under rotation system, regardless to soil management system, presents yield improvements of the order 200 to 300 kg/ha in relation to continuous cropping. Based on these studies Paz (1999) states:

- species as soybean, maize, wheat, and sunflower when cropped under no-till system present higher productivity combined with crop rotation than under continuous cropping;
- lower productivity tends to occur under conventional tillage;
- the difference in productivity under no-till using crop rotation and continuous cropping is 500 kg/ha for soybean, 1,000 kg/ha for maize, 450 kg/ha for wheat, and 350 kg/ha for sunflower.

Campero and Wall (1999) concluded that in regions of Bolivia with rain shortage during winter season, the crop residues kept on the soil surface affect positively the water balance and consequently the wheat productivity. Production of 2,000 kg/ha and 4,000 kg/ha of crop residues has proportioned yield improvements in the order of 67.3% and 88.7%, respectively (PROTRIGO, 2002).

Field trials in subtropical Brazil comparing conventional till, reduced till and no-till systems carried out over a period of 18 years showed that annual variation in yield was not necessarily associated with the type of soil management but that such variations could be accounted for by climatic oscillations and, especially, variations in rainfall during the annual growth cycle (Denardin et al., 2001).

For the central area of the Pampas Region as well as for some other regions of the Argentina, an almost generalized trend for a crop yield increase when raced under no-till was reported by several authors (Ferrari, 1998; Quiroga et al., 1998). It appears that for any given region and under rain-feed crop condition, the improved water management that no-till allows, could be

part of the explanation for the yield increase. Similar results were observed for Bolivia (ANAPO, 2005).

In tropical areas of Brazil, especially in the Cerrado (Brazilian savannah), agricultural expansion was first promoted by soybean continuous cropping using intensive tillage. This intensive tillage system was based on the use of plowing and harrowing and systematic use of only disks harrowing, accelerating the process of soil degradation in much of the area under cultivation (Séguy et al., 1996). No-till system started in areas of soybean continuous cropping because in these areas rainfall is concentrated in the rainy season (October to March), not allowing growing other crops during the rest of the year. The absence of crop rotation and permanent cover crops prior to or after soybean continuous cropping, the use of exclusively harrowing (Farias, 1979), and the use of conventional tillage with deep plowing (Séguy et al., 1988), as soil management systems, resulted in higher soybean yields than with no-till system. The no-till system only started to produce yield equivalent, or superior to, conventional tillage after adjustment of production models to take advantage of the rainy season. As result, production models managed under no-till system should contemplate crops as beans, maize, millet, sorghum and sunflowers to be used as green manure (Landers, 1995).

A study carried out in tropical Brazil showed that no-till system plus crop rotation using crops such as maize, soybean and wheat and animal feed crops such as Brachiaria and oats has shown that such a system not only produces higher yield and profit but also improves total soil fertility as compared to systems based on conventional tillage and continuous cropping (Salton et al., 2001). It has also been shown that beans grown under no-till system have a higher leaf surface area index, a longer leaf surface area duration period, a larger growth rate and relative growth rate and produce more dry matter (Urchei et al., 2000). Data also shows that beans produce higher yields when grown under no-till system plus crop rotation and that yields are affected by the temporal arrangement in which the component crops are grown. Yield of beans are usually higher when grown in rotation with rice than it is grown with maize and when beans is grown successively in the same area for two years (Silveira et al., 2001).

In Bolivia, the broad climatic variation in frequency and rain distribution has lead to studies oriented to the construction of production models able to promote agriculture sustainability under no-till system. Nowadays, a great number of the production models are being evaluated specifically for each type of climate in this region of the country (ANAPO, 2004).

Precision Agriculture, site specific management could potentially be technologies that can further enhance the benefits of no-till. Some of these issues are discussed by Borletto (2001). Other authors had considered the potential usefulness of this modern last generation technologies to improve the general agricultural operation as well as the management under no-till (Bragachini, 2000; Bragachini, 1999). Belloso (1999) had reinforced the idea of the actual and potential importance of the technology to generate detailed records and knowledge of the soil functioning at the farm level.

1.2 Soil characteristics

Global soil fertility: From an elementary standpoint, the soil may be considered a body composing natural landscape represented by volumetric element. Such body consists of a solid matrix containing gases, liquids, and organisms, which, together, constitute a complex physical-chemical-biological system possessing characteristics and properties resulting from

the effects of relief, climate, time, and the biological activity on the original material (pedogenetic processes) but also by anthropic effects.

From a functional and agricultural point of view, soil constitutes the environment in which plants grow, providing a support substrate, nutrients, and water. From the point of view of agricultural production system, soil is only a determining component of the productivity of such system because of the limitations imposed on agricultural system by its fertility (Figure 1). In this context, it is important to remember that an agricultural production system is produced by the interaction between the environment, plants, and soil in which the environment has the potential to provide energy, plants provide the genetic potential, and soil potential fertility. Agricultural productivity, measured as the amount of product produced per unit area, is the integrated result of these factors so in a agricultural production system it is not possible to consider environmental, plant or soil productivity in isolation because no product can be generated in the absence of any one of those factors or without interaction between factors. Since it is the interaction between factors which determines the productivity of the agricultural production system such productivity cannot exceed that of the limiting factor, this being exemplified by the ‘limiting factor law’ which states that if alterations are made in environmental or plant factors with a view to increasing productivity such alterations will be of no effect if the soil factor is at the limit of its productive potential. It may thus be said that management of a productive agricultural system is nothing less than the exploitation of the potential of the production factors that make up the system (Denardin *et al.*, 2003).

Although soil fertility involves physical, chemical, and biological factors it is principally determined by the structure of the soil because this decisive parameters such as the capacity of the soil to store water, water availability, heat storage and diffusion, permeability to air, gases, roots, and water, pH and nutrient availability. Soil structure is based on the relationship between the volume occupied by the soil particles and the apparent volume of the soil and varies in function of the dimensions of the interstitial spaces (pores) between the soil particles, although pedogenetic and anthropomorphic (e.g. soil management practices) factors may also play a part in soil structure (Taylor and Aschroff, 1972). When considered in the light of an agricultural production system the application of soil structure to the concept of soil fertility extends the scope of this concept beyond the purely chemical aspects of pH, nutrient availability, and organic matter content.

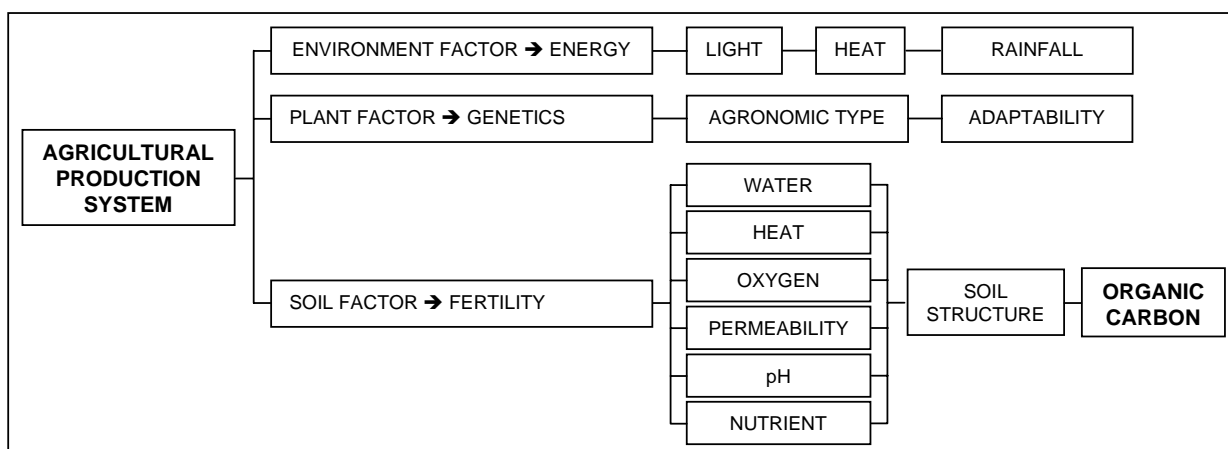


Figure 1. Conceptual structure of an agricultural production system.

The association between, and stability of, the soil aggregates determine the type and quality of

the soil structure and are directly dependent of the amount and quality of organic matter in the soil which in turn can be inferred as being due to the type of plants growing in the agricultural production system of which the soil is a part, such plants constituting a primordial factor for the development of global soil fertility (Denardin *et al.*, 2003). Soil organic matter interacts with soil minerals to form complex organominerals that result in the formation of secondary particles of various shapes and sizes (Tisdall and Oades, 1982), with plant roots (Silva and Mielniczuk, 1997) and fungal hyphae (Miller and Jastrow, 1990) increasing such interactions by forming and stabilizing aggregates of soil particles. The formation of soil aggregates results a decrease in microbial decomposition of soil organic matter and accumulation of organic compounds, especial in untilled soils (Feller and Beare, 1997; Six *et al.*, 1999). The quantity and flux of organic material produced by the agricultural production system governs factors such as the biological activity of the soil, the production of secondary organic compounds, aggregation of soil particles and other, less well-defined, emergent soil properties all of which contribute considerably to total soil fertility. In general, carbon cycle emergent soil properties such as aeration, aggregation, cation exchange capacity, infiltration and retention of water, nitrogen balance, organic matter content, porosity, etc. serve only to improve total soil fertility (van Breemer, 1993; Vezzani, 2001).

The agricultural use of soils influences amount of organic matter in a soil due to the diversity of the plant species within a particular productive agricultural production system. Agricultural production systems involving tillage, cultivation of low phytomass species or the burning or removal of crop residues (or all these factors) normally present annual rates of phytomass accumulation which are lower than the mineralization rates of the organic material added to the soil. Some researchers suggest that it is important to consider not only the aerial phytomass but also the contribution of the root system of plants (Bolinder *et al.*, 1999) because some crops, with extensive and aggressive root system (principally perennial grasses forage crops) allocate a larger fraction of photosynthetic fixed carbon to their rootstocks than do annual species (Shamoot *et al.*, 1968) and are therefore more efficient in increasing the stock of organic matter in the soil.

The rate of loss of soil organic matter is highly influenced by tillage because tillage oxygenates the soil and homogenizes crop thereby stimulating microbial decomposition and, compared with the no-till system, tillage can double the rate of organic matter decomposition (Bayer *et al.*, 2000c). The decomposition of soil organic matter is agriculturally undesirable because improved soil fertility is undoubtedly associated with processes that maximize soil organic material and minimize losses.

The dynamics of soil carbon and nitrogen are intimately linked so that degraded soils and with low levels of organic matter are also usually nitrogen deficient and this limits carbon input from plant material, which in agricultural terms principally means grasses crops in productive (Bayer *et al.*, 2000a,b). This means that the inclusion of leguminous crops in the crop rotation cycle of some agricultural production system allied to the use of inorganic nitrogen-based fertilizers is highly efficient in elevating soil carbon stocks and improving total soil fertility and hence crop productivity (Teixeira *et al.*, 1994; Testa *et al.*, 1992; Vezzani, 2001).

Alterations in global soil fertility: In Brazil the soils of the main annual agricultural production systems for the production of grain crops are predominantly Oxisols, Ultisols and Alfisols and a smaller proportion these systems are grown on Mollisols, Inceptisols, and Entisols, mainly in the subtropical Brazilian states of Rio Grande do Sul, Santa Catarina, and

Paraná. In tropical Brazil, Entisols (quartzite sands type) support some restricted areas with these systems (Miyasaka and Medina, 1981). Oxisols, Ultisols, Alfisols, and Entisols (quartzite sands type) are generally deep, well-drained soils which form undulating or semi-undulating deposits that present no limitations for the implementation of annual agricultural system for the production of grain crops, although Mollisols, Inceptisols, and some Entisols the adoption of such system due to lack of depth, stoniness, and problematic topography because they are often located in areas of uneven relief (Embrapa, 1999). The insoluble clay fraction of these soils is predominantly composed of type 1:1 minerals (kaolinite) and iron and aluminum sesquioxides (Embrapa, 1999) which are very important because they confer high structural stability to soils especially at the micro aggregate level (Kiehl, 1979). The organic matter content of uncultivated Entisols (quartzite sands type) soils is less than 2% and in Oxisols, Ultisols, and Alfisols rarely exceeds 4% while in Mollisols, Inceptisols, and some Entisols it is often 3% and can be in excess of 5%, the organic matter content of these soils being responsible for macro aggregate stability.

Under natural conditions these soils are dystrophic and limit plant growth because chemically they are acidic with low exchangeable base saturation and contain high levels of exchangeable aluminum (Embrapa, 1999). These soils are, however, physically suited to crop development because they possess considerable structural stability at both the micro- and macro-aggregate level such that total porosity can reach up to $0.6 \text{ m}^3 \text{ m}^{-3}$ which means that they are highly permeable air, water and the roots and consequently have low natural susceptibility to erosion. Once the chemical deficiencies of these soils are corrected these soils have high total fertility and are very suitable for annual agricultural systems for grain production (Denardin *et al.*, 2003).

However, it has been postulated that the mechanical mobilization of soil (ploughing, scarification, and grading) for conditioning prior to the implementation of agricultural production systems unleashes integrated and serial chain reactions in the complex physicochemical-biological systems of the soil that alters soil structure and redefines its total fertility. Depending on the intensity of soil mobilization such changes can result in increased or decreased patterns of soil fertility (Denardin *et al.*, 2003).

In Argentina, grain production system under no-till is conducted in soils that vary from region to region. In the south of Buenos Aires Province, soils are deep, with a loamy texture, and most of them are classified as Mollisols. In general, organic matter levels range from 4.0 to 7.0%. There is a large area in this region that has hard layers of rock calcium carbonate that vary in depth from 0.2 to 0.9 m. This layer can severely affect water storage in the soil profile, so there is a high dependence on the rainfall frequency. In central and west of Buenos Aires Province, the most frequent soils (Haplustolls and Hapludolls) have a sandy to sandy-loam texture, and the organic matter levels range from 1.8 to 2.5%. In the center-west of this region, soils have restrictions to the root exploration due the presence of hard layers that vary in depth. In the rest of the region soils are deep, but with some limitations to store water and susceptibility to wind erosion. In the Semi-Arid Pampas, soils are deep, sandy, with low organic matter levels (0.8 to 2.0%) and with a high susceptibility to wind erosion (Entic Hapludolls and Typic Hapludolls). The water holding capacity of these soils is low and the soil structure is very weak. In the north of Buenos Aires and South of Santa Fé Provinces, the predominant soils are Argiudolls in the east, and Hapludolls in the west. Soil textures vary from clay-loam to silt loam, organic matter levels range from 2.5 to 4.0%. Soils in the area have mainly susceptibility to water erosion. Central Santa Fé and Cordoba Provinces soils are

classified as Mollisols (Argiudolls, Argiustolls and Hapludolls), with a high content of silt (silty to silt-loam textures), and low aggregate stability, that gives a high susceptibility to physical degradation. Organic matter levels range from 1.8 to 3.5%. In Entre Rios and Corrientes Provinces, soils are classified as Vertisols and Vertic Argiudolls. Texture varies from clay-loam to silt-clay-loam with clay contents that range from 33 to 45%. Soils have moderate to high susceptibility to erosion, and organic matter levels vary from 2.0 to 3.5%. Soils of Northeast Argentina are mainly Mollisols. Textures vary from loamy to silt-loam, and organic matter levels range from 1.0 to 2.8%. Susceptibility to water erosion is moderate to low. Actual phosphorus levels are, in general, very high (>40-50 ppm Bray-1 P). In Northwest Argentina, soils are classified as Mollisols, Alfisols, Inceptisols and Entisols. Soil texture has a high variation (from sandy to clayed) and organic matter levels range from 0.8 to 2.2%. The main problems in the area are the high water and wind erosion and the low structure stability in most of the soils.

