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CONSERVATION AGRICULTURE AS A TOOL TO REDUCE EMISSION OF GREENHOUSE GASSES. A CASE FROM SOUTHERN BRAZIL

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Emissions of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), resulting from human activities are substantially enhancing the greenhouse effect, which is alleged to increase the average temperature of the earth's surface.
Conventional agricultural practices, like ploughing, mixing crop residue and other biomass into the soil surface and burning of residues, have contributed to the emission of carbon dioxide to the atmosphere as this is related to the mineralization and decomposition processes of soil organic matter by micro-organisms. A clear indicator of this is the decline in soil organic matter, which was estimated to be reduced in average with 50% in the soils of Rio Grande do Sul in hardly 15 years of conventional tillage.
However, the emergence, development and improvement of new systems of land preparation and land management, in short conservation agriculture, have changed this balance. Systems, based on high crop residue addition and no tillage, tend to accumulate more carbon in the soil, compared to the loss into the atmosphere. This turns the soil into a net sink of carbon. The figures presented confirm the potential of conservation agriculture for carbon sequestration, or at least reduce the amount of carbon dioxide to the atmosphere. Assuming an average accumulation of 1.0 t C ha-1 year-1, an area like southern Brazil (Rio Grande do Sul, Santa Catarina and Paraná) under cultivation, applying the three principles of conservation agriculture (no mechanical soil disturbance, permanent soil cover and crop rotations) would have the potential to sequester 8 million tonnes of C annually, which corresponds with 29 million tonnes atmospheric carbon dioxide.

INTRODUCTION

Emissions of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), resulting from human activities, are substantially increasing the average temperature of the earth's surface. Fifty percent of the increase in global warming, since the industrial revolution, is considered to be the consequence of an increased level of carbon dioxide and other gasses in the atmosphere (Lal, 1999). Sources of gas emissions include

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burning of fossil fuels, industrial production, deforestation and agriculture. Although estimates of the total emissions vary widely, the contribution of agricultural activities and forestry products extraction to the emission of especially carbon dioxide, is estimated at only five percent of the global total (Benites, *et al.*, 1999). Conversely, the potential of agriculture and forestry for sequestering carbon (the absorption of carbon in biomass) is significant.

The effect of tillage systems versus no soil inversion, different cover crops and crop rotations on the accumulation of carbon in the soil, compared to the loss into the atmosphere, is being evaluated in long term soil management experiments in southern Brazil. The following case illustrates how certain water and soil conservation-effective practices contribute to the reduction of carbon dioxide into the atmosphere and to sequestering carbon into the soil.

BACKGROUND

In many areas of southern Brazil erosion problems started at the time of colonialization, when large areas were taken into cultivation for the production of forage crops and crops like coffee and sugarcane (Castro Filho *et al.*, 1993). Conventional agricultural practices, such as ploughing, monocropping of demanding crops, planting along the slopes, burning of crop residues, and excessive grazing, provoked little soil protection, causing an accelerated degradation (compaction, runoff and erosion) and led to the deterioration of soil physical, chemical and biological characteristics. A clear indicator of this is the decline in soil organic matter. Pottker (1977) estimated that in hardly 15 years of conventional tillage the organic matter content of the soils in Rio Grande do Sul was reduced with 50 percent (Figure 1) (Burle, *et al.*, 1997), which was a consequence of high erosion rate and high biologic oxidation of organic matter.

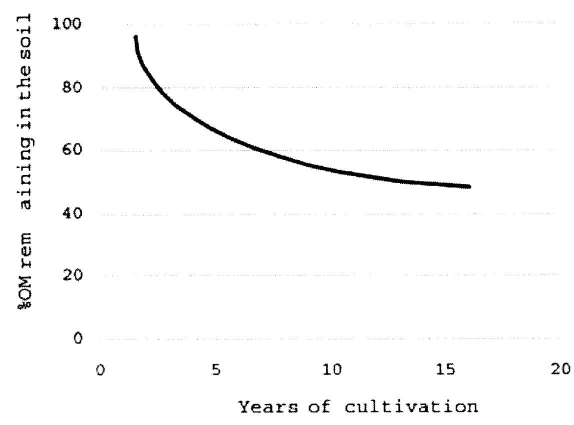

Figure 1. Reduction in organic matter content of soils of Rio Grande do Sul with conventional tillage (Pottker 1977).

