Conservation tillage technology for tropical agriculture
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1. Background
1.1 - Brazilian agriculture before 1970

In the early 1970's, Brazilian economic situation was unstable and almost all our agriculture had its greatest expression in the South and the Southeast. During this period, agricultural production did not meet the demands of the country and there was a crisis of food supply, causing dependence on foreign commodities with high prices of food for our needy and poor. The main consequences of this phase are high inflation and increasing rural and urban poverty.

According to Alves and Tollini (2008), during the 1970s, trends in population and other major variables indicated that agricultural production could become a constraint to development. Population projections indicated the need for increasing the capacity of agriculture to supply higher quantities of agricultural products. At the same time, urbanization, income trends and the need to stabilize the economy required supplying food at decreasing prices. Creating a new production capacity in the Midwest was also necessary to avoid the use of virgin land in the Amazon basin. The Cerrado (Savannah) could work as a buffer zone between the developed South and Southeast regions and the Amazon region, and could promote closer integration of the poorer and populous Northeast to the process of national development, diminishing regional income differences.

In fact, the country situation showed the reflex of the lack of adequate public policies for agriculture, aggravated by the fact that public agricultural research was not structured to meet this challenge and, therefore, not capable to modify this external dependence. Given the continental size of the country, with 8.5 million of km², distributed over five (5) very distinct geographical regions, it would require an effective organization of the major research institutions and an availability of trained human resources to develop knowledge for our tropical conditions.

1.2 1st cycle of agriculture development: technology for food production in the 1970’s

This trend lead to the development of a new agricultural frontier; in the Cerrados area (Figure 1), this happened by means of the expansion of the land with agricultural potential, and the use of tropical knowledge to be applied in large cultivated land in order to reduce production costs. The 1st cycle of agriculture development achieved the goals established by the Brazilian Government, and food security could to be solved with food production systems in the expanded area of Cerrados (Figure 2).

2. RESEARCH ORGANIZATION: Brazilian Agricultural Research Corporation - EMBRAPA

To provide feasible solutions for the sustainable development of Brazilian agriculture, the Brazilian Agricultural Research Corporation - Embrapa was established in 1973, as a public corporation with some characteristics of a private corporation, subordinated to the Ministry of Agriculture and Food Supply, dedicated to agricultural research. Embrapa is organized as a large network of 1 headquarter, 14 central divisions, 39 decentralized research centers and 3 service centers, distributed among nearly all the regions of Brazil (Figure 3), plus 2 international virtual labs and 2
international technology transfer units, with a total of 2207 researchers, being 27% with master's degree and 72% with doctor's degree.

Since its creation in 1973, Embrapa has generated and recommended technologies for Brazilian agriculture, increasing food supply and reducing dependence on imports of new technologies, basic food products and genetic materials.

EMBRAPA coordinates the National Agricultural Research System in cooperation with other national and international institutions.

During the 80s, there was a massive investment, through the Ministry of Education, in a cooperative program with Land Grant Universities in the USA, and that particular action was the largest formal training program in the field of agriculture abroad. Figure 4 shows the performance of agriculture resulting from the use of Embrapa new cultivars of soybean, corn, rice, bean, cotton, sorghum and other minor crops adapted to the different regions with high management technology that increased grain production by 126%. At the same time, the planted area increased only by 21%.

The increases in productivity and their effect on consumer prices are discussed in Mendonça de Barros, Rizzieri and Picchetti, cited by Tollini (2008) (Figure 5). They present data for basic food basket for the period 1973 to 2007. The real price for the basket decreased continuously during these years. It was equal to 1.0, in December 1994 and fell to 0.3 in June 2000. This fall in real prices of food implied significant increases in the welfare of consumers. Again, this happened during a period where demand for food was increasing due to increases in population and income. Development necessarily includes improvements in the well being of the population at large. [12]

The knowledge obtained abroad allowed starting the innovation process in agriculture, adapting scientific and technological knowledge for application in the tropics. This induced a new cycle of tropical agricultural processes, optimizing the use of Brazilian agricultural land. [14]

2.1 2nd Cycle of agriculture development: sustainability in tropical agriculture

More intensive and systematic research on No Tillage was initiated at IAPAR, Fundação Instituto Agronomico do Paraná, Londrina in 1976, in a cooperative research effort with ICI, resulting in the first comprehensive research publication on No Tillage in Brazil in 1981 (IAPAR, 1981). At present, some research institutions in Brazil, including EMBRAPA Trigo, in Passo Fundo, Rio Grande do Sul, have decided that all their research programs (varieties, rotations, cover crops, etc.) should be carried out in No Tillage, and their goal is to achieve (together with the extension service and the private sector) a 100% adoption of this farming system by farmers.