In general in most of the regions, the actual organic matter level is between 40 and 60% of the original, and this was evaluated by taking soil samples in the fences of the fields. In southeast Buenos Aires original phosphorus levels are low (<10 ppm Bray-1 P), whereas these levels were originally high and very high (>40-50 ppm) in the rest of the regions previously described. In no-till, phosphorus levels tend to increase in the 0-0.1 m layer, an often in this layer, 2 to 4 times more Bray-1 P is found compared to the 0.1-0.2 m layer (Bianchini, et al., 2004). The lack of residue incorporation in no-till may explain this surface accumulation. Potassium levels are very high (>400 ppm ammonium acetate K) in all regions and can reach 1,000 ppm in fertile and deep soils, so little stratification is observed in no-till.

In Bolivia, Santa Cruz department, the region where the grain production under no-till is concentrated, the main soils are Alfisols (loam textured) and Inceptisols with moderated to high fertility, but unstable structure (PROTRIGO, 2002).

Any transformations in the physicochemical and biological properties of soils resulting from the implementation of no-till system are dependent on environmental factors, soil type and, most importantly, the agricultural production system model, i.e. the set of species which make up the productive agricultural system. Transformations related to the creation or recuperation of total soil fertility are based on the amount of organic carbon within the system because this is the factor which is most affected the adoption of no-till system. The most important changes in soil properties originate on or near the surface of the soil due to the presence of plant residues and roots. The great majority of practical reports and scientific studies involving the implementation of no-till system support the affirmation that no-till system increase soil organic carbon, improve soil structure, and increase nutrient availability (Muzilli, 1983; Sidiras and Pavan, 1985; Kochhann, 1996; Stone and Silveira, 1999; Caíres, 2000; Sousa and Lobato, 2000; Silveira and Cunha, 2002).

In Argentina there are observations that different kind of no-till positive impacts related to soil conservation, water infiltration and crop yield. After ten years of cultivating a high clay content soil of Entre Rios Province under the no-till principles, improvements for several soil characteristics were reported for (Chesta, 2001). Some interesting conclusions were drawn by Fontanetto (2002a) analyzing the evolution of several soils parameter on a seven years no-till and different crop rotation experiment. No-till and an appropriate level of nitrogen fertilization led to a soil organic matter increase especially of its younger fraction of the organic matter. Also, the amount of crop residues, the organic matter content and the water

capturing and conductivity soil capacity were increased when grasses increased its participation on the crop rotation. Continuous no-till increased the total soil porosity. The same author obtained similar conclusion in other ten years long study. On this study was evaluated different soils physical and chemical parameters as well as crop yields for to different rotations wheat/soybean and wheat/soybean followed by corn. The conclusion is that continuous agriculture might decrease the chemical properties of the soil. To be able to carry out continuous agriculture with an appropriate level of agronomic sustainability, there is necessity of carefully manage the agro-ecosystem and include crops that give back larger amounts of crop residues. From the physical soil properties standpoint, no-till was the best choice. The inclusion of corn on the rotation allowed increasing the water use efficiency. The best yields were obtained with the combination of wheat/soybean corn rotation and no-till. The utilization of no-till principles along with some other good agro-ecosystem management practices it is possible to carry out a continuous agriculture (Fontanetto, 2002b).

Muzilli (1983) and Sidiras and Pavan (1985) have shown that four years after the adoption of no-till system soil organic matter was significantly increased in the 0–5 cm layer of Oxisols and Alfisols in the Brazilian state of Paraná and Sá (1995a) has shown that soil organic matter in the 0–10 cm layer of the same soils increased by 27% after 15 years of no-till system. Over 10 years no-till system has resulted in an overall increase of 0.5 to 1.5% in the level of organic matter in the 0–10 cm layer of subtropical Brazilian soils (Lopes et al., 2004).

Valpassos et al. (2001) conclude that the continuous use no-till system within a crop rotation management system results in organic carbon accumulation, reduced soil density and improvements in the chemical properties of the soil related to plant nutrition and constitutes a conservationist alternative for the maintenance of total soil fertility and the productive potential of agricultural production systems in tropical Brazil.

Salton et al. (1998), Bayer and Mielniczuk (2001), and Muzilli (2003) affirm that alterations in soil properties such as improved structure, elevated cation exchange capacity, controlled release of nitrogen and phosphorous and reduced acidity observed in studies of no-till system are a result of the quality and quantity of organic matter contained in no-till soils.

However, Stone and Silveira (1999), Stone and Moreira (2000), and Kluthcouski et al. (2000) in tropical Brazil and Tormena et al. (2002) in subtropical Brazil have reported that no-till system applied to production models that result in the production of phytomass in quantities inferior to the mineralization potential the soil can induce soil compaction and a fall in productivity. Corrêa (2002) showed that after 2 years there was an increase in the proportion of water stable aggregates in a tropical Brazilian Oxisol subjected to no-till system in a production model involving the rotation of soybean and maize as compared to the percentage of the same type of aggregates in a soybean in continuous cropping. In addition, the percentage of soil organic matter correlated positively with the percentage of aggregates larger than 2 mm, the weighted mean diameter of the aggregates and the degree of clay flocculation. In the Brazilian state of Rio Grande do Sul an Oxisol was studied by Barcelos et al. (1999) who found that when this soil had been subjected to 10 years of crop rotation using three soil handling methods (conventional, minimum-till, no-till system) no-till system resulted in higher levels of organic carbon; increased soil water retention; increased weighted mean aggregates diameter; increased macro-porosity; and increased water infiltration rates. Kochhann (1996) has pointed out that in no-till system aggregates in the superficial soil layer are more stabile and that larger diameter aggregates are more common because the presence

of vegetable residues in the surface of the soil protects aggregates from the impact of rain drops, surface organic material is constantly decomposing and producing adhesive substances, and absence of tillage prevents aggregate breakdown.

Reinert et al. (1984), Eltz et al. (1989), Carpenedo and Mielniczuk (1990), and Derpsch (1991) conducted comparative studies of different methods of soil preparation as applied to subtropical Brazilian Oxisols and Ultisols and found that no-till system consistently improved soil structure as expressed by increased mean aggregate diameter and increased macro aggregate water stability. However, Carpenedo and Mielniczuk (1990) also pointed out that no-till system soil macro aggregates had micro pores and were compacted in relation to the soils of cultivated pasture, natural fields or forests in which the soils contained a greater proportion of macro pores and were more porous.

Some soil chemical and physical changes derived from no-tilling two different soil types representative of the Central and Central East area of Argentina, were analyzed by Michelena (2000). The two types of soils were compared between them and also with other similar soils cultivated under conventional till management. A significant increase in most fertility indicators were found when they were no-tilled for a period ranging between nine to eleven years. Some of the reported results for the no-till benefits were: A significant organic matter and total nitrogen increase. No changes in soil pH. Regarding the physical properties evolution under no-till, the bulk density was similar for both types of soils. The resistance to be penetrated values encountered do not represent any troublesome situation and the yield and general productivity evolution of both farms followed a clear positive trend. The soil water infiltration value reported indicates a significant improvement. For a rainfall simulator with a heavy rain intensity (60 millimeters per hour during one hour), the infiltration change from 83 to 100%. Considering that under conventional tillage the most common values for this parameter would be around 40 to 50% or even less in many cases. This increased soil ability to capture rainwater implies a very positive and important benefit derived from no-till. The effect has big positive impact on the water availability for crops increasing the yield and decreasing yield variability among years. It represents a phenomenon that has a similar practical impact that if we could increase the rainfall of a given area. Since the soil water capturing capacity is enlarged, the irrigation total efficiency is increased and hence a true possibility of reducing the irrigation need when under irrigated condition appears. The soil losses by mean of water erosion were drastically cut on both cases. In Argiudol soil, was equal to zero after applying a sixty millimeters rain in an hour. For Argiudol typical soil, the soil loss value was only 0.15 metric ton/ha, which is extremely low while compared with the values for the average losses obtained on the area. Some measurements under conventional tillage are as high as 50 metric ton/ha/year and even higher.

Nutrient cycling and the addition of chemical soil conditioners and fertilizers promote nutrient concentration in the superficial layers of no-till system soils. Bartz (2003) states that the least mobile nutrient is phosphorus which results in this nutrient having the largest concentration gradient (measured from the soil surface) in no-till system soils. In the 10–5 cm layer the phosphorous concentration can be seven times greater in no-till soils as compared to that in conventionally tilled soil, and according to Sá (1995a), this effect is proportional to the time for the soil has been subjected to no-till system but independent of the soil order or soil textural class. Muzilli (1983), Sidiras and Pavan (1985), Sá (1993, 1995b), Caires (2000), and Sousa and Lobato (2000) affirm that the low mobility and high availability of phosphorous in the superficial layer of a soil is due the annual application in furrow or broadcast application

of phosphate fertilizers, the liberation of organic phosphorous from decomposing of crop residues on the surface of the soil and reduced contact with phosphorous sequestering soil minerals such as iron and aluminum oxides, oxi-hydroxides and hydro-oxides. Bartz (2003) emphasizes that no-till system optimize the use of organically derived phosphorous and reduces retention or immobilization of inorganic phosphorous applied as fertilizer, this is because soil managed under no-till system is not subjected to mobilization, such optimization having reduced the use of phosphate fertilizer by 30 to 70% in the Brazilian state of Paraná.

Reinheimer and Anghinoni (2001) have reported that elevated soil solution phosphate levels can result in the formation of low solubility aluminum, calcium and iron phosphates and result in decreased availability of phosphates to plants, but Sá (1995b) has pointed out that as compared with conventional tillage no-till system has various advantages in terms of phosphate behavior because the absence of soil mobilization decreases phosphate adsorption by reducing contact between soil colloids and ion phosphate and the slow and gradual mineralization of crop residues occurring in no-till system results in the liberation and redistribution of organic phosphates which are more stable and less susceptible to adsorption.

Pöttker (1995) has pointed out that there is relatively little information on the behavior of potassium in soils under no-till system. Bartz (2003) has reported that in no-till system soils potassium has a similar, but less intense, concentration profile to phosphorous, with potassium levels decreasing from the soil surface downwards and that the principal potassium losses are lixiviation and/or surface runoff due to the high aqueous solubility of potassium. The improvement soil structure in no-till soils increases the rate of aqueous infiltration and reduces potassium loss by runoff but this may be offset by increased losses due to lixiviation. A further factor being that the annual pluvial precipitation in the grain producing areas Brazil is in excess of 1,400 mm and precipitation often exceeds the soil infiltration rate thereby causing potassium loss due to runoff. Such losses are important in both subtropical and tropical regions of Brazil but are accentuated in tropical regions because most of the annual pluvial precipitation takes place during October to March.

Lopes et al. (2004) have affirmed that nitrogen is the nutrient whose dynamics are most influenced by the adoption of no-till system and Freire et al. (2000) have pointed out that nitrogen is the principal nutrient limiting crop and that when the soil is the only source there is usually not enough nitrogen to assure high productivity. The soil organic nitrogen reserve represents 95% of the total soil nitrogen and is subjected to transformations that determine the balance between organic and inorganic forms of this element and, consequently, availability of nitrogen to plants. Sá (1999) states that in the initial years of no-till system plant nitrogen availability is problematic due to the high carbon/nitrogen ratio of crop residues, the presence of compaction and relatively low levels of phytomass, such effects occurring principally in degraded soils. Such problems are well-known to occur in newly implanted no-till system because the amount of fresh material on the surface of the soil but also occur when climatic conditions are unfavorable to decomposition. As the amount of surface organic material undergoing decomposition increases due to the continued use of no-till system nitrogen availability stabilizes (Sá, 1996). A solution which is often adopted has in ploughed systems is to apply inorganic nitrogen-based fertilizer to the furrow during sowing.

Most Brazilian soils used for grain production are highly acidic as expressed by pH or the presence of phytotoxic aluminum and/or manganese, liming being the recommended practice correcting these problems. The factors responsible for the re-acidification of soils under continued agricultural use are mineralization of crop residues, the type and amount of applied

fertilizer and loss basic cations by lixiviation and/or surface runoff.

In Brazil, conventionally tilled soils become re-acidified and require re-liming about every five years (Pöttker et al., 1998) but in no-till system there tends to be a decrease in the level of exchangeable aluminum and or manganese with time and hence a decrease in the need for liming (Sidiras and Pavan, 1985; Sá, 1993).

Various mechanisms have been proposed to explain the reduction of acidity in soils under no-till system (Miyazawa et al., 1993; Salet, 1998; Franchini et al., 1999; Sumner and Pavan, 2000; Miyazawa et al., 2000).

Miyazawa et al. (2000) have suggested that one mechanism might be related to the level of basic cations and soluble organic carbon presents in the phytomass of the green fertilizers *Avena sativum*, *Brassica napus*, *Lupinus albus*, *Leucaena* spp, *Mucuna aterrima* and *Crotalaria juncea* during flowering than in other commercial species such as maize (*Zea mays*), soybean (*Glycine max*), and wheat (*Triticum aestivum*) post-harvest. Reduced aluminum and/or manganese toxicity can depend on the species cultivated but is mainly related to the developmental stage of the plant, with growing plants being more resistant than mature plants. This implies that in no-till system in tropical and subtropical Brazil the level and periodicity of liming may be affected by the type of green fertilizer or crop residue which are produced by the different crop rotation systems because such residues can interfere with soil organic matter dynamics, increase pH and reduce aluminum and/or manganese toxicity.

Kaminski (2000) has proposed an alternative mechanism to explain the reduced acidity in no-till system based on the existence of channels (produced by insects or the decay of roots) in the soil profile, such channels having lower levels of aluminum, higher levels of exchangeable calcium and magnesium, raised available phosphorous and potassium, more organic matter, and higher pH than the adjacent soil.

Miyazawa et al. (2000) have reported that many commercial cultures show maximum economic productivity when the soil pH is 5 (as measured in water) and the aluminum saturation is 40%. However, the frequent and intensive use of ammonium or amide nitrogen-based fertilizers can annul the effect of the plants and reduce soil pH.

In no-till system soil acidity is reduced by applying calcareous material directly to the surface of the soil without incorporation, with various workers (Pöttker, 1998; Sá, 1993 & 1999; Caires, 2000) having concluded that this procedure has dramatic results on the acidity of the first 10 cm of soil; promoting pH elevation, increased levels of exchangeable calcium and magnesium; and reduced exchangeable aluminum and/or manganese. In addition, the productivity of the species cultivated using this type of liming is equal to that in systems using conventional tillage-liming. Pöttker (1998) emphasizes that in certain soils the surface application of lime requires only half or a quarter of the quantity of liming agent required by conventional tillage-liming but that the productivity of surface-limed crops is the same as that of tillage-limed crops.

In their review of the literature on the surface-liming of no-till crops Lopes et al. (2004) affirm that when the level of soil phosphorous is satisfactory it is possible to achieve highly productive cultures in no-till soils by applying quantities of calcareous material to the soil surface without incorporation and that the quantity of material needed is lower than when the

material is incorporated into the soil. These authors also state that when calcareous material is applied the surface of the soil the maximum effect on soil acidity occurs in the 0–10 cm soil layer.

In subtropical Brazil the southern regional branch of the Brazilian Soil Science Society South Regional Nucleus (*Sociedade Brasileira de Ciência do Solo – Núcleo Regional Sul; SBCS-NRS*) coordinates the network of official soil analysis laboratories (*Rede Oficial de Laboratórios de Análise de Solo; ROLAS*), conducts quality control, publishes liming-tables and stimulates research by mounting scientific and technical events catering to regional technological demands. No-till system account for more than 75% of the agricultural area under cultivation in subtropical Brazil because of which the SBCS-NRS has, since the early 1990's, been organizing specific research related to the application of fertilizers and liming to no-till soils, the results of this research having been published in the '*Fertilizer and Liming Manual for the States of Rio Grande do Sul and de Santa Catarina*' (SOCIEDADE, 2004) which places an emphasis on no-till soils in subtropical Brazil, recommendations for tropical Brazil having not yet been published due to lack of data.