Consequently, these practices have contributed to the emission of carbon dioxide to the atmosphere as this is related to the mineralization and decomposition processes of soil organic matter by micro-organisms (Lal, 1999). The CO2 emission from the soil is accentuated by ploughing, mixing crop residue and other biomass into the soil surface or burning of biomass.

A PROCESS OF CHANGE

Mainly due to relevant research, together with rural extension work the outlined situation began to change with awareness raising activities on natural resource conservation (Calegari *et al.*, 1998). Studies related to soil conservation research started in 1942 with plots to measure soil losses and then evolved to terracing, fertilisation and tillage systems. Reduced tillage systems were introduced in the 1960's and 1970's (Castro Filho *et al.*, 1993). It had become clear that in order to maintain soil losses within tolerable limits, similar to those which occur in nature, as for example in a forest, a farmer must cause minimum soil disturbance regardless of the situation and the agricultural activity (Eltz *et al.*, 1977; Wünshe *et al.*, 1980).

This resulted in the revival of the use of the ancient practice of *green manuring*, with a focus firstly to protect the soil from compaction and erosion. Research showed that, more important than using physical barriers to control runoff, the ideal solution is to maintain soils covered as much of the time as possible with cover crops and crop residues. By avoiding the detachment of soil particles by raindrop impact, which accounts for 95 percent of erosion, soil losses can be avoided and at the same time the soil can be cultivated in conditions similar to those found in forests (Freitas, 2000).

Nevertheless, the problem was not entirely resolved. Initially, green manure options were few, and knowledge about green manure was limited especially for the conditions of southern Brazil. Moreover, until a short time ago the prevailing concept was that green manures were to be incorporated into the soil to improve soil fertility by providing nutrients, especially nitrogen in the case of legumes. As the use of green manures increased, so did the use of conventional methods of land preparation which consisted of incorporating the green manure or crop residues by cultivating the whole soil surface by one or more ploughings and two or more passes with a harrow (Calegari and Alexander, 1998).

The present concept of green manuring or the use of cover crops consists of the practice to maintain the soil covered with the living or dead biomass of these crops for as long as possible, with the objective to improve soil quality by protecting the soil from the direct impact of rain drops, excessive insolation and wind action and in order to maintain and improve soil physical, biological and chemical characteristics (Calegari *et al.*, 1998).

This was accompanied by the emergence of new systems of land preparation as alternatives to the conventional practices introduced from temperate climates, like minimum tillage and direct sowing techniques, which appear more appropriate for tropical and subtropical climate conditions. Under tropical conditions, with high temperatures and humidity levels, crop residues tend to decompose rapidly, even when maintained on the soil surface, which allows for a good synchrony with the demands of the successive crop (Amado *et al.*, 2001).

Traditionally, both leguminous crops, like lupine (*Lupinus angustifolius*), vetch (*Vicia sativa*), clover (*Trifolium subterraneum*) and cowpea (*Vigna unguiculata*), and nonleguminous crops, like black oats (*Avena strigosa*), radish oil (*Raphanus sativus*) and wheat (*Triticum aestivum*), are being used as a cover crop during winter time in the production of maize (*Zea mais*) in southern Brazil. New cover crops include castor bean (*Ricinus communis*), mucuna (*Mucuna pruriens*), canavalia (*Canavalia* sp.) and lablab bean (*Dolichos lablab*).

EFFECT OF COVER CROPS AND REDUCED TILLAGE SYSTEMS ON SOIL PROPERTIES

The greater production of foliage in a system with cover crops and reduced tillage compared to monocrop cultures with conventional tillage, leaves a protective blanket of leaves, stems and stalks from the previous crops on the surface. In this way organic matter can be built up in the soil, which has great influence on the activity and the population size of the microorganisms.