Although the economic aspect was the first priority in the 1st Cycle of agriculture development, in order to have food security and food production, this was not enough in terms of soil problems and social aspects. A continuous challenge to develop an agriculture model capable of approaching all the sustainable development dimensions, such as economic, social, environmental and political, was the main priority of the 2nd Cycle on agriculture development.

Traditional soil cultivation systems in the tropics and subtropics, with intensive soil tillage, will result in soil degradation and loss of crop productivity. This will lead to poverty and exodus of farmers from rural areas, resulting in an increase of city slums and marginal populations, and, finally, in social conflicts. If we are to offer the small-scale agriculture a chance to survive on the farm and if sustainable agriculture is to be achieved, then the paradigms of soil use and management must be changed and new farming practices must be implemented (Derpsch, 1998).

The conservation techniques of soil management, initially used in Brazil were mostly recommendations used for soils in temperate regions and proved not to be suitable for our
conditions. Several problems occurred mainly in the tropical and subtropical region of Brazil, and among the most serious ones are subsoil compaction and erosion, with excessive soil loss from 30 to 40 t/ha/year, as shown in Figure 6.

According to Derpsch (1998), Conventional farming practices utilized in many parts of the world have had negative consequences in terms of soil and water preservation as well as on the conservation of the environment as a whole. This is due to improper soil use, monoculture and the use of tillage tools that leave the soil bare and pulverize it excessively, leaving it in such a condition that heavy rains can carry it away. The utilization of inadequate technologies that are not adapted to specific conditions (slope, rainfall intensities) results in runoff and soil erosion.

Furthermore, most European and American experiences of soil conservation management put great emphasis in the use of equipment for soil preparation, paying little attention to the production system itself.

The unavoidable negative effects of intensive and repeated soil tillage in the tropics and subtropics on organic matter content, soil erosion, soil structure, soil temperature, soil moisture, water infiltration, soil flora and fauna (soil biological processes) and loss of nutrients result in chemical, physical and biological soil degradation. This causes a decrease in yields over time and productivity losses of the soil, leading to poor soils and farmers (Derpsch et al. 2006).

Later on, with the development of Tropical Agriculture, the soil conservation tillage systems began to emerge, especially with the improvement of agricultural equipment, the development of new short-cycle cultivars, pasture grass for the winter growing season and plants less sensitive to water stress, such as millet. Since 1991, with the development of a new concept of No Tillage system adapted to the subtropical conditions, most of the erosion problems in the Southern Region have been solved, by reducing the amount of soil losses to acceptable levels. According to Denardin et al. (2007), in the State of Rio Grande do Sul a regional program was established to expand the production of Dairy Cattle, for small and medium producers, and farmers decided to replace species for soil cover crop by species to produce forage. The result was very impressive, with an increment in milk production from 8 million liters, in 1986, to 340 million liters, in 2002. On top of such programs, the change in concept became much more acceptable to Rio Grande do Sul farmers and the No Tillage area increased from 320,000 hectares, in 1992, to 3,817,000 hectares, in 1998. All this effort was very effective for erosion control and soil losses, as shown in Figure 7.

With the success of the experience of No Tillage system in the South, the Midwest began its first experiments in the late 1980th and early 1990th, using much of this technology already developed and with great support from the Agricultural Machinery Industry, together with the Public Research System and the farmers. As a result of these efforts, a new conservation system for the tropical conditions, called Cerrados’s No Tillage was established.

In these two regions, Southern and Midwest, the production systems are cultivated based on well-established schedules, crop rotation and crop succession, improvements of tillage equipment for all production scales, and more efficient herbicides at low cost. All these factors have enabled the expansion of the No Tillage system exponentially, with an estimated use of 25,500,000 hectares of Brazilian production area, in 2008, as shown in Figure 8.