In Argentina, no-till has changed several fertilization practices. Higher nitrogen rates are required the first years after adoption, because nitrogen released by mineralization is lower compared to conventional tillage, although in good soils of the eastern part of Cordoba Province managed under CA for the last fifteen years, it was possible to obtain around ten tons of maize per hectare without applying any nitrogen or other fertilizer at all. Under CA, one may find a lower mineralization rate and different cadency, but it does not mean that the potential nitrogen supply along the crop cycle is necessary lower. Therefore, different nitrogen application and management strategies are required when using CA. Furthermore, under CA a higher efficiency of nitrogen use (maybe due to a better, improved and higher water supply and water use efficiency) can be achieved. A phosphorus stratification process is also observed in no-till, however, Bianchini et al. (2004) found that broadcast phosphorus application in no-till is equally efficient as banding phosphorus. Liming is not a common practice in none of the tillage systems.

3.3 Weed management

Differently from conventional, agriculture that relies mainly on mechanical and chemical methods weed management, in CA relies on a broader set of methods. Allelopathic and physical effects of many cover crop species on the germination of weed seeds have been exhaustively studied and well documented. These methods, combined to the use of crop rotations and chemical control, comprise what has been called as Integrated Weed Management in CA. New strategies are needed for controlling weed pressure and some key options are being proposed: i) the systematic use of cover crops able to compete with weeds whenever there is no commercial crop growing; ii) the presence of a thick mulch layer during the commercial crop cycle; iii) the control of cover crops mechanically with "Roller-knives", which is mostly feasible for annual cover crop species.

The first aspect to be considered regarding conservation systems is the impact on the use of pesticides in agriculture as well as on the environment and human health. A great advantage of no-tillage was the substitution of incorporated herbicides by post or pre emergence products less persistent and used at low doses. For small scale farmers, however, it was usual to use mechanical methods alone or complementary to herbicide. Conservation systems has

made the weed control more dependent on herbicides, but similar to large scale farmers and in the situation where the small farmers used herbicides, the substitution of incorporated herbicides was also a great advantage. Overall, however, despite the great advantage of herbicide substitution motivated by no-tillage regarding weed control, the system is dependent on herbicides because of the use of burn down herbicides and the elimination of mechanical control of the weeds. In some cases, and particularly for small-scale farmers, this dependence is both costly and risky, and may run counter to desires for achieving a fully ecological agriculture.

The substitution of herbicides on conservation systems to post emergence ones, the stubble presence limiting mechanical control and the lack of crop rotation with the intensive use of same herbicides has accelerated the development of cases of weed resistance.

The weed population, due to relevant changes on the basic agro-ecosystem variables, is different while comparing the “No Till Environment” with the “Conventional Till” one, both in size and composition. Using the allelopathic and physical effects of cover crops a reduction on the number of species and its density can be obtained. In some situations some species with more aggressive behavior and more tolerant to herbicides (like perennials) have been selected in no-tillage.

The presence of stubble covering the top soil along with the absence of soil tillage strongly modify the biological, physical and chemical activity reducing the negative effects by increasing degradation and retention of the herbicides in soil.

Results of some studies have demonstrated the agronomic, economic and ecological viability of Integrated Weed Management. Weed resistant, presence of problematic weed species, and high use of herbicides can be avoided or eliminated adopting Integrated Weed Management strategies.

Production of organic crops under no-tillage using natural products to weed control has been done, as well as attempts to eliminate the use of any herbicide. The limitation, in both cases, has been the labor requirements to weed control.

Concerning the use of genetically modified herbicide-resistant crops, there are not yet scientific results that allows drawing conclusions on its technical, economic and environmental impacts. The only evidence on the benefits of its use is the adoption of GM soybean varieties of herbicide-resistant crops in Argentina. The adoption pattern and the synergy with no-tillage in Argentina has made the crop resistant technology a valuable tool to improve the weed management under CA and to further push the CA adoption into areas where perennial weeds were a serious limitation for the expansion of agriculture. Also the simplicity and high reliability of the technology is considered to be useful to reduce the risk of failures on weed control. Considering this aspect together with the reduction in operative time achievable by adopting CA, the synergy went even further at enhancing the adoption of both CA and biotechnology.

3.4 Pests/diseases management

The suppression of soil tillage, the maintenance of crop residues and the use of crop rotations has been the main factors influencing the incidence of pests in No-Tillage systems. In general,

the soil management systems (conventional/no-tillage) has a more important influence on insects with underground habits and those that feed soil organic matter; these species will have a higher incidence in NT. At the other side, crop rotations will have more influence on insects of aerial parts, although they can also influence the soil fauna (Viana et al. 2001).

Research results indicate rather an increase of pests incidence in No-tillage, except for *Elasmopalpus lignosellus* and aphids. They also indicate that crop rotations and the use of specific cover crops could reduce the incidence of some pests.

It has been demonstrated by many authors, that the maintenance of crop residues on the soil surface has been one of the most important factors that contribute to a higher incidence of saprophytic organisms that will cause diseases in crops such as wheat, maize and soybeans. It has also been demonstrated that no-tillage must be associated with crop rotations in order to keep the (inoculum potential) within an acceptable level. Therefore, from the point of view of diseases control, no-tillage is technically feasible if associated to crop rotations. The big challenge that still remains is to have alternatives of crop rotations that address technical requirements from the phytosanitary point of view, while assuring economic returns to the farmers, within a uncertain context of agriculture in Brazil.

The beneficial effects of No-Tillage on predators/natural enemies of pests also have been reported, although there is still not much available information on this. There is a need of more research to evaluate the effect of the greater persistence and prevalence of fungi in no-tillage systems, so as to devise cultural practices aimed at increasing the natural occurrence of enthomopatogenic fungi on soybean insects (Sosa-Gomes & Moscardi, 1994).

3.5 Rainwater efficiency

Global revision made on these items for both countries stressed the next points:

- Because of the presence of vegetal mulch, CA systems can reduce runoff and increase water infiltration by 50% compared with conventional systems.
- Direct evaporation from soil is reduced by 10 to 50% compared to conventional systems even if, in quantity, this saving is less important than effect on runoff.
- Water directly intercepted by crop residue distributed on the soil surface is minor compared to water conserved through the reduction of soil evaporation. This negative effect of the mulch can reduce a bit its positive effect on soil direct evaporation.
- Available water during eventual dry spells is then higher under CA systems reducing climatic risks

4. Socioeconomic impacts

4.1 Small scale Agriculture

4.1.1 Labor and machinery requirements

The main aspects related to labor and machinery in conservation agriculture are drudgery, total labor requirement, the calendar year of labor demands, equipment and machinery wearing and their maintenance expenditure.

Since conservation agriculture does not require plowing and harrowing drudgery is reduced, especially for those farmers who depend on animal traction that is very tiresome. Also, as

many authors have observed, the suppression of these and other mechanical operations promotes reductions ranging from 11% to 46% in total labor required, depending on the crop being grown.

No less important is the reduction in labor peaks throughout the agricultural year, especially from August to December. Although there is a slight increase on labor demand on April and May these are months of labor availability.

These important social impacts have allowed farmers to increase the cultivated area or, if they have no land available, to undertake other income activities or even to provide help for their neighbors, which is also socially relevant.

Economic studies have shown that conservation agriculture promotes a reduction of 46% in the total hours of equipment and machinery use due to no plowing and harrowing. Thus a 42% reduction in the consumption of fuel and other lubricants is also observed. Insofar as labor is directly related to the use of these equipments its employment is reduced by 46%.

Equipment and machinery wear out less in conservation agriculture because it works in a less dusty environment and uses less tractor power. A tractor used in conservation agriculture lasts from three to four years longer than one in the conventional system. Moreover the replacement of parts and lubricants is less intense.

4.1.2 Costs and Profitability

As far as costs and profitability are concerned it is already been proved that the impacts of conservation agriculture are positive in spite of the higher prices of the special machinery needed for undertaking it. Economic evaluation of experiments comparing conservation agriculture with conventional systems has shown lower operation costs for the first one. Again, this is explained by reduced use of equipment and machinery. As already stated fuel, lubricants and labor costs are also inferior.

Furthermore, the reduction in operational time offers an opportunity to improve the economic efficiency of the investment on machinery. This benefit can be achieved basically by two ways. Enlarging the machinery operative scale-up to a proper size by offering the service to third parties. This mechanism will optimize the use of a given piece of equipment and hence economically justify the investment on it. On the other hand, it will also avoid the necessity of buying the machinery for those farmers that operate on a smaller scale as required and so economically justify the investment .

Spending with herbicides though is higher. The economic studies mentioned above have shown that when total production costs are considered those for conservation agriculture are higher than the ones for conventional agriculture. This was attributed to the excessive use of high glyphosate dosages, sometimes twice in the same crop year, in the first five crops.

Nevertheless, the economic performance of conservation agriculture, when compared to conventional, must be assessed in a long run to be fully appreciated. At the transitional phase there are some learning costs, investment in new equipment and soil improvement. The last one takes some time to occur.

During the first phase of the process (improvement of tillage techniques) expenditures in chemical inputs for weed and disease control may offset gains from diminished labor and machinery demands. In the second phase (improvement of soil conditions and fertility) reduced production costs from less labor and machinery requirements may lead to an increase in farm net income obtained through higher yields. The third phase (diversification of crop pattern) should bring increased and more stable yields, higher soil fertility and a decrease in plant protection costs resulting in more gains in net farm income. Finally, in the fourth phase (integrated farming system) crop output and productivity would be stabilized.

Two main approaches are used to compare conservation agriculture and conventional tillage profitability. The so called “all or nothing” (most common) compares the conventional farmer’s practice with conservation agriculture enhanced with a package of other inputs (improved varieties and optimal levels of soil fertilization and pest and disease control). The “step by step” approach combines the farmer conventional system plus conservation agriculture practices.

As expected, the first approach results in higher profitability. Logically, the more intensive the package the better is the profitability outcome. Depending on the approach used the profitability results are attributed to different factors from soil decompaction and lime application to better fertilization and the use of improved varieties.

4.1.3 Multipurpose role of agriculture

The reduction in labor requirements resulted from the adoption of CA can create opportunities for other non-agricultural sources of income, provided that economic environment enables for employment and/or income-generation. This is especially important in economies of scale, such as the case of Southern Brazil, where the low profitability of the small scale of production of beans has been resulted in the need to search for other economic alternatives for family farmers. Studies indicate that only farmers who will have part of their income originated from non-agricultural activities will be economically viable (Laurenti, A.C. & Del Grossi, M.E.), because of the crescent lower profitability of traditional products such as maize and beans for small-scale farmers.

For instance, in the State of Paraná (Brazil), 27% of the farms have already incorporated non-agricultural activities such as home employees, hotel workers, clubs, shops, hospitals, schools, and industries for processing of agricultural products (dairy, meat, fruits).

4.2 Large scale agriculture

Socioeconomic impacts of conservation agriculture in larger farms also regard equipment and machinery and costs and profitability. The differences are due to returns to scale, as shown below by the case of a large farm in the humid tropic of South America.

This agricultural enterprise doubled its crop area through the more efficient use of machinery expressed by a 23% increase in the hour/tractor employment and decrease in the rate HP/ha from 0.40 to 0.27, which also meant less intense labor use. The harvested area increased from 59% to 88% made possible by the labor force no more needed for land preparation for the winter season. A better employment of the labor force was also expressed through an increase in the rate of hectares labored per man from 148 to 217 in the summer crop and from 178 to 379 for the whole year. All accomplished with no new investments whatsoever.

In addition to enhanced efficiency in equipment and machinery use there are also returns to scale in costs per hectare when conservation agriculture is compared with conventional practices. This specific farm lowered its machinery maintenance costs from US\$12.47/ha to US\$9.65/ha. Moreover, the lowering of costs has allowed the farm to increase the profitability in wheat, for example, in the amount of 50% of net income.

In addition, some South American studies analyzing linkages between sustainability and competitiveness and profitableness concluded that no-tillage systems create a favorable environment to simultaneously achieve these goals.

The noticeable rate of adoption of no-tillage may prove the economic effectiveness of the system in some South American countries that adopt high taxation and unprotected economic environments.

5. Environmental impacts

5.1 Carbon stratification and sequestration

In Brazil, estimates of the rate of carbon accumulation have generally been restricted to the two main regions under CA (the south and central west). In the southern region, Sá (2001) and Sá et al. (2001) estimated a greater accumulation rate ($0.8 \text{ t C ha}^{-1} \text{ yr}^{-1}$ in the 0-20 cm layer and $0.9 \text{ t C ha}^{-1} \text{ yr}^{-1}$ in the 0-40 cm layer) after 22 years under CA compared to the same period under conventional tillage. The authors mentioned that accumulated carbon was generally greater in the coarse fraction ($> 20 \mu\text{m}$) than in the fine ($< 20 \mu\text{m}$) one, indicating that most of this additional carbon is weakly stable. Bayer et al. (2000a, 2000b), found a carbon accumulation rate of $1.6 \text{ t ha}^{-1} \text{ yr}^{-1}$ for a 9-year no-tillage system compared with $0.10 \text{ t ha}^{-1} \text{ yr}^{-1}$ for the conventional system in the first 30 cm layer of an Acrisol, in the southern part of Brazil. Corazza et al. (1999) reported an additional accumulation of approximately $0.75 \text{ t C ha}^{-1} \text{ yr}^{-1}$ in the 0-40 cm soil layer due to no-tillage, in the Cerrado region located in the centre-west. Estimates by Amado et al. (1998, 1999) indicated an accumulation rate of $2.2 \text{ t ha}^{-1} \text{ yr}^{-1}$ of soil organic carbon in the first 10 cm layer. Other studies considering no-till systems carried out in the central-western part of Brazil (Castro Filho et al., 1998, 2002; Lima et al., 1994; Peixoto et al., 1999; Resck et al., 2000; Riezebos and Loerts, 1998), reported soil carbon accumulation rates due to no-tillage, varying from 0 to $1.2 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for the 0-10 cm layer.

More detailed accumulation rates are reported in Table 1. Rates are organized by region. In the Cerrado region carbon accumulation rates vary from 0.4 to 1.7 t C ha^{-1} for the 0-40 cm layer, which is similar to the range found in the Southern region (-0.5 to 0.9 t C ha^{-1}). Mean rates of carbon storage were similar among “Cerrado” (0.65 t C ha^{-1}), “South” (0.68 t C ha^{-1}), and “Other” (0.60 t C ha^{-1}) regions, when the soil surface layer was considered (0-20 cm). More variability was found in the Southern region (-0.07 to 1.6 t C ha^{-1}) for the 0-20 cm layer, than in the other regions. However, it is important to mention that these mean values aggregate different soil and crop types and the variability is high. For instance, the Mean value of 0.68 t C ha^{-1} for the South region was obtained averaging 15 observations (Table 1) and the associated standard deviation is 0.54 t C ha^{-1} .

Some other studies performed in Brazil reported that organic carbon (OC) contents under conservation and conventional management systems can be very similar (Corazza et al., 1999;

Freixo et al., 2002; Roscoe and Burman, 2003; Sisti et al., 2004). These contradictory results are to be related to the high clays contents of the studied soil and probably a high stability of their organic matter.

In Brazilian Oxisols, soil organic matter stability is determined by clay content and its mineral components. Bayer (1996) observed for three soils in the southern part of Brazil that colloidal physical stability of soil organic matter was associated with ferric oxides and kaolinite content on clay fraction. The high organic matter stability observed for Brazilian Oxisols is the major determining factor for reduced organic matter decomposition rate observed for the conventional tillage. For example, mean rate loss for organic carbon on Red Latossol with 660 g kg⁻¹ clay were similar among conventional tillage (1.4% a.a.) and no tillage (1.2% a.a.) (Bayer, 1996).

Sisti et al. (2004) reported that the soil under native vegetation (measured in areas near to the experimental site) had a high carbon and nitrogen content (37 g C and 3.1 g N per kg soil) in the first 5 cm depth. Carbon and nitrogen content declined to approximately half these values at 10-15 cm layer. The carbon concentration in the top 5 cm of soil was considerably higher in all three rotations managed with no-tillage compared with the conventional system, although not as high as under the native forest. Machado and Silva (2001) showed decreases in SOC of 23.4% and 47.8%, respectively, at 0-5 cm depth for no-tillage and conventional tillage systems, when compared to an adjacent non-cultivated area. The study was carried out on an Oxisol in the south of Brazil, following 11 years of Sorghum-wheat cultivation. However, the authors also found SOC at the 0-40 cm to be the same as the forest soil for both CA and conventional tillage.

Results about soil organic carbon stratification and sequestration from Bolivian soils are not available.

The dynamic of soil organic carbon for Argentinean soils are similar to Brazilian soils. For example, Casas (2002) documented differences in several farmer fields and soil types from Argentina, and found a positive correlation between years of no-till and soil organic C stratification and C content. In southern Santa Fe Province, Casas (2001) measured a 3.8% organic matter at 0-2 cm depth and 2.8% OM at 2-4 cm depth in a field with 3 years of no-till, whereas, the organic matter levels were 6.1% and 4.2% for the 0-2 and 2-4 cm depth respectively, in a field that has been in no-till for 9 years. Another study (Casas, 2002) conducted in several fields with different soil types (Hapludolls and Argiudolls), showed organic matter contents that ranged 4.2-6.3%, 3.2-4.4%, 2.8-3.7%, 2.6-3.1%, for the 0-2 cm, 2-4 cm, 4-6 cm, 6-8 cm depths, respectively.

The advantage that no-till represents regarding the soil carbon management was reported and analyzed by Andriulo (2002). Puricelli et al. (2002) monitored the evolution of certain soil chemical properties of a Mollisol located on the southern part of the Buenos Aires Province. Even the study was run on soils that just begun to be cultivated under no-till, after fifty months some positive trends were detected for organic carbon and phosphorous content. The validity of this information would have only to be restricted to a short no-till period because no-till treatment started at the same time the study began. However, on the same paper the authors revised the information derived from different no-till long term trials, between nine and twenty eight years, carried out in different parts of the world and found a generalized

positive correlation trend between no-till and some important soils properties as organic carbon content and total nitrogen.

At the beginning of the XX century, the Central Pampas region used to have 4% organic matter (20-cm depth) in northern Buenos Aires and southern Santa Fe, and 3% organic matter in southeastern Cordoba (Casas, 2002). Measurements made during the 80's (during the main agriculturization process with conventional tillage) showed those organic matter levels decreased 1-1.5 units in the first mentioned area and 0.5-1.0 units in the second one. The decrease in the soil organic matter content affected the soil quality and health, increasing erosion processes, structure degradation, and a decrease in soil fertility. Other measurements (Michelena et al., 1989) made in the Central Pampas Region (5 million ha) showed that the organic matter levels progressively decreased with the agricultural use, going from an average of 3.2% in soils with agriculture and pastures rotation to 2.7% in soils under a continuous conventional tillage agriculture system for more than 20 years. The organic matter decrease is variable for the different soils and management systems, and ranges from 24% to 64% of the original organic matter levels. Part of this C was lost by soil erosion and part by CO₂ emission to the atmosphere. In this case, soil function as a source of the greenhouse gas.

Regarding to soil C losses in Brazilian soils, it is well established that conventional tillage systems decrease soil C and N pools. For example, after 14 years on conventional tillage, losses of soil organic C for an Argisol at 0-30cm depth were 14,4 Mg ha⁻¹. Soil erosion contributing to soil C decrease in this site so, C emission was not possible to estimate.

Similar to on Brazilian soil, no-till on Argentinean soils increases the soil organic C and produces changes in the quality of the organic matter, with a trend to increase the coarse fractions, especially in soils with a lower relative content of fine materials. In Argiudolls, the increase in C stock is greater during the first 6-7 years after no-till adoption, with an annual increase of 1.2 t/ha expressed in organic matter (10-cm depth), that declines to 0.7 ton/ha between the sixth and tenth year (Casas, 2002). In Hapludolls, the initial annual increase is 1.6 t/ha, with a decrease to 0.8 t/ha after the sixth year, approximately. Compared to Brazilian soils (Table 1), rates of soil organic carbon increase are similar.

The crop rotation and the soil fertility management of the field have a fundamental importance, related to the quality and quantity of the residue added to the soil. There are no studies in Argentina that evaluated the impact of C in the air and soil quality, so research is needed in this area.

It is well established that conservation management systems on Brazilian soils increase passive and labile soil organic carbon pools, contributing to CO₂ sequestration. For the global impact on global warming, C sequestration is important through CO₂ depletion from the atmosphere. For example, Pillon (2000) evaluated the long-term (16-year) effect of six no-till cropping systems with varying additions of C and N on soil organic matter contents in a Red Argisol profile. The additions of 28 to 142 Mg C ha⁻¹ and 656 to 5984 kg N ha⁻¹ increases soil C and N pools down to 30 cm depth. Compared with fallow/maize system, the accumulate of C in the soil at 0-30cm depth varied from 4,1 Mg ha⁻¹ in the oat/maize to 12,5 Mg ha⁻¹ in the lablab/maize system, corresponding to a net sequestration of C-CO₂ from 15 to 46 Mg ha⁻¹, respectively.

Table 1. Carbon storage rates (accumulation following conversion of a conventional tillage system to no-tillage) in Brazil regions.

Place	State ^a	Succession or dominant plant ^b	Reported soil classification	Clay (%)	Layer (cm)	Duration (yr)	Rate (t C/ha)	
<i>Cerrados region</i>								
Planaltina	DF	S/W	Latossol (Oxisol)	40-50	0-20	15	0.5	Corazza et al., 1999
					0-40	15	0.8	
Sinop	MT	R - S/So – R/So - S/M- S/E	Latossol (Oxisol)	50-65	0-40	5	1.7	Perrin, 2003
Goiânia	GO	Rice/Soybeans	Dark red Latossol		0-10	5	0.7	ud
Rio Verde	GO	M or S/Fallow S/M or So or Mi	Red Latossol	45-65	0-20	12	0.8	Scopel et al., 2003
Planaltina	DF	M or S	Dark Red Latossol (Oxisol)	>30	0-40	16	0.4	Resck et al., 2000
<i>South region</i>								
Londrina	PR	W/S	Oxisol		0-10	22	0.31	Machado and Silva, 2001
					0-20	22	0.25	
					0-40	22	-0.17	
Londrina	PR	S/W – S/L –M/O	Red Latossol		0-20	7	0.5-0.9	Zotarelli et al., 2003
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol Typic Haplorthox		0-10	14	0.4 ^d	Castro Filho et al., 1998
					0-20		0.2 ^d	
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol Typic Haplorthox		0-40	21	0 ^c	Corazza Filho et al., 2002
Ponta Grossa	PR	(S or M)/(O or W)	Oxisol Typic Hapludox	40-45	0-40	22	0.9	Sá et al., 2001
Tibagi	PR	(S or M)/(O or W)	Oxisol Typic Hapludox	40-45	0-40	10	-0.5	Sá et al., 2001

Tibagi	PR	M/W – S/O – S/O	Red Latossol Oxisol	40-45	0-10	22	1.0 ^d	Venzke Filho et al., 2002
Tibagi	PR	M/W-S/O-S/O	Red Latossol Oxisol	42	0-20	10	1.6	Siqueira Neto, 2003
Toledo	PR	S/O	Haplic Ferrasol		0-10	3	-0.68 ^d	Riezebos and Loerts, 1998
		S/O	Haplic Ferrasol		0-10	10	0.37 ^d	
Passo Fundo	RS	W/S	Oxisol		0-10	11	0.59	Machado and Silva, 2001
					0-20	11	-0.07	
					0-40	11	0.29	
Passo Fundo	RS	W/S	Red Latossol Typic Hapludox	63	0-30	13	0 ^c	Sisti et al., 2004
		W/S-V/M			0-30	13	0.4	
		W/S-O/S-V/M			0-30	13	0.7	
Passo Fundo	RS	W/S	Red Latossol Typic Hapludox	63	0-10	11	0.3	Freixo et al., 2002
					0-20	11	0 ^c	
					0-30	11	0 ^c	
		W/S – W/M	Red Latossol Typic Hapludox		0-10	11	0.4	Freixo et al., 2002
					0-20	11	0.2	
					0-30	11	0 ^c	
Santa Maria	RS	M and Mu/M	Ultisol	15	0-20	4	1.3	Amado et al., 2001
Eldorado do Sul	RS	M/G	Podzólico Vermelho Escuro		0-17.5	5	1.4 ^d	Testa et al., 1992
		M/La			0-17.5	5	0.6 ^d	
		O/M			0-17.5	5	0.2 ^d	

Eldorado Sul	do	RS	O+V/M+C	Clay loam Acrisol Typic Paleudult	22	0-17.5	9	0.84	Bayer et al., 2002
Eldorado Sul	do	RS	O/M	Clay loam Acrisol Typic Paleudult	22	0-30	9	0.51	Bayer et al., 2000b
			O+V/M+C			0-30	9	0.71	
Eldorado Sul	do	RS	O+V/M+C	Clay loam Acrisol TypicPaleudult	22	0-17,5	12	1.26	Bayer et al., 2000a
Lages <i>Other regions</i>		SC	M or S / W or O	Cambisol		0-20	8	1.0	Bayer and Bertol, 1999
Campinas		SP	S or C / M	Rhodic Ferralsol Typic Haplorthox	60	0-20	3	0.8 ^{de}	De Maria et al., 1999
						0-20	8	0.4 ^{de}	
Sete Lagoas		MG	M/B	Dark red Latossol Typic Haplustox		0-15	10	0 ^c	Roscoe and Burman, 2003
						0-45		0 ^c	

^aPR =Paraná, RS =Rio Grande do Sul, DF = Distrito Federal, SC = Santa Catarina, SP = São Paulo, MT = Mato Grosso, GO = Goiás, MG = Minas Gerais; ^b Dominant succession: W = Wheat (*Triticum aestivum*), S = Sorghum (*Glycine max*), So = Sorghum (*Sorghum vulgaris*), R = Rice (*Oriza sativa*), E = *Eleusine coracana*, O = Oat (*Avena sativa*), V = Vetch (*Vicia sativa*), M = Maize (*Zea mays*), B = Beans (*Phaseolus vulgaris*), Mu = Mucuna (*Stizolobium cinereum*), C = cowpea (*Vigna unguiculata*), L=Lupine bean (*Lupinus angustifolius*), La = Lablabe (*Dolicbos lablab*), G = Guandu (*Cajanus cajan*);^c 0 means that the difference was not significant; ^d calculated using an arbitrary soil bulk density of 1.2 g cm⁻³; ^e value reported for OM, C= OM / 1.724, ud =unpublished data from Metay.
Source : Bernoux et al. (2005)

Nevertheless, other greenhouse gases may be taken into account. Few results have been published regarding N₂O emissions in Brazilian tropical regions. One of them was realized in the Cerrados region (Métay et al. 2004). The results demonstrated that N₂O emissions were very low ($< 1 \text{ g ha}^{-1} \text{ day}^{-1}$) for both conventional and conservation management systems. Peaks of N₂O were observed after fertilization. N₂O is produced mainly by denitrification, which may be explained by low NO₃⁻ levels in soils and a $< 60\%$ water filled pore space (WFPS) within the soil for the majority of the time. Low WFPS under these crops can be caused by evaporation at high temperature (more than or equal to 25°C). However, measurements of gas concentrations in soil showed that the production of N₂O is reasonably prolific (concentrations of 1 to 30 times the atmospheric concentration). This suggests that N₂O is produced but cannot diffuse to the soil surface, both because denitrification is complete and N₂ is produced or because the N₂O is nitrified before diffusing.

In conclusion, for any agro climatic region, conservation management systems as no tillage seem to be an interesting cropping management option to mitigate global warming becoming from greenhouse gas effects. Soil C stocks tend to increase when additional cover crops, especially grasses plus legumes are used in order to increase the total photosynthetic production during the year and provide high levels of biomass returned to the soil. In this case CO₂ emissions due to microbial activities are important but widely compensate by organic returns.

5.2 Nitrogen and nutrient cycling

Global revision made on these items for both countries stressed the next points:

- In humid region CA systems increase drainage probability and N lixiviation during the crop cycle.
- Previous risk is compensated if an additional cover crop is added before or after the main commercial crop. This crop is able to recycle part of the drained water and lixivate nutrients and to reduce these losses when no commercial crop is growing. Global efficiency at the year scale is then hugely increased. They act as "Nutrient pumps".
- Nutrients extracted by the additional cover-crop are then released to the system through the mineralization of its residue. Amount and dynamic of N and other nutrients mineralization will depend on the quantity and nature of the residues, as well on the kind of cover-crop.
- The kind of cover-crop and the way it is managed will determine the amount of residual N available at the beginning of the next cycle. Too important amounts of mineral N at the beginning of the rainy season when the commercial crop is just germinating can increase strongly lixiviation risk.
- Because of important biomass production in CA systems, soil C and N stocks tend to increase over time.
- Because of better general conditions (temperature, moisture, total Soil and residue organic matter), mineralization processes are often more important and more continuous over time, resulting in higher nutrients availability for the commercial crop.
- N fertilization of commercial crop needs then to be adequate in function of the previous cover-crop and the organic status of the field (linked with time of CA application).

- N immobilization is more frequent after grass cover-crops and during the first years of CA implementation.
- N fertilization efficiency can be increased by splitting applications, by applying below the residue layer, by banding to reduce contact with residue, by using urease inhibitors and/or alternative sources to urea as an N source.
- Global N and other nutrients efficiency increases because of the important total biomass produced in such CA systems with additional cover-crops.

5.3 Erosion mitigation

The soil water born erosion comes out as a result of the interaction among some factors like erosibility rainfall, soil erodibility, land topography features, soil, crops, stubble management and mechanical techniques of drain control (Wischmeier & Smith, 1978).

Two main factors rainfall erosibility on and zone topographic features (slope length and land inclination) are the strong components to bring about erosion; and the factors of soil erosion, soil management, crop management stubble management and mechanical techniques of drain control build up the energy dissipater component. Therefore, some different soils, at different lands, with random pluvial precipitation, diverse topographic features put under different practice cultivation are shown to have soil erosion losses with different measurements. The water born erosion shown in this way comes as a result of the mechanical work of the incident energy over the soil, slightly dissipated.

Standard data shows that some management techniques as for example to low the removal intensity and preserve the stubbles over the surface of the soil can diminish a big deal the water born erosion in cultivated zones with annual species and perennial as well, which is a common fact in Brazil, Argentina and Bolivia.

Despite stubble plays an important role on the energy dissipation which is able to provoke erosive process, new researches in Brazil have shown that No-tillage has critical boundaries on the slope length where such efficacy is overreached, causing the water born erosion to happen. The stubble shows a great potential to dissipate up to 100% the kinetic energy of the rain drops, but this efficacy is not shown as well to dissipate the erosive energy of the drain. At some specific point of the slope length, the stubble of the soil gets reached the erosive energy dissipation potential, allowing flotation and transportation of the stubble as well as releasing new erosive processes which are under the coverage of the soil stubble. These processes become relevant mainly at sequence where the slope length passes to the drain some breaking energy and superior dragging to the cut critical resistance or dragging set by the stubble and the soil. Over the rocky and steep mountains of Bolivia, the water born erosion is a big, serious problem and no works nor support are doing to prevent it; however, over the plain lands, where conservative techniques are put in practice mostly, the water born erosion is a minor problem and the process of wind born erosion plays an important role as well.