Today, the leading countries in the world with crop production area under No Tillage are Brazil, with 25.5 million ha, and the United States, with 25.3 million ha, as shown in Figure 9. But this represents, today, 50% of the total cultivated area in Brazil, against 16% in the USA.

Figure 10 shows the 3 phases of No Tillage development in Brazil and indicates the beginning of the major adoption period (1991/2006), when most of the technological problems were solved in the Southern Region and in the Midwest, with an exponential increase of the curve in phase 3.
Considering the improvement in Conservation Tillage in Brazil in 3.5 decades, the 3 phases of No Tillage System will be discussed in this paper to explain the process as a whole. Although the subject matter, Conservation Tillage Techniques in Brazil, may indicate a specific area of soil management, it is important to mention that all this technological achievement was only made possible due to the integration of the National Agricultural Research System, the private sector and the farmers, after the development of Tropical Agriculture.

**No Tillage System – PHASE I: MAIN CHALLENGES 1974-1979**

\[ Y=11.901X - 2.34E7 \quad R^2=0.84 \]

According to Derpsch (1998), No Tillage trials in Latin America were first introduced in 1971 by the Instituto de Pesquisas Agropecuarias Meridional, IPEAME, in Londrina, the State of Paraná, Brazil, in cooperation with a GTZ (German aid) project. This project set up demonstration plots in the farm of Herbert Bartz, a Brazilian farmer of German descent, in Rolândia, Paraná. After seeing the results of these plots, Herbert Bartz visited the UK and the USA, carried out research on the advances of this technique, visited ICI in Fernhurst and Harry Young in Kentucky, bought a no tillage planter in each country, and started seeding his first soybeans under no tillage in 1972. Thus Herbert Bartz became the first farmer to apply the technology in Latin America and to use it continuously until the present day.

According to Denardin et al (2007), the eight items listed below describe very well the challenges of Phase I:

- operational limitation of equipment: planters were not adapted for No Tillage planting and trying to conduct the work in areas with high density of straw was almost impossible;
- inefficient pre seedling herbicides: weed dissection in previous seedling presented serious technical problems and proved to be inefficient, with consequences such as regrowth and perennial in crop lands;
- post emergence weed control with low selectivity: weed control was not satisfactory due to the low efficiency of selectivity herbicide, and, consequently, it was very difficult to promote mechanical weeding in view of the straw on soil surface;
- pre seedling high cost herbicide: to guarantee efficiency on weed control in conventional soil management, farmers applied double dose of herbicide to maintain residues on soil surface. The technology of chemical application in pre and post emergence weed control was not satisfactory;
- crop production system: the usual crop system used was soybean-wheat succession and soybean in monoculture, with insufficient crop residue to benefit the soil, besides the proliferation of pathogen and the predominance of certain species of weed;
- The actual knowledge of soil management applied to tropical conditions promoted excessive soil erosion: the initial conservation tillage used by farmers was by simply eliminating normal tillage operation, as disk and moldboard plow, heavy disk harrow, followed by disking and seedbed leveling prior to planting, without use of cover crop or crop rotation. The main consequence was erosion caused by soil compaction on the degraded soil with low organic matter;
- lack of technology for control erosion: the technological problems to implement conservation tillage by farmers increased the erosion problems using the conventional tillage system. The techniques to avoid soil losses, as contour terraces and no tillage were not well accepted by farmers;
most of tillage equipment was not adapted to subtropical and tropical conditions: the initial tests were to improve the following mechanisms of seeders and planters-weight necessary to maintain all mechanisms such as straw cutting disk, opening furrows for seedlings, triple disc and double dephased disc working adequately (straw cutting, opening furrow for fertilizing and seedling) and other related activities.

The beginning of No Tillage was not easy in terms of area size, since the first machines built in Brazil in 1975/76 based on the rotary hoe (Howard Rotacaster) were slow and the only herbicides available were 2,4-D and Paraquat. Hand hoeing saved many crops from failure at this stage. Despite the difficulties at the beginning, the area under No Tillage increased from 1,000 ha in 1973/74 to 400,000 ha in 1983/84 and reached 6,500,000 ha in 1996/97 (Table 1). The Federation of No-till Associations in Brazil - FEBRAPDP estimates that in 1998 the area under No Tillage in Brazil had expanded to 8.4 million hectares (Derpsch, R, 1998).