Pluvial precipitation becomes the main agent of soil erosion in those regions with some slopes and those with soil used for annual cultivation that is Brazil, Argentina and Bolivia. Particularly in Brazil, the erosive potential of the rain which is set by erosion index from the Soil Losses Universal Equation, it ranges between 5.200 and 12.600 MJ.mm/ha. In Brazil two

regions are identified as to have rainfall erosibility: a subtropical and a tropical. In the tropical region, erosivity ranges from 70% to 95% on the spring-summer season; consequently, the risks of water born erosion are the highest ones during the spring-summer season, yielding the same effects on most regions of Bolivia (high plateaus, valleys and most of rainforests) and the north-west of Argentina. In the subtropical region of Brazil, which is located to the southern of 24° parallel of south latitude, in spite of the highest level are common during the spring-summer season, rainfall of great erosive potential may fall at any season of the year which becomes and steady risk to erosion. Similar situations are presented in several regions of Argentina and some area humic tropic of Bolivia as well.

Susceptibility of Brazilian soils to the water born erosion, mostly of Oxisols, Ultisols and Alfisols, expressed by the Universal Soil Loss Equation, ranged between 0,008 to 0,044 t/ha.h/MJ.ha.mm which are usually considered low values, but when used in real practice they become high due to wrong soil management practices and the land topography features. Some evaluations due to water born erosion losses in some Brazilian experimental plots range between 0,2 and 51,5 t/ha/year. In high rainfall areas in Bolivia, soil losses under different managements range between 0,04 to 353,8 t/ha/year; in general the results show that as long as the crops residue are kept over the soil surface and the intensity of removal is reduced, the erosion values fall down to 97% in the case of annual crops.

In some regions of Argentina and the rainforest of Bolivia, the wind born erosion becomes of real importance in the plain areas mainly, affecting aggressively to the fall-winter season crops. The positive impact of the No-tillage in order to control the wind born erosion is favored due to the greater stability of the input and the real barrier built up by the stubble of the soil layer; without removal of the soil reduces the number of tiny particles which are responsible toward the first stage of the wind born erosion process. In Bolivian humic tropic this process is controlled by windbreak curtains which slow down the wind speed and protect the soil and the crops against the wind actions.

According to empiric observations and the results of erosion-control, in Brazil, it was thought that No-tillage by itself was good enough to control erosion, that's why former techniques were eliminated. At the present time, the No-tillage problem in Brazil, which has gotten worse due to the great amount of erosion of compounds as a result of depositions of agro-chemical input over the soil's surface, is introduced on situations when the cutting tension of the drain goes higher than the cut resistance or drag residues kept over the surface, generating rich sediment. In addition to be money-losses, they turn into contaminating elements of the superficial water making higher the risks of the natural balance of the hydrologic hermeneutics in the agro- echo-systems.

Taking into account all its advantages, No-tillage needs to be supported by complementary conservationist techniques and not to be considered as a conservative technique sufficient enough to control erosion. For that reason, every conservationist technique capable of keeping the length of the slope within boundaries where the covering of the soil doesn't lose efficacy on the dissipation of the incident energy, will contribute greatly to diminish the water born erosion process. Some other techniques like contour planting, aerial planting, strip cropping, buffer strip among others, are good conservationist techniques to segment the slope, what is more, they proved to be a good stimulus for the stubble, assisting in that way to an effective erosion control. In conclusion, in order to diminish the erosive effect of the rainfall and drain, it is fundamental to dissipate the erosive energy of such agents, that is, dissipate the kinetic

energy from the action of the rainfall drops and dissipate the kinetic energy from the cutting action of the drain by keeping the soil steadily covered and reducing the amount and speed of the superficial drain.

5.4 Pollutants

The main pollutants of water sources from agricultural areas are organic matter, sediments, nutrients and pesticides, withdrawn by runoff waters from farming lands. The development and application of new technologies that could reduce such undesirable side effects are required.

5.4.1 *Herbicides*

Information based on scientific data from direct in-field measures regarding herbicides in CA systems are considered as insufficient in the LA literature. In a recent symposium held in Brazil¹, Regitano *et al.* (2005) makes some considerations on this issue, however: a) the information is based on international literature; b) most of the experiments are carried out at laboratory level, with disturbed soil samples that does not represent the real situation of soil structure in the field; c) experiments do not consider the effect of the mulch in intercepting the herbicide. A literature review carried out by the same authors indicates different results, with some situations where CA increased herbicide lixiviation and reduced herbicide runoff and other situations where the results were the contrary.

CA increases the level of organic matter, the soil moisture, and the macro and microorganisms population. It is expected a greater degradation and retention of the pesticides in soil, diminishing wash off and contamination of subterranean waters. These conditions are confirmed by results found by Silver (2004) that in the no-till system there was enhancement of glyphosate mineralization in the soil and Papini (2004) verified that higher the organic content of the soils less is the probability of edaphic organisms contamination with simazine. Ferri & Vidal (2002) verified less persistence of the herbicide acetochlor in no-tillage; however, after irrigation, the persistence of the herbicide in the soil was the same in the 2 soil management systems, thus indicating irrigation or rainfall can overcome the effect of the mulch.

Rodrigues *et al.* (2000) studying the retention of herbicides by the straw in no-tillage verified differences between the tested products; after irrigation with 20 mm the products with higher retention were metolachlor, alachlor, acetochlor and trifluralin with indices of 5 to 30% of wash off of the straw into the soil; imazaquin, simazine, clomazone, metribuzin and isoxaflutole as intermediate level of wash off with indices of 30 to 50%; and atrazine and sulfentrazone as the ones that more easily passed through the layer of straw with recuperation of until 90% in the soil. Ferri (2002) also verified higher soil sorption of acetochlor in no-tillage. Oliveira *et al.* (2004) found out that the retention of the imazaquin was higher in areas with high level of organic matter meaning the areas where the no-till was utilized by long time.

Ferri *et al.* (2004) that studied the effect of the soil management and soil cover in the transport of the herbicides alachlor and atrazine. They found out that these herbicides had higher

¹ Simpósio sobre Plantio Direto e Meio Ambiente: Seqüestro de Carbono e Qualidade de Água. Held at Foz do Iguaçu (Brazil) From May 18-20, organized by Federação Brasileira de Plantio Direto na Palha and Itaipu Binacional.

transport by water of runoff in no-tillage when compared to the conventional system. They verified also that atrazine had higher transport than alachlor in the presence of straw.

Nevertheless, different aspects should be weighted carefully before reaching a final verdict. First, the actual use of pesticides (products, rates, frequency of applications) in CA must be compared to that of the conventional systems they are displacing. For example, whereas rates of 4 to 5 l/ha of atrazine and simazine-based pre-emergent herbicides were used in conventional maize management in the Cerrados region in Brazil, now, these same types of herbicides are used post emergence in CA, at early stages of maize development, at rates of 1 or 2 l/ha. Moreover, very stable pre-emergent products have been substituted with post-emergent quickly degradable ones in the case of soybean production.

One of the herbicides widely used in maize production in Argentina is atrazine. The peaks of this herbicide lost are related to the amount and intensity of the precipitation after the herbicide application; however, only between 0.85 and 0.01% of the applied rate was lost from the soil measured at a 1.5 m depth. Most of the Sorghum varieties planted in Argentina are tolerant to glyphosate, so this herbicide is one of the most widely used. Studies indicated that in the same northern Buenos Aires soils mentioned in the nitrate experiment, the amount of glyphosate leached only represented between 0.3 and 0.6% of the rate applied

5.4.2 Pig slurry

Some differences have been observed regarding the behavior of pig slurry in the soil as a function of soil management systems. Port et al. (2003) verified less loss of nitrogen by volatilization of ammonium with the use of pig slurry in no-tillage. Ceretta et al. (2003), however, warn for the risk of environmental contamination by the pig slurry use. Studies of the application of pig liquid manure, associated with cover crops, about nitrification and nitrates distribution in the soil profile were carried out by Almeida (2000). The lack of control of the runoff water and a possible higher wash out due to the greatest soil macro porosity can contribute for adverse effects in the environment by using manure in no-tillage.

5.4.3 Nitrate contamination in soils

Nitrate leaching in agricultural lands is closely related to water management, which drives the downward movement of nitrates out reach the of plants roots. Nitrate diffusion goes on very slowly without a appreciable water movement; on the other hand, nitrate transferring is only greater with increasing water movement. Simulations models, like DSSAT (performed in Brazil) and NLEAP (performed in Argentina) showed that downward movement of nitrates in soil profiles is consistently linked to irrigation scheduling and management.

The use of animal slurry is common in small farms of southern Brazil, mainly from pigs in agricultural areas. The risk of environmental contamination is greater without the control of runoff water, even on a no-tillage system.

In Buenos Aires (Argentina) region nitrate-N concentrations, were found to be higher than accepted level for safe drinking water of 10 mg L⁻¹ in 36% of sampled wells and 67% of samples had nitrate concentrations exceeding the background level of 5 mg L⁻¹. Temporal fluctuation of nitrate concentrations in the groundwater was attributed to seasonal fluctuations in recharges and plant growth.

5.4.4 Soil and water losses

No-tillage practices reduce significantly soil losses; however, the protection of soil surface by crop residues in no-till systems is not always followed by reduction in water losses. Soil losses were exponentially correlated with the soil cover percentage by crop residues and with the soil cover percentage by cover crops.

The effect of crop residues on the prevention of soil erosion, and the easiness of minimizing field operations, led some farmers to neglect complementary conservation practices and eliminate terracing systems, plant and seed along the largest field slope length. In addition to leaching of nutrients and pesticides, these factors yielded sheet and rill erosion even on sites where no-tillage system has been used.

A new technique, called *vertical mulching*, used in southern Brazil under a no-tillage system reduces water losses by runoff by 49.6 and 67.1%, as a function of rill spacings and rainfall intensities.

5.4.5 Human health

The present-day “classical” CA systems are still very dependent on biocides, which are both costly and risky, mainly in small-scale farms (family farms). Use of higher amounts of pesticides may also expose manipulators and sprayers more frequently, increasing the risk of human intoxication.

On the other side, CA has benefits for human health as a result of less drudgery (already discussed in this report) and because it results in a less powdery environment.

5.5 Soil microbiology

Soil microorganisms are the living and most active (labile) part of the soil organic matter (SOM). Modification of the soil environment by various crop management systems affects crop growth through influences on microbial activity and nutrient mineralization-immobilization processes. These modifications cause a disruption in the original soil microbiological equilibrium. The clearing and cultivation of undisturbed native areas is accompanied by a decline in soil organic matter.

Conventional tillage practices would cause disruption in soil aggregates and place crop residues in intimate contact with soil, leading to a more rapid decomposition than surface placement with no tillage. Conservation tillage practices, especially no-till, result in the accumulation of organic matter in the first few centimeters of the soil profile. On the other hand, carbon levels at lower depths are similar in both systems, or slightly higher under plow tillage. The stratification of SOM observed under no tillage systems associated with increased levels of soil moisture and smaller variations in temperature, due to soil cover, reflects directly upon the soil microbial community, which has its total microbial biomass and activity more concentrated in the first centimeters of the soil profile as well. For this reason the biological functioning of soils under no tillage systems is completely different of that found in soils under conventional tillage.

Understanding the biological functioning of soils along with the identification of early warning indicators of ecosystem stress is needed to provide strategies and approaches for land

resource managers and policymakers to promote long-term agricultural sustainability. Considering the ability of soil biological parameters being early and sensitive indicators of soil ecological stress or restoration, their determination is very important when we evaluate the impacts of different crop management practices on the soil properties.

State of the art in Brazil, Argentina and Bolivia: In Brazil and Argentina there are few studies regarding the effects of not-till and conventional till on the biological functioning of soils. In Bolivia these studies have not been carried out yet.

The microbiological data available for the Brazilian conditions can be divided in two groups of data set: one for the South Region (beginning in middle eighties) and other for the Cerrados region (more recent).

Among the studies carried out in Southern Brazil, increases in the soil microbial biomass at 0 to 10 cm depth were observed in soils under no till as compared to conventional till (Cattelan & Vidor, 1990; Carvalho, 1997; Cattelan et al., 1997; Hungria et al., 1997; Balota et al., 1998, Hungria et al., 2002). Moreover in the Parana state a reduction in the metabolic coefficient (qCO_2) associated with an increase in the soil microbial biomass was observed, indicating that in the long term no till might increase C sequestration in subtropical soils (Balota et al., 1998, 2004; Hungria et al., 2002). Balota et al. 2003, reported in Paraná, increases of 100%, 54% and 39% in microbial biomass C, N and S, respectively, for a clayey Oxisol under no tillage for 22 years, at the 0 to 5 cm depth. These authors also reported that the crop rotations had no effect on microbial biomass C and N. In relation to biological nitrogen fixation it was observed, in Paraná state, that the number of *Rhizobium* and *Bradyrhizobium* cells and the accumulation of flavonoids (nodulation genes inducers) were superior under no tillage (Hungria et al., 1997; Ferreira et al., 2000; Hungria, 2000). Bean and Sorghum nodulation were stimulated under no tillage resulting in higher yields (Voss & Sidiras, 1985; Hungria, 2000).

At the Cerrados region, the results showed that the impacts were more accentuated at the 0 to 5 cm depth. At this depth, the no-tillage (NT) system presented higher levels of phosphatase, arilsulfatase and β -glucosidase activities as compared to the conventional tillage (Mendes et al., 2003; Carneiro et al., 2004). These effects were related to the lack of soil mechanical preparation, fertilizers' placement, and to the accumulation of crop residues at the soil surface. In relation to the areas under native vegetation, located near the experiments, significant reductions in microbial biomass and phosphatase activity associated with increased levels of mineralizable carbon and activity levels of the soil enzyme β -glucosidase were observed in the agricultural areas (Mendes, 2002; Matsuoka et al., 2003 and Mendes et al., 2003).

Although the Argentinean studies are fewer than the Brazilian some of them showed a relationship between No Till and the increase of microbial biomass carbon in two types of soils: one of the central area of Argentina and other of the central west (a sandy soil) (Sagardoy, et al, 2002). Studies on the evolution in time of some microbiological parameters on soils cultivated under No Till, reported a general tendency for higher enzymatic activity under no-till and also a positive relation between the soil organic matter content, microbial biomass and the action of the soil enzymes urease and catalase (Montero, 2000).

The search for agricultural practices that are able to promote high yield, while maintaining the sustainability of the agro ecosystems has been one of the greatest challenges for the Research

& Development institutions. Many evidences show that the microbiological indicators are able to detect early changes in soil quality, as opposed to the chemical and physical parameters, which change in advanced stages of soil degradation. The understanding about the biological functioning of soils in different regions of Latin America is at its very beginning with the majority of these studies conducted in Brazil.

Considering the variety of methods to assess the microbiological status of a soil, studies are necessary in Brazil, Argentina and Bolivia to define what methods should be included in a data set of microbial indicators of soil quality. Another challenge consists in defining the critical values for each of the parameters of these data set, and to consider them in concert with soil chemical and physical measurements. In order to build up a vigorous and consistent data bank, regarding the biological functioning of soils, efforts will be necessary in order to standardize the procedures for soil sampling and also for the analytical procedures. The idea is that in the future, assessments of the biological status of a given soil could be made in a routine basis by using proper indicators that are at the same effective, simple, cheap and relatively rapid, allowing the farmer to evaluate the impacts of local management systems on soil quality.

Studies on the impacts of agricultural systems on soil microbial biodiversity also are extremely necessary, as well as the agronomic implications of increased microbial biomass and soil enzyme activities in areas under no-till.

6. Conclusions and Proposals

The revised evidence lead to the participants of the Latin America platform to come up with the following conclusions and proposals about what is known and what is not yet known about CA:

6.1 Technical changes

- Reduction in the intensity of soil disturbance;
- Maintenance of the crop residues on the soil surface;
- Changes in the seeding and planting processes;
- Changes in the liming and fertilization processes;
- Adoption of crop rotation systems;
- Changes on cover crop management;
- Integrated insects, diseases and weed management;
- Changes in the spraying technology and types of herbicides

6.2 Innovation processes

- Adaptation and development of equipment for planting/seeding and crop residues/cover crop management;
- Changes in the methodology for soil sampling and interpretation of soil analysis;
- Feasibility of and additional cropping season (“safrinha”);
- Feasibility of integrated crop and pastures systems;
- Incorporation of marginal areas for crop production;
- Suppression of contour planting and terracing;
- Re-design of mechanical measures for erosion control

6.3 Economic, social and cultural aspects

- Formation of farmers' and technicians' groups for the exchange of experiences
- Formation of research, technical assistance, dissemination and technology transfer, supported by farmers and private sector
- Increase in the farmers' technical knowledge
- Reduction of drudgery
- Increase in the life of agricultural equipment
- Decrease in power requirements
- Decrease in the operational costs
- Increase in the stability of production
- Economic feasibility of marginal areas for annual crops

6.4 Environmental aspects

- Reduction in soil erosion
- Increase in the use of pesticides
- Increase in the microbial biomass and in the biological activity at the surface layer
- Increase in the overall soil fertility
- Increase in the carbon sequestration
- Increase in water retention
- Reduction of environmental costs

6.5 Further research needs

- Impacts of the use of pesticides in CA on soil and water quality and on biodiversity;
- Definition of soil quality indicators for different agro ecosystems
- Definition of indicators of farming systems' sustainability
- Dynamics of soil organic matter in agro ecosystems
- Dynamics of soil nutrients in agro ecosystems
- Quantification of the potential of CA for carbon sequestration
- Studies of genesis and mitigation of soil compaction in CA areas
- Technology development for the increase of efficiency of liming and fertilization
- Development of CA systems less dependant on pesticides
- Development of cover crop more tolerant to abiotical stress and compatible to different farming systems
- Development of agricultural machinery for mixed cropping
- Comparative economic studies between CA and conventional agriculture
- Technology development for runoff management in CA
- Technology development for precision agriculture

6.6 Policies

- Technical assistance
- Research and development
- Credit
- Environmental legislation

References

- ALMEIDA, A.C.R. 2000. Uso associado de esterco líquido de suínos e plantas de cobertura de solo na cultura do milho. Tese de Mestrado. Santa Maria: UFSM. 114 p.
- AMADO, T.J.; FERNANDEZ, S.B.; MIELNICZUK, J. (1998) Nitrogen availability as affected by ten years cover crop and tillage systems in southern Brazil, *Brazilian Journal of Soil and Water Conservation* 5, 268 271.
- AMADO, T.J.; PONTELLI, C.B.; JÚNIOR, G.G.; BRUM, A.C.R.; ELTZ, F.L.F.; PEDRUZZI, C. 1999. Seqüestro de carbono em sistemas conservacionistas na Depressão Central de Rio Grande do Sul. In: V Reunión bienal de la red latinoamericana de agricultura conservacionista. p.42 43, Florianópolis, 57p.
- ANAPO (2004). No tillage rotation of crops, Agricultura Sostenible Program (PAS).
- ANAPO/CAO (2005) Document without publishing.
- ANDRIULO, A.; SASAL, C.; RIVERO, M.L. 2002. Los Sistemas de Producción Conservacionistas como Mitigadores de la Perdida de Carbono Orgánico del Suelo. En *Siembra Directa II*, J.L. Panigatti, D. Buschiazzi, H. Marelli (Editores). Ediciones Instituto Nacional de Tecnología Agropecuaria. Argentina. Buenos Aires. Págs. 17:28. ISBN 982-521-046-3.
- ARZENO, J.L. 1993. Siembra Directa en el NOA. En : II Congreso Nacional de SIEMBRA DIRECTA, Agricultura de fin de Siglo. Trabajos Presentados. Huerta Grande Córdoba, 8,9 y 10 de Septiembre de 1993. Págs. 117:133. AAPRESID Paraguay 777. Piso 8. Of. 4. 2000 Rosario República Argentina.
- BALOTA, E.L.; COLOZZI-FILHO, A.; ANDRADE, D.S.; DICK, R.P. Microbial biomass in soils under different tillage and crop rotation systems. *Biology and Fertility of Soils*, 38: 15-20, 2003.
- BALOTA, E.L.; COLOZZI-FILHO, A.; ANDRADE, D.S.; HUNGRIA, M. Biomassa microbiana e sua atividade em solos sob diferentes sistemas de preparo e sucessão de culturas. *Revista Brasileira de Ciência do Solo*, Campinas, v. 22, p.641-649, 1998.
- BARCELOS, A.A.; CASSOL, E.A .; DENARDIN, J.E. Infiltração de água em um latossolo vermelho-escuro sob condições de chuva intensa em diferentes sistemas de manejo. *Revista Brasileira de Ciência do Solo*, 23(1):35-43, 1999.
- BARTZ, H.R. Dinâmica dos nutrientes e adubação em sistemas de produção sob plantio direto. <http://www.rau.edu.uy/agro/eupp/siembra6.htm>. 2003.
- BAYER, C.; MARTIN NETO, L.; MIELNICZUK, J.; CERETTA, C.A. Effect of no till cropping systems on soil organic matter in a sandy clay loam Acrisol from Southern Brazil monitored by electron spin resonance and nuclear magnetic resonance. *Soil and Tillage Research*. 2000; 53(2): 95 104.
- BAYER, C.; MARTIN-NETO, L.; MIELNICZUK, J.; CERETTA, C.A. Effect of no-till cropping systems on soil organic matter in a sandy clay loam Acrisol from southern Brazil monitored by electron spin resonance and nuclear magnetic resonance. *Soil Till. Res.*, 53:95-104, 2000a.

BAYER, C.; MIELNICZUK, J. Inter-relações do manejo com as propriedades físicas e químicas de solos intensivamente cultivados. In: CARLESSO, R. Irrigação por aspersão no Rio Grande do Sul. Santa Maria, 2001. 165p.

BAYER, C.; MIELNICZUK, J.; AMADO, T.J.C.; MARTIN NETO, L.; FERNANDES, S.V. 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in Southern Brazil. Soil and Till. Res. 54:101-109.

BAYER, C.; MIELNICZUK, J.; MARTIN NETO, L. Efeito de sistemas de preparo e de cultura na dinâmica da matéria orgânica e na mitigação das emissões de CO₂. Revista Brasileira de Ciência do Solo. 2000; 24(3): 599-607.

BELLOSO, C. 1999. Análisis y Manejo del Sistema de Producción con Información Georeferenciada. En Manuales del VII Congreso Anual de AAPRESID. Mar del Plata 18 al 20 de Agosto 1999. Tomo II. Págs. 183:188. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.

BOLINDER, M.A.; ANGERS, D.A.; GIROUX, M.; LAVERDIÈRE, M.R. Estimating C inputs retained as soil organic matter from corn (Zea mays L.). Plant Soil, 215:85-91, 1999.

BORLETTO, J.M. 2001. Franjas con Distintos Tratamientos de Fertilización. En, Resúmenes del primer Seminario AAPRESID para Estudiantes. Págs. 87:93. AAPRESID. Paraguay 777, 8vo Piso. Of. 4. 2000 Rosario. Prov. de Santa Fé. República Argentina.

BRAGACHINI, M. 1999. Agricultura de Precisión para Aumentar la Productividad. En Manuales del VII Congreso Anual de AAPRESID. Mar del Plata 18 al 20 de Agosto 1999. Tomo II. Págs. 265:272. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.

BRAGACHINI, M.T. 2000. Manejo Sitio Específico de los Cultivos, Agricultura de Precisión Presente y Futuro. En El Desafío es Innovar. Proceedings del VIII Congreso Anual de AAPRESID. Mar del Plata 16 al 18 de Agosto 2000. Tomo II. Págs. 59:65.

CAIRES, E.F. Manejo da fertilidade do solo no sistema plantio direto: experiência no estado do Paraná. In: REUNIÃO BRASILEIRA DE FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS, 24, 2000. Santa Maria. Fertbio 2000. Santa Maria: SBCS, 2000. CD-ROM.

CALEGARI, A.; FERRO, M.; GRZESTUK, F.; JACINTO JR., L. Plantio direto e rotação de culturas. Experiência em Latossolo Roxo. IAPAR-COCAMAR-ZENECA. Maringá, 1992. 1 v.

CAMPERO, M.; WALL, P.C. 1999. Strubble effects in the soil surface on the hydric balance and the yield. Memories, III National Meeting of Wheat and Smaller Cereals. Cochabamba, Bolivia 115-121 p.

CARMONA, M. 2003. La Rotación de Cultivos, El porque de su escasa adopción, la relación con la Siembra Directa y sus efectos positivos para el agrosistema y el manejo de enfermedades. En: "La Hora Del Empowerment". Proceedings del XI Congreso Anual de AAPRESID. Tomo I. Págs. 227:235. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000 Rosario. República Argentina.

CARMONA, M. 2003. La Rotación de Cultivos, El porque de su escasa adopción, la relación con la Siembra Directa y sus efectos positivos en el agro ecosistema y el manejo de las enfermedades. En "Rotaciones en Siembra Directa". Revista Técnicas de la Asociación

Argentina de Productores en Siembra Directa. Diciembre del 2003. Págs. 37:42. AAPRESID Calle Paraguay 777. Piso 8. Of. 4. 2000 Rosario. Republica Argentina.

CARNEIRO, R.G; MENDES, I.C; LOVATO, P.E; CARVALHO, A.M. Indicadores biológicos associados ao ciclo do fósforo em solos de Cerrado sob plantio direto e plantio convencional Pesquisa Agropecuária Brasileira, Brasília, v.39, n.7 p. 661-669, 2004.

CARPENEDO, V.; MIELNICZUK, J. Estado de agregação de Latossolos Roxos submetidos a diferentes sistemas de manejo. R. bras. Ci. Solo, Campinas – SP, 14: 99-105, 1990.

CARVALHO, Y. Densidade e atividade dos microrganismos do solo em plantio direto e convencional, na região de Carambeí – PR. 1997. (Mestrado em Agronomia). Agronomia, Universidade Federal do Paraná, Curitiba.

CASAS, R. 2002. El Aumento de la Materia Organica en Suelos Argentinos – El Aporte de la Siembra Directa. En “XI Congreso Nacional de AAPRESID - Darse Cuenta”. Proceedings del XI Congreso Anual de AAPRESID. Tomo I. Págs. 155:168. AAPRESID Paraguay 777. Piso 8. Of. 4. 2000 Rosario. República Argentina.

CASTRO FILHO, C.; LOURENÇO, A.; GUIMARÃES, M. de F.; FONSECA, I.C.B. (2002) Aggregate stability under different soil management systems in a red latosol of Paraná, Brazil, Soil & Tillage Research 65, 45 51.

CASTRO FILHO, C.; MUZILLI O.; PODANOSCHI, A.L. (1998) Estabilidade dos agregados e sua relação com o teor de carbono orgânico num Latossolo Roxo distrófico, em função de sistemas de plantio, rotação de culturas e métodos de preparo das amostras, Revista Brasileira de Ciência do Solo 22, 527 538.

CATTELAN, A.J.; GAUDÊNCIO, C.A.; SILVA, T.A. Sistemas de culturas em plantio direto e os microrganismos do solo, na cultura da soja, em Londrina. Revista Brasileira de Ciência do Solo, Campinas, v.21, p.293-301, 1997.

CATTELAN, A.J.; VIDOR, C. Sistemas de culturas e a população microbiana do solo. Revista Brasileira de Ciência do Solo, Campinas, v.14, p.125-132, 1990.

CERETTA, C.A.; DURIGON, R.; BASSO, C.J. et al. 2003. Características químicas de solo sob aplicação de esterco líquido de suínos em pastagem natural. Pesq. agropec. bras., Jun/2003, v. 38, n. 6. p. 729-735.

CHESTA, M.O. 2001. Experiencia en diez años de Siembra Directa en Suelos Vertisoles. En, Resúmenes del primer Seminario AAPRESID para Estudiantes. Págs. 94:96. AAPRESID. Paraguay 777, 8vo Piso. Of. 4. 2000 Rosario. Prov. de Santa Fé. República Argentina.

CORAZZA, E.J.; SILVA, J.E.; RESCK, D.V.S.; GOMES, A.C. (1999) Comportamento de diferentes sistemas de manejo como fonte e depósito de carbono em relação a vegetação de Cerrado, Revista Brasileira de Ciência do Solo 23, 425 432.

DENARDIN, J.E.; KOCHHANN, R.A.; DENARDIN, N.D. Adensamento e compactação em latossolos: fatos e hipóteses. In: WORLD CONGRESS ON CONSERVATION AGRICULTURE, 2, 2003, Iguassu falls. Producing in harmony with nature: extended summary e posters =Fóz do Iguaçu: Federação Brasileira de Plantio Direto na Palha; Confederación de Asociaciones Americanas para la Agricultura Sustentavel, 2003. p. 482-485.

DENARDIN, J.E.; KOCHHANN, R.A.; FAGANELLO, A.; SATTLER, A. Evolução da área cultivada sob sistema plantio direto no Rio Grande do Sul. Passo Fundo, Embrapa Trigo, 2001. 32p. (Embrapa Trigo. Documentos, 29).

DERPSCH, R. 1997. Importancia de la Siembra Directa, para obtener la sustentabilidad de la producción agrícola. In Proceedings of the V AAPRESID annual No Till Conference. Pág. 153:176. AAPRESID, Calle Paraguay 777, Piso 8. Of. 4. 2000 Rosario, República Argentina.

DERPSCH, R.; CALEGARI, A. Plantas para adubação verde de inverno. Londrina: IAPAR, 1992. 80p. (IAPAR, Circular, 73).

DERPSCH, R.; ROTH, C. H.; SINDIRAS, N.; KÖPKE, C. V. Controle da erosão no Paraná, Brasil: Sistemas de cobertura do solo, plantio direto e preparo conservacionistas do solo. Londrina: GTZ - IAPAR, 1991, 272p.

DERPSCH, R.; ROTH, C.H.; SIDIRAS, N.; KÖPKE, U. Importância da rotação de culturas. In: DERPSCH, R.; ROTH, C.H.; SIDIRAS, N.; KÖPKE, U. Controle da erosão no Paraná, Brasil: sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo. Eschborn: GTZ; IAPAR, 1991. p.147-164.

DÍAZ-ZORITA, M.; GROVE, J.H. 2002. Rotaciones de Cultivos en Siembra Directa y las propiedades de Suelo en la Pampa Arenosa. En Siembra Directa II, J.L. Panigatti, D. Buschiazzo, H. Marelli (Editores). Ediciones Instituto Nacional de Tecnología Agropecuaria. Argentina. Buenos Aires. Págs. 235:238. ISBN 982-521-046-3.

EKBOIR, J. 2003. Sistemas de Innovación Política y Tecnológica. Siembra Directa en MERCOSUR. En “ XI Congreso Anual de AAPRESID – Darse Cuenta”. Proceedings del XI congreso Anual de AAPRESID. Tomo I “Actas”. Págs. 99-109. AAPRESID Paraguay 777. Piso 8. Of. 4. 2000 Rosario Rep Argentina.