During this period, on Phase I, many actions were taken to provide technical training in No Tillage for farmers and for technical assistants. and, at the same time, their experience served as an opportunity to solve problems. Although the farmers were aware that the conservationist aspect was very important to solve erosion problems and degraded soils, and, in spite of the intensive training actions of technology transfer, the adoption of No Tillage system by farmers continued under standby.

So the challenge was to move from soil management technology applied to the tropics to tropical management technology developed for our conditions.


Since the beginning, the main characteristics of Phase II was the great effort made by all the organizations involved in the process to disseminate the knowledge in No Tillage System in meetings and in technology transfer activities. Many entities and clubs were established, mainly in the States of Rio Grande do Sul and Paraná, with the objective to spread the No Tillage System and to find solutions for the problems that research had not been able to solve yet.

In order to disseminate information, the "Cooperativa Central Agropecuária Campos Gerais" promoted the first National No-till Conference held Ponta Grossa, Paraná, in 1981. Two other national conferences, held in 1983 and 1985, boosted the area under No Tillage in the "Campos Gerais" of Ponta Grossa to about 200,000 ha in 1986, this being the first sizeable region to be completely subjected to No Tillage practice in Brazil.

Denardin et all (2007) describe the many and important facts that characterize Phase II. The more relevant ones are:

- diversity of workshops: Knowledge exchange;
- process and equipment improvements;
- no Tillage technology transfer.

Clubs organizations:
- the "Worm Club” established in 1979;
- friends of the Earth Clubs – 1982;
- zero Tillage Clubs;
• associations of Zero Tillage Producers;
• no Tillage Association for Cerrado – 1990.
• ABC Foundation established in 1984, with the mission to promote research in No Tillage, associated with extension service and farmers;
• tests were carried out by Embrapa Wheat Research Center in:
  • annual crops in natural fields;
  • mechanization of No Tillage: Seeders with triple disc and double dephased disc;
  • mechanisms for opening furrows seedlings in No Tillage;
  • more efficient post emergence herbicides for the management of weeds.
• The largest expansion of No Tillage in Brazil, in the 1990s, occurred in the Cerrados, with only one growing season per year, by APDC (No-till Association of the Cerrados).

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

The change in concept was very significant and now, the No Tillage System comprehends a complex of technologies that established a diversity of crop species, using crop rotation/succession associated with soil preparation in planting row, to maintain permanent residue soil cover from previous crop (Denardin et al., 2001).


\[ Y = 1.709.957X - 3,40E9 \quad R^2 = 0,98 \]

Phase III can be characterized as the great “Revolution” of Brazilian Agriculture, called Tropical Agriculture. The pioneer work of Frank Dijkstra and Manoel Henrique Pereira (President of the Federation of No-till Farmers - FEBRAPDP, from 1992-1998), both farmers and leaders in their community, played a major role in the development and diffusion of this method of farming, not only in Brazil, but in all the Latin American countries and abroad. The technology spread mainly to the States of Santa Catarina and Rio Grande do Sul, in the South of the country, where significant progress has been achieved with the use of cover crops and crop rotations, thus reducing fertilizer and herbicide costs. During this period, Denardin et al.(2007) describe the many and important facts that characterize Phase III, but the most relevant are:

• substantial decrease of herbicides price: from US$ 48,32 to US$ 8,74 in 1986, and US$ 4,53 in 2002;
• proliferation of No Tillage in Brazil and the Americas 1990/1992, with the Midwest Associations and American Confederation;
• conversion of conventional planters to No Tillage planters, early in 1990 and on the 2nd half of 1990, industrialization of drills to attend to small-scale farms, to work with manual planters, animal traction, tractor power and self-propelled traction;

• fertilization technology of soil was adjusted for No Tillage System;

• integrated pest weeds control;

• great potential for biological nitrogen fixation;

• development of soybean cultivars and hybrids of corn with total cycle shortened by 30 days allowed the sequence Soybean-small crop with corn- Brachiaria spp.;

• from the year 2000: the season maize intercropped with Brachiaria spp and Panicum spp. enabling the integration of crops and livestock, and having forage throughout the winter;

• Santa Fé System: rotation and intercropping of annual crops and semi perennials (soybean / winter maize + grass pasture) under No Tillage system maintain the soil permanently covered with living or dead plants;

• enabling No Tillage practice in all regions and all scales of production, supported by the use of planters adapted for small and medium farm size;

• Technology transfer: the fifth and sixth national No-till conference was organized in Goiânia and Brasília in 1997 and 1998, each one with more than 2300 participants.

Reduced cost of production under No Tillage is probably the main driving force in achieving high adoption rates. Production costs per acre of soybeans under No Tillage are reduced by US$ 27.00 in Argentina, by US$ 14.18 in the USA and by US$ 11.50 in Brazil. No Tillage accounts for less than 50% of conservation tillage practices in the USA, but it is almost the only form of conservation tillage practiced in Latin America(Desrpsch, 1998).

The converging technological innovation creates economic advantages, resulting in a stunning annual rate of adoption of the No Tillage System, as shown by the slope of the curve with linear trend, growing more than 21 times, from 79,016 ha / year in the previous period, to 1,709,957 ha / year in the 3rd Phase, 1991-2006. The R² coefficient = 0.98 shows the consistency of the system adoption process by the farmers. Finally, the magnitude of the rate of adoption of the No Tillage System by farmers in all regions is considered, today, a great revolution of Brazilian Agriculture, simply named as Tropical Agriculture (Denardin et all,2007).

2.2 3rd Cycle of agriculture development: Tropical Agriculture

Over 3.5 decades a new agriculture has been developed for Brazil, solving the initial problem of food security and attending to the requirements for a sustainable agriculture, thus establishing a most promising agriculture of the 21st Century. As a result of this process, Brazilian agribusiness plays a most important role in the national economy, accounting for 23% of the Gross Domestic Product. The data below in Tab. 1 show the performance of agribusiness and of our export products, and also the ranking of the main products with global leadership.

Figure 11 shows the worrisome situation of the distribution of urban and rural population in Brazil, which is also a reality in many other countries as well. In view of this situation, with more than 80% of the population living in cities, the rural sector assumes the responsibility for producing food to meet the demands of the country and also the surplus for export. National and global population growth data, coupled with the increase of the income distribution, indicate growth in the demand for food and, hence, the need for expansion of production. Few countries in the world, however, have enough land or productivity increase of the main cultures for production expansion.
Figure 12 examines the global situation of the expansion of world agriculture, considering 3 important items: GDP above 400 billion dollars, land area greater than 100 million km² and a population larger than 100 million people. Considering the above 3 items, four countries fall into this category: China, United States, Russia and Brazil. Taking into account the agrarian situation, the production fields and the possibility of expansion, Brazil presents itself as more able to expand its agriculture and the opportunity for Brazilian agribusiness, due to the large amount of areas available for expansion, as well as the possibility of some crops to increase productivity.

To illustrate the opportunity to expand our agriculture, Figure 13 shows the central region, with the large area of the Cerrado to be cultivated, considering all aspects of preservation of this biome.

In this scenario, the need for expansion of our agriculture and modernization of production systems –with techniques such as precision agriculture, nanotechnology, biotechnology, etc. – as well as for meeting different demands of small-scale farming, characterizes the 3rd Cycle Development of our agriculture. So, Figure 14. shows a summary of the activities that are underway at Embrapa, to face these challenges for the next 4 and 15 years, described in its Strategic Plan V, when, in 2023, it will turn 50 years old.

Finally, there is a great program that is underway in the 3rd cycle, called Integrated crop-livestock-forestry Program (Figure 15), being considered a major technological innovation in development, aiming to improve degraded pastures (50 million ha), degraded forest areas and annual crops to increase the productivity of production systems, without the need to advance over forest areas.