ELTZ, F.L.F.; PEIXOTO, R.T.G.; JASTER, F. Efeitos de sistemas de preparo do solo nas propriedades físicas e químicas de um Latossolo Bruno Álico. R. bras. Ci. Solo, Campinas, 13 : 259-267, 1989.

FELLER, C.; BEARE, M.H. Physical control of soil organic matter dynamics in the tropics. Geoderma, 79:69-117, 1997.

FERRARI, M. 1998. La Siembra Directa y el rendimiento de los Cultivos en la Pampa Húmeda”. En Panigatti J.L. y otros. Editores “Siembra Directa”. Págs. 191:196. Editorial Hemisferio Sur. Pasteur 743 – 1028 Buenos Aires. República Argentina. ISBN 950-504-551-4.

FERREIRA, M.C.; ANDRADE, D.S.; CHUEIRE, L.M.O.; TAKEMURA, S.M.; HUNGRIA, M. Effects of tillage method and crop rotation on the population sizes and diversity of bradyrhizobia nodulating soybean. Soil Biology & Biochemistry, Oxford, v.32, p.627-637, 2000.

FERRI, M.V.W., VIDAL, R.A., GOMES, J. et al. 2002. Atividade do herbicida acetochlor em solo submetido à semeadura direta e ao preparo convencional. Pesq. agropec. bras., Dez 2002, vol.37, no.12, p.1697-1703.

FERRI, M.V.W.; PERALBA, M.C.R.; ELTZ, F.L. et al. 2004. Efeito da cobertura do solo nas perdas por erosão hídrica do herbicida imazethapyr. Boletim Informativo da Sociedade Brasileira da Ciência das Plantas Daninhas (SBCPD), v. 10 (supl.), p.94. 2004.

- FERRI, M.V.W.; PERALBA, M.C.R.; ELTZ, F.L. et al. 2004. Efeito do preparo do solo sobre o transporte dos herbicidas alachlor e atrazina por erosão hídrica. Boletim Informativo da Sociedade Brasileira da Ciência das Plantas Daninhas (SBCPD), v. 10 (supl.), p.93. 2004.
- FONTANETTO, H.; SÉLLER, O. 2001(b). Efecto de Diferentes Secuencias de Cultivos en Siembra Directa Continua. En Siembra Directa en el Cono Sur: Coordinador Díaz Rosello, Roberto. Págs. 269:273. PROCISUR. Montevideo, Uruguay. ISBN 92-9039-515 X.
- FRANCHINI, J.C.; MALAVOLTA, E.; MIYAZAWA, M.; PAVAN, M.A. Alterações químicas em solos ácidos após a aplicação de resíduos vegetais. R. Brás. Ci. Solo., Viçosa, 23(3):533-542, 1999.
- FREIRE, F.M.; VASCONCELLOS, C.A.; FRANÇA, G.E. de. Manejo da fertilidade do solo em sistema plantio direto. Informe Agropecuário, Belo Horizonte, 22(208):49-62, 2000.
- FREIXO, A.A.; MACHADO, P.L.O. de A.; SANTOS, H.P. dos; SILVA, C.A.; FADIGAS, F. de S. Soil organic carbon and fractions of a Rhodic Ferralsol under the influence of tillage and crop rotation systems in southern Brazil. Soil and Tillage Research. 2002; 64(3/4): 221 230.
- GHIO, H. 1999. Producción en Agricultura Continua. En Manuales del VII Congreso Anual de AAPRESID. Mar del Plata 18 al 20 de Agosto 1999. Tomo II. Págs. 197:210. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.
- GUDELJ, V.; otros. 2002. 16 Años de Experiencias de Fertilización en Siembra Directa. Ensayo de Larga Duración. En “Los Rastrojos y Mas allá de los Rastrojos”. Manual del X Congreso Anual de AAPRESID. Tomo I. Págs. 239:256. AAPRESID Paraguay 777. Piso 8. Of 4. 2000 Rosario. República Argentina.
- HERNANI, L.C.; SALTON, J.C.; FABRÍCIO, A.C.; DEDECEK, R.; ALVES JR., M. Perdas por erosão e rendimentos de soja e de trigo em diferentes sistemas de preparo de um Latossolo Roxo de Dourados (MS). Rev. Bras. Ci. Solo, 21(4):667-676, 1997.
- HUNGRIA, M.; ANDRADE, D.S.; BALOTA, E.L.; COLOZZI-FILHO, A. Importância do sistema de semeadura direta na população microbiana do solo. Londrina: EMBRAPA-CNPSO, 1997. 9p. (EMBRAPA-CNPSO. Comunicado Técnico, 56).
- HUNGRIA, M.; CAMPO, R.J.; FRANCHINI, J.C.; CHUEIRE, L.M.O.; MENDES, I.C.; ANDRADE, D.S.; COLOZZI-FILHO, A.; BALOTA, E.L.; LOUREIRO, M.F. Microbial quantitative and qualitative changes in soils under different crops and tillage management systems in Brazil. In: INTERNATIONAL TECHNICAL WORKSHOP ON BIOLOGICAL MANAGEMENT OF SOIL ECOSYSTEMS FOR SUSTAINABLE AGRICULTURE. Program, abstracts and related documents... Londrina: Embrapa Soja, 2002. p.76.
- KAMINSKI, J. coord. Uso de corretivos da acidez do solo no plantio direto. Pelotas: SBSC- Núcleo Regional Sul, 2000. 123p. (SBSC- Núcleo Regional Sul. Boletim Técnico, 4).
- KIEHL, E. J. Manual de edafologia. São Paulo. Ed. Agronômica Ceres. 264 p. Cap. 10: Estrutura, p. 145 – 160. 1979.
- KLUTHCOUSKI, J.; FANCELLI, A.L.; DOURADO-NETO, D. Manejo do solo e o rendimento de soja, milho, feijão e arroz em plantio direto. Scientia Agrícola, 57(1):97-104, 2000.
- KOCHHANN, R.A. Alterações das características físicas, químicas e biológicas do solo sob sistema plantio direto. In: CONFERÊNCIA ANUAL DE PLANTIO DIRETO, 1. Passo Fundo, RS. Anais... Passo Fundo, 1996. p. 17-25.

LANDERS, J.N. Fascículo de experiências de plantio direto no Cerrado. Associação de Plantio Direto no Cerrado, 1995. 259p.

LIMA, V.C.; LIMA, J.M.C.; EDUARDO, B.J.P.; CERRI, C.C. (1994) Conteúdo de carbono e biomassa microbiana em agrossistemas: comparação entre métodos de preparo do solo, *Agrárias Curitiba* 13, 297-302.

LOPES, A.S.; WIETHÖLTER, S.; GUIMARÃES, L.R.; SILVA, C.A. Sistema plantio direto: bases para o manejo da fertilidade do solo. São Paulo, ANDA, 2004. 110p.

MACHADO, P.L.O. de A.; SILVA, C.A. Soil management under no tillage systems in the tropics with special reference to Brazil. *Nutrient Cycling in Agroecosystems*. 2001; 61(1/2): 119-130.

MATSUOKA, M.; MENDES, I.C.; LOUREIRO, M.F. Biomassa microbiana e atividade enzimática em solos sob vegetação nativa e sistemas agrícolas anuais e perenes na região de Primavera do Leste/MT. *Revista Brasileira de Ciência do Solo*, Viçosa, v.27, p. 425-433, 2003.

MENDES, I. C. Impactos de sistemas agropecuários na atividade enzimática e biomassa microbiana dos solos de Cerrado. In: II CONGRESSO BRASILEIRO DE SOJA /MERCOSOJA 2002, 2002, Foz do Iguaçu. Anais do II Congresso de Soja: Perspectivas do agronegócio da soja. Londrina: Documentos/Embrapa Soja, 2002. p. 246-257.

MENDES, I. C.; SOUZA, L. V.; RESCK, D. V. S.; GOMES, A. C. Propriedades biológicas em agregados de um LE sob plantio convencional e direto no Cerrado. *Revista Brasileira de Ciência do Solo*, Viçosa, v. 27, p. 435-443, 2003.

METAY, A. (2004) Influence of no tillage and cover plants on N₂O production and emission from soils in the Cerrados (Brazil), International conference on greenhouse gas emissions from agriculture, mitigations options and strategies, Leipzig, Germany, February 2004, Congress communications.

MICHELENA, R.; otros. 2001. Fertilidad y Propiedades Físicas de Diferentes Suelos en Siembra Directa. En: Los Desafíos de la Agricultura en un Complejo Mundo Globalizado. Proceedings del IX Congreso Anual de AAPRESID. Mar del Plata 16 al 18 de Agosto 2000. Tomo I. Págs. 177:186. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.

MILLER, R.M.; JASTROW, J.D. Hierarchy of root and mycorrhizal fungal interactions with soil aggregation. *Soil Biol. Biochem.*, 22:579-584, 1990.

MIYASAKA, S.; MEDINA, J.C. A soja no Brasil. Campinas, SP, ITAL. 1062p. 1981.

MIYAZAWA, M.; PAVAN, M.A.; CALEGARI, A. efeito de material vegetal na acidez do solo. *R. Brás. Ci. Solo*, Campinas, 17(3):411-416, 1993.

MIYAZAWA, M.; PAVAN, M.A.; FRANCHINI, J.C. Resíduos vegetais : influência na química de solos ácidos. In: SIMPÓSIO SOBRE FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS NO SISTEMA PLANTIO DIRETO, 1., Ponta Grossa, 2000. Anais... Ponta Grossa:Associação dos Engenheiros Agrônomos dos Campos gerais, 2000. p.82-94.

MONTERO, F.; SAGARDOY, M. 2000. Estudios Microbiológicos en Suelos Cultivados bajo Siembra Directa en Argentina. . En El Desafío es Innovar. Proceedings del VIII Congreso Anual de AAPRESID. Mar del Plata 16 al 18 de Agosto 2000. Tomo I. Págs. 217-222.

AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.

MUNDSTOCK, C.M. A evolução da genética e da tecnologia da cultivo de milho no Rio Grande do Sul. Cláudio Mário Mundstock, Porto Alegre: Departamento de Plantas de Lavoura da Universidade Federal do Rio Grande do Sul: Evangraf, 2004. 34p.

MUZILLI, O. Influência do sistema de plantio direto, comparado ao convencional, sobre a fertilidade da camada arável do solo. R. Bras. Ci. Solo, 7(1):95-102, 1983.

MUZILLI, O. Manejo da matéria orgânica no sistema plantio direto: a experiência no Estado do Paraná. <<http://www.ppifar.org/ppiweb/pbrazil.nsf>. 2003.

MUZILLI, O.; VIEIRA, M.J.; OLIVEIRA, E.L. Avaliação dos sistemas de plantio direto e convencional em diferentes sucessões de culturas. Londrina, PR: IAPAR – Programa Recursos Naturais. Relatório Técnico Anual, 1994. 1 v.

OLIVEIRA, G.C. DIAS JUNIOR, M.S.; RESCK, D.V.S.; CURI, N. Caracterização química e físico hídrica de um Latossolo Vermelho após vinte anos de manejo e cultivo do solo. Revista Brasileira de Ciência do Solo. 2004; 28(2): 327-336.

PAZ, C.E. (1999), Program of Agricultura Sostenible (PAS) in Santa Cruz of the mountain range, published in memories of III National Meeting of Wheat and Smaller cereals, p. 185 – 189.

PEIRETTI, R.A. 1998. La Siembra Directa y las rotaciones como estrategia de crecimiento empresarial. En Proceedings del VI Congreso anual de AAPRESID. AAPRESID, Paraguay 777. 8vo Piso. Of. 4. 2000 Rosario. Republica Argentina. Págs. 67-123.

PEIRETTI, R.A. 2003. The CAAPAS actions and the development of the MOSHPA. In Proceedings of the II World Congress on Conservation Agriculture. Vol. I. Págs. 127-128. Printed by Federacao Brasileira do Plantio Directo Na Phala. Rua 7 de Setembro, 800 - Sala 301 A - , CEP 84350-210 – Ponta Grossa – Paraná – Brasil.

PEIRETTI, R.A. 2004. The No Till Cropping System and its evolution toward the achievement of the MOSHPA Model Principles. In Proceedings of the World Soybean Congress- Foz de Iguazú, Brazil, March 1-5, 2004. 282-290. Copyrighted by EMBRAPA Brazil. ISBN 85-7033-004-9 . pp. 282-290

PEIXOTO, R.T.; STELLA, L.M.; MACHULEK JUNIOR, A.; MEHL, H.U.; BATISTA, E.A. (1999) Distribuição das frações granulométricas da matéria orgânica em função do manejo do solo, in: Anais 3º Encontro brasileiro sobre substâncias húmicas, Santa Maria, Brasil, pp. 346-348.

PORT, O.; AITA, C.; GIACOMINI, S.J. 2003. Perda de nitrogênio por volatilização de amônia com o uso de dejetos de suínos em plantio direto. Pesq. agropec. bras. Jul/2003, v. 38, n. 7. p. 857-865.

PROTRIGO (Investigation and Technology Transference for wheat crop National Program) Secend phase. (2002). Technical studies about the Valleys region, Bolivia. ANNEXED 74.

PROTRIGO (Investigation and Technology Transference for Wheat National Program) 2002, Final Design, Second Phase. Santa Cruz, Bolivia. 15-20 p.

PURICELLI, C.A.; ECHEVERRIA N.E.; PELTA H.R.2002. Cambio en Algunas Propiedades del Suelo Bajo Siembra Directa. En Siembra Directa II, J.L. Panigatti, D.

Buschiazzo, H. Marelli (Editores). Ediciones Instituto Nacional de Tecnología Agropecuaria. Argentina. Buenos Aires. Págs. 225:233. ISBN 982-521-046-3.

QUIROGA, A.; ORMEÑO, O.; OTAMENDI, H. 1998. La Siembra Directa y el Rendimiento de los Cultivos en la Región Semiárida Pampeana Central”. En Panigatti J.L. y otros. Editores “Siembra Directa”. Págs. 237:43. Editorial Hemisferio Sur. Pasteur 743 – 1028 Buenos Aires. República Argentina. ISBN 950-504-551-4.

REINERT, D. J.; MUTTI, L. S. M.; ZAGO, A. ; AZOLIN, M. A.; D. HOFFMANN, C. L. Efeito de diferentes métodos de preparo do solo sobre a estabilidade de agregados em solo Podzólico Vermelho Amarelo. R. Cent. Ci. Rurais., Santa Maria, 14: 19-25, 1984.

RESCK, D.V.S.; VASCONCELLOS, C.A.; VILELA, L.; MACEDO, M.C.M. (2000) Impact of conversion of Brazilian Cerrados to cropland and pastureland on soil carbon pool and dynamics, in: Lal R., Kimble J.M., Stewart B.A. (Eds.), Global climate change and tropical ecosystems, Advances in Soil Science, CRC Press Boca Raton, pp 169 196.

RHEINHEIMER, D; ANGHINONI, I. Distribuição do fósforo inorgânico em sistemas de manejo do solo. Pesquisa Agropecuária Brasileira. Brasília, 36(1):151-160, 2001.

RIEZEBOS, H.T.H.; LOERTS, A.C. (1998) Influence of land use change and tillage practice on soil organic matter in southern Brazil and eastern Paraguay, Soil & Tillage Research 49, 271 275.

RODRIGUES, B.N.; FORNAROLLI, D. A.; LIMA, J. et al. 2000.Comportamento de herbicidas pré-emergentes aplicados sobre cobertura morta em plantio direto. In: Congresso Brasileiro da Ciência das Plantas Daninhas, XXII. Foz do Iguaçu. 2000. Resumos. Londrina:SBCPD. p.380.

ROSCOE, R.; BUURMAN, P. (2003) Tillage effects on soil organic matter in density fractions of a Cerrado Oxisol, Soil & Tillage Research 70, 107 119.