3. Final Remarks

- The development of tropical agriculture technologies allowed for the growth in production with minimum expansion of the cultivated area;

- conservation Tillage in Sub Tropical and Tropical regions was implemented by the No Tillage system which showed to be the most appropriated technique for soil management of erosion control;

- most recommendations used for soils in temperate regions were not adequate for Sub Tropical and Tropical regions. Several problems of subsoil compaction and erosion occurred, with excessive soil loss varying from 30 to 40 t/ha/year;

- the soil conservation tillage systems began to emerge, starting with the improvement of agriculture equipment, the development of new short cycle cultivars, pasture grass for the winter growing season and plants less sensitive to water stress, diversity, low price and efficiency of herbicide and their application technology;

- the change in concept was very significant and, at present, the No Tillage System comprehends a complex of technologies that have established a diversity of crop species, using crop rotation/succession associated with soil preparation in planting row, to maintain permanent residue soil cover from previous crops;

- reduced cost of production estimated between 10-15% under No Tillage was initially the main driving force in achieving high adoption rates;

- later on, the use of No Tillage in the Cerrado’s area allowed farmers to produce two or three crops per year, increasing planting efficiency by establishing proper seasonality for the sequence of crops;
• the use of this technology with its favorable impact on nitrogen fixation, and biological(integrated) pest control associated to precision farming, allowed for better natural resources management;

• converging technological innovation creates economic advantages, resulting in a stunning annual rate of adoption of the No Tillage System, shown by the slope of the curve with linear trend, growing more than 21 times since 1991;

• all the technological achievement in tillage was made possible only due to the integrated effort of the National Agricultural Research System, the private sector producing modern inputs, and the farmers;

• the magnitude and rate of adoption of the No Tillage System by farmers in all regions is considered today a great revolution of Brazilian Tropical Agriculture.

References


Figure 1 - Cerrado’s area in the early 1970’s

Figure 2 - Midwest showing agricultural expanded area of *Cerrados (Savannah)*

Figure 3 - Embrapa and National Agriculture Research System.

*Embrapa & National Agriculture Research System*
Figure 4 - Grain production and cultivated area, million of ha & ton - 1991-2007

Figure 5 - Cost of living in the city of São Paulo, Brazil, January 1973-February 2007

Figure 6 - Soil losses and superficial compaction on crop field under Conventional Tillage System
Figure 7 - No Tillage soybean crop system in the Sub Tropical region

Figure 8 - No Tillage cultivated area evolution in Brazil
Figure 9 – No Tillage cultivated area in the world, 2008. Source: Federação Brasileira de Plantio Direto na Palha – FEBRAPDP, 2004-2006

Figure 10 - No Tillage development Phases in Brazil
Figure 11 - Population distribution in Brazil.

Figure 12 - The Global context for agriculture expansion.
**Figura 13** - Cerrados’s area available for agriculture expansion.

![Innovation and technology: agriculture expansion](image)

- Production Area (millions ha)
  - Total Area: 204
  - Farming Area: 127
    - Cultivated pastures: 35
    - Annual crops: 10
    - Perennial crop and cultivated forests: 2
    - Available area: 80

**Figura 14** - Summary of Embrapa’s activities for the future.

![From small-scale agriculture... to precision agriculture...](image)

**Summary:**
- Institutional and RD&I challenges
- Partnerships: national and international
- Knowledge frontier: nanotechnology, integrative functional genomics ...
- Accelerating-Growth Program (PAC): budget and modernization
- V Strategic Master Plan 2008-2011-2023: Mission and goals

**Embrapa tomorrow**

**Figura 15** - Embrapa’s national Integrated Crop–Livestock-Forestry Program

![Innovation and technology: production systems](image)

- Recovery of degraded pasture:
  - 1 ha recuperated pasture = 1.8 ha of preserved forest

**Integrated crop-livestock-forestry**
Table 1 - Brazilian Agribusiness performance in 2008

*The Agribusiness in Brazil*

One of the most dynamic sectors of the economy:

- 5 million rural properties - 18 million people.
- 23% GNP 2007 and 37% employment on the country.

Main source of International income: main source

- 37% of Brazilian exports.

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<th>EXPORTS</th>
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<td>Pork meat</td>
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Source: MAPA e USDA
**Brazilian No Tillage seeding machines addresses (Source: Derpsch, R, 1998)**

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