ROSSO, H. 1992. Nuestra Evolución Hacia la Siembra Directa. En : Primer Congreso Interamericano de Siembra Directa Trabajos Presentados. Villa Giardino (Córdoba) 25 al 28 de Marzo de 1992. Págs. 28:33. AAPRESID Paraguay 777. Piso 8. Of. 4. 2000 Rosario Rep Argentina.

ROSSO, H. 2001. Siembra Directa: Por que el Cambio?. En, Resúmenes del primer Seminario AAPRESID para Estudiantes. Págs. 33:35. AAPRESID. Paraguay 777, 8vo Piso. Of. 4. 2000 Rosario. Prov. Snata Fe. República Argentina.

RUEDELL, J. Plantio direto na região de Cruz Alta. Cruz Alta: FUNDACEP/FECOTRIGO, 1995. 134P.

RUFFO, M.L. 2003(b). Factibilidad de Inclusión de Cultivos de Cobertura en Argentina. En: “La Hora Del Empowerment”. Proceedings del XI Congreso Anual de AAPRESID. Tomo I. Págs. 133:138. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000 Rosario. República Argentina.

RUFFO, M.L.; PARSONS, A.T. 2003(a). Cultivos de Coberturas en Rotaciones Agrícolas Mixtas. En “Rotaciones en Siembra Directa”. Revista Técnicas de la Asociación Argentina de Productores en Siembra Directa. Diciembre del 2003. Págs. 31:35. AAPRESID Calle Paraguay 777. Piso 8. Of. 4. 2000 Rosario. Republica Argentina.

SÁ, J.C. de M. Manejo da fertilidade do solo no plantio direto. Castro, PR: Fundação ABC, 1993. 96p.

- SÁ, J.C. de M. Manejo da fertilidade do solo no sistema plantio direto. In: SIQUEIRA, J.O.; MOREIRA, F.M.S.; LOPES, A.S.; GUILHERME, L.R.G.; FAQUIM, V.; FURTINI NETO, A.E.; CARVALHO, J.G. (eds). Inter-relação fertilidade, biologia do solo e nutrição de plantas. Lavras; SBCS, 1999. p.267-319.
- SÁ, J.C. de M. Manejo de nitrogênio na cultura de milho no sistema plantio direto. Passo Fundo: Aldeia Norte, 1996. 23p.
- SÁ, J.C. de M. Plantio direto: transformações e benefícios ao agroecossistema. In: CURSO SOBRE MANEJO DO SOLO NO SISTEMA PLANTIO DIRETO, 1995, Castro, Fundação ABC, Anais..., 1995a. p.9-20.
- SÁ, J.C. de M. Fósforo: resposta das culturas de milho, trigo e soja no sistema plantio direto. In: CURSO SOBRE MANEJO DO SOLO NO SISTEMA PLANTIO DIRETO, 1995, Castro, Fundação ABC, Anais..., 1995b. p.256-263.
- SÁ, J.C.M. (2001) Dinâmica da matéria orgânica do solo em sistemas de manejo convencional e plantio direto no estado do Paraná, PhD Thesis, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba.
- SAGARDOY, M.A.; otros. 2002. Influencia del Sistema de Siembra Directa sobre los Microorganismos del Suelo. En Siembra Directa II, J.L. Panigatti, D. Buschiazzi, H. Marelli (Editores). Ediciones Instituto Nacional de Tecnología Agropecuaria. Argentina. Buenos Aires. Págs. 69:82. ISBN 982-521-046-3.
- SALET, R.L. Toxidez de alumínio no sistema plantio direto. Porto Alegre: Universidade Federal do rio Grande do Sul, 1998. 117p. (Tese de Doutorado).
- SALTON, J.C.; FABRÍCIO, A.C.; MACHADO, L.A.Z.; MELHO FILHO, G.; URCHEI, M.A.; OLIVEIRA, H.; BROCH, D.L.; FREITAS, P.L. de; MUSSURY, R.M.; RICHETTI, A. Impacto ambiental de sistemas intensivos de produção de grãos e de carne bovina na região oeste do Brasil. In: ROSSELLO, R. coord. Siembra Directa en el Cono Sur. Montevideo: PROCISUR, 2001. p.43-53.
- SALTON, J.C.; HERNANI, L.C.; FONTES, C.Z. Sistema plantio direto: o produtor pergunta, a Embrapa responde. Brasília: Embrapa-SPI; Dourados: Embrapa-CPAO, 248p, 1998. (Coleção 500 perguntas, 500 respostas).
- SANTOS, H.P. dos. Efeito da rotação de culturas no rendimento, na eficiência energética e econômica do trigo, em plantio direto. 136p. 1992. Tese (Doutorado) – Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Piracicaba.
- SANTOS, H.P. dos; AMBROSI, I.; LHAMBY, J.C.B.; CARMO, C. do. Lucratividade de sistemas de manejo de solo e de rotação e sucessão de culturas. Ciência Rural, Santa Maria, 34(1):97-103, 2004.
- SANTOS, H.P. dos; IGNACZAK, J.C.; LHAMBY, J.C.B.; CARMO, C. do. Conversão e balanço energético de sistemas de manejo de solo e de rotação de culturas. Pesq. Agrop. Gaúcha, 9(1-2):113-120, 2003a.
- SANTOS, H.P. dos; LHAMBY, J.C.B.; LIMA, M.R. de. Efeito de métodos de preparo de solo no inverno e de rotação de culturas no rendimento de grãos de soja. Pesq. Agrop. Gaúcha, 7(1):69-76, 2001.

SANTOS, H.P. dos; LHAMBY, J.C.B.; PRESTES, A.M.; LIMA, M.R. de. Efeito de manejos de solo e de rotação de culturas de inverno no rendimento e doenças de trigo. *Pesq. agropec. bras.*, Brasília, 35(12):2355-2361, 2000.

SANTOS, H.P. dos; REIS, E.M. Rotação de culturas. In: SANTOS, H.P. dos; REIS, E.M. Rotação de culturas em plantio direto. Passo Fundo: Embrapa Trigo, 2001. p.12-132.

SANTOS, H.P. dos; REIS, E.M.; DERPSCH, R. Rotação de culturas. In: EMBRAPA. Centro Nacional de Pesquisa de Trigo. Plantio direto no Brasil. Passo Fundo: Embrapa-CNPT; FUNDACEP FECOTRIGO; Fundação ABC; Aldeia Norte, 1993. p.85-103.

SANTOS, H.P. dos; REIS, E.M.; LHAMBY, J.C.B.; SANDINI, I. Características agronômicas e controle de doenças radiculares da cevada, em sistema plantio direto em rotação com outras culturas. *Pesquisa Agropecuária Brasileira*, Brasília. 30(11):1297-1303, 1995.

SANTOS, H.P. dos; TOMM, G.O. Disponibilidade de nutrientes e teor de matéria orgânica em função de sistemas de cultivo e de manejo de solo. *Ciência Rural*, Santa Maria, 33(3):477-486, 2003.

SANTOS, H.P. dos; TONET, G.E.L. Efeito de sistemas de produção incluindo culturas produtoras de grãos e pastagens anuais de inverno e de verão no rendimento de grãos e em outras características agronômicas de soja, sob sistema plantio direto. In: EMBRAPA, Centro Nacional de Pesquisa de Trigo. Soja: resultados de pesquisa do Centro Nacional de Pesquisa de Trigo, 1996/97. Passo Fundo, 1997. p.88-93. (Embrapa-CNPT. Documentos, 35).

SEGUY, L.; BOUZINAC, S.; PACHECO, A.; CARPENEDO, V.; SILVA, V. de. Perspectiva da fixação da agricultura na região Centro Oeste de Mato Grosso. EMPA-MT, EMBRAPA-CNPAP, CIRAD-IRAT, 1988.

SEGUY, L.; BOUZINAC, S.; TRENTINI, A.; CÔTES, N. A. L'agriculture brésilienne des fronts pionniers. *Agriculture et Développement*, Montpellier, 12 :2-61, 1996.

KLUTHCOUSKI, J.; FANCELLI, A.L.; DOURADO-NETO, D. Manejo do solo e o rendimento de soja, milho, feijão e arroz em plantio direto. *Scientia Agrícola*, 57(1):97-104, 2000.

SEGUY, L.; BOUZINAC, S. Direct seeding on plant cover: sustainable cultivation of our planet's soils. *Conservation agriculture, a worldwide challenge First World Congress on conservation agriculture*, Madrid, Spain, 2001. Volume 1: keynote contributions. 2001; 85 91.

SEGUY, L.; BOUZINAC, S.; MARONEZZI, A.C. Cropping systems and organic matter dynamics. Eds: Garcia Torres, L.; Benites, J.; Martinez Vilela, A. *Conservation agriculture, a worldwide challenge First World Congress on conservation agriculture*, Madrid, Spain, 1 5 October, 2001 Volume 2: offered contributions. 2001; 301 305.

SEGUY, L.; BOUZINAC, S.; SCOPEL, E.; RIBEIRO, M.F.S. 2003. New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks. In "Producing in harmony with nature", II World congress on Sustainable Agriculture proceedings, Iguaçu, Brazil.

SEGUY, L.; BOUZINAC, S.; SCOPEL, E.; SANTOS, M.F.R. dos. 2003. New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks. In "Producing in harmony with nature", II World congress on Sustainable Agriculture proceedings, Iguaçu, Brazil.

nature”, II World congress on Sustainable Agriculture proceedings, Iguaçu, Brazil, 10 15 of August.

SHAMOOT, S.; MacDONALDS, L.; BARTHOLOMEW, W.V. Rhizodeposition of organic matter debris in soil. *Soil Sci. Soc. Am. J.*, 32:817-820, 1968.

SIDIRAS, N.; PAVAN, M.A. Influência do sistema de manejo do solo no seu nível de fertilidade. *R. Bras. Ci. Solo*, Campinas, 9(3):249-254, 1985.

SILVA, I.F.; MIELNICZUK, J. Ação do sistema radicular de plantas na formação e estabilização de agregados de solo. *R. Bras. Ci. Solo*, 21:113-117, 1997.

SILVEIRA, P.M. da; SILVA, O. F. da; STONE, L.F.; SILVA, J.G. da. Efeitos do preparo do solo, plantio direto e de rotações de culturas sobre o rendimento e a economicidade do feijoeiro irrigado. *Pesq. agropec. bras.*, Brasília, 36(2):257-263, 2001.

SILVEIRA, P.M.; CUNHA, A.A. Variabilidade de micronutrientes, matéria orgânica e argila de um Latossolo submetido a diferentes sistemas de preparo. *Pesquisa Agropecuária Brasileira*, 37(9):1325-1332, 2002.

SISTI, C.P.J.; SANTOS, H.P. dos; KOHHANN, R.A.; ALVES, B.J.R.; URQUIAGA, S.; BODDEY, R.M. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. *Soil and Tillage Research*. 2004; 76(1): 39 58.

SIX, J.; ELLIOTT, E.T.; PAUSTIAN, K. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J.*, 63:1350-1358, 1999.

SOCIEDADE BRASILEIRA DE CIÊNCIA DO SOLO. Núcleo Regional Sul. Comissão de Química e Fertilidade do Solo. Manual de adubação e de calagem para os estados do Rio Grande do Sul e de Santa Catarina. 10. ed. Porto Alegre, 2004. 394 p.

SOUSA, D.M.G.; LOBATO, E. Manejo da fertilidade do solo no sistema plantio direto: experiência no cerrado. In: REUNIÃO BRASILEIRA DE FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS, 24, 2000. Santa Maria. Fertbio 2000. Santa Maria: SBCS, 2000. CD-ROM.

STONE, L.F.; MOREIRA, J.A.A. Efeitos de sistema de preparo do solo no uso da água e na produtividade do feijoeiro. *Pesquisa Agropecuária*, 35(4):835-841, 2000.

STONE, L.F.; SILVEIRA, P.M. Efeitos do sistema de preparo na compactação do solo, disponibilidade hídrica e comportamento do feijoeiro. *Pesquisa Agropecuária*, 34(1):83-91, 1999.

SUMNER, M.E.; PAVAN, M.A. Alleviating soil acidity through organic matter management. In: ROTAÇÃO SOJA/MILHO NO PLANTIO DIRETO, 2000, Piracicaba. Anais... Piracicaba: POTAFOS, 2000. CD-ROM.

TAYLOR, S. A.; ASCHROFF, G. L. Physical edafology; soil structure. San Francisco, W. H. Freeman. P.309-351. 1972.

TEIXEIRA, L.A.J.; TESTA, V.M.; MIELNICZUK, J. Nitrogênio do solo, nutrição e rendimento de milho afetados por sistemas de cultura. *R. Bras. Ci. Solo*, 18:207-214, 1994.

TESTA, V.M.; TEIXEIRA, L.A.J.; MIELNICZUK, J. Características químicas de um Podzólico Vermelho-Escuro afetadas por sistemas de cultura. *R. Bras. Ci. Solo*, 16:107-114, 1992.

- TESTA, V.M.; TEIXEIRA, L.A.J.; MIELNICZUK, J. (1992) Características químicas de um podzólico vermelho escuro afetada por sistemas de culturas, *Revista Brasileira de Ciência do Solo* 16, 107-114.
- TISDALL, J.M.; OADES, J.M. Organic matter and water-stable aggregates in soils. *J. Soil Sci.*, 33:141-163, 1982.
- TORMENA, C.A.; BARBOSA, M.C.; COSTA, A.C.S. Densidade, porosidade e resistência à penetração em Latossolo cultivado sob diferentes sistemas de preparo do solo. *Scientia Agrícola*, 59(4):795-801, 2002.
- TRUCCO, V. 2001. AAPRESID y la Innovación. En, Resúmenes del primer Seminario AAPRESID para Estudiantes. Pág. 9. AAPRESID. Paraguay 777, 8vo Piso. Of. 4. 2000 Rosario. Prov. Santa Fe. República Argentina.
- UMA REVOLUÇÃO na lavoura. *Anuário Brasileiro do Milho*, p.16-19, 2002.
- URCHEI, M.A.; RODRIGUES, J.D.; STONE, L.F. Análise de crescimento de duas cultivares de feijoeiro sob irrigação, em plantio direto e preparo convencional. *Pesq. agropec. bras.*, Brasília, 35(3):497-506, 2000.
- VALPASSOS, M.A.R.; CAVALCANTE, E. G. S.; CASSIOLATO, A. M. R. et al. 2001, Effects of soil management systems on soil microbial activity, bulk density and chemical properties. *Pesq. agropec. bras.*, Dec 2001, vol.36, no.12, p.1539-1545.
- van BREEMER, N. Soils as biotic construct favoring net primary productivity. *Geoderma*, 57:183-211, 1993.
- VEZZANI, F.M. Qualidade do sistema solo na produção agrícola. Porto Alegre, Universidade Federal do Rio Grande do Sul, 2001. 184p. (Tese de Doutorado).
- VOSS, M.; SIDIRAS, N. Nodulação da soja em plantio direto em comparação com plantio convencional. *Pesquisa Agropecuária Brasileira*, Brasília, v.20, p.775-782, 1985.
- WISCHMEIER, W.H.; SMITH, D.H. Predicting rainfall-erosion losses: a guide to conservation planning. SEA-USDA Agricultural Handbook. N° 537. U.S. government Printing Office, Washington, D.C. 1978.
- WRIGHT, S. 2001. Los Sistemas de Siembra Directa Aumentan la Estabilidad de los Agregados y de la Glomalina. En: Los Desafíos de la Agricultura en un Complejo Mundo Globalizado. Proceedings del IX Congreso Anual de AAPRESID. Mar del Plata 16 al 18 de Agosto 2000. Tomo I. Págs. 67:122. AAPRESID. Paraguay 777. Piso 8. Of. 4. 2000. Rosario. Provincia de Santa Fe. República Argentina.