The protective blanket, the greater biological activity and higher humus formation reduce the impact of raindrops on soil surface, and thus the runoff of rainwater. With this soil erosion is reduced close to the regeneration rate of the soil or even adding to the system as was found by Debarba and Amado (1997) in the cropping system oats+vetch/maize (Figure2).

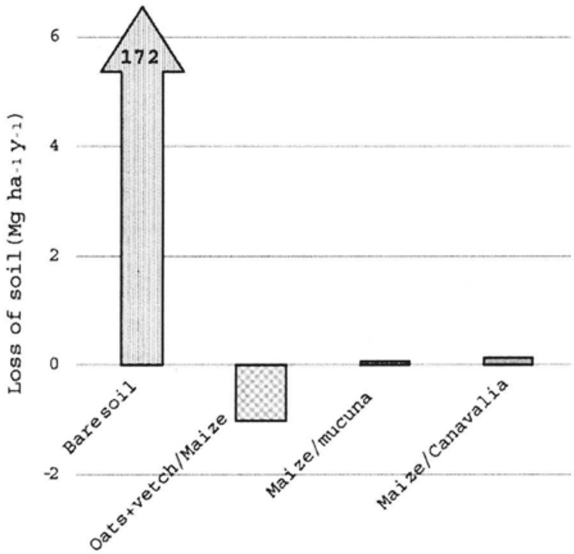

Figure 2. Soil loss due to water erosion (corrected with soil regeneration = 1.7 t ha-1 y-1) for different maize production systems (Debarba and Amado, 1997)

Infiltration of rainwater is increased under no-tillage because of the higher number of large pores due to biologic activity and roots growth (Roth, 1985). In southern Brazil rainwater infiltration increased from 20mm h-1 under conventional tillage to 45mm h-1 under no-tillage (Calegari *et al.*, 1998). In an experiment under natural rainfall conditions, Debarba and Amado (1997) found an increase in rainwater infiltration in maize-cover crop systems under no-tillage, with prominent results in oats+vetch/maize and maize/mucuna (Figure 3).

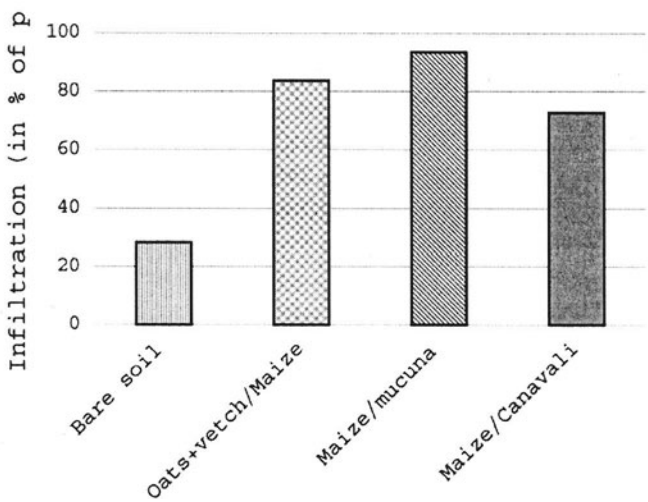

Figure 3. Infiltration of rainwater under different maize production systems (Debarba and Amado, 1997)

ACCUMULATION OF SOIL CARBON

According to Greenland and Adams (1992), systems, based on high crop residue addition and no-tillage, tend to accumulate more carbon in the soil, compared to the loss into the atmosphere. This turns the soil into a net sink of carbon (Reicosky *et al.*, 1995). The studies executed in southern Brazil show indeed an increase in organic carbon in the soil.

The initial incorporation of lime and fertilisers in an experiment in Rio Grande do Sul resulted in a decrease of the organic carbon content of the soil during the first four years, compared to the soil under natural vegetation, probably because of a reduction in physical structure of the organic matter, through breaking the aggregates and an increase in soil oxygen (Reicosky and Lindstrom, 1993; Amado *et al.*, 2001). From the fourth year the different maize/cover crops systems added carbon to the soil (Figure 4).

Bayer and Mielniczuk (1997) found that five years after the introduction of intensive cropping systems, containing leguminous crops (especially the cropping systems oats+clover/maize and oats+clover/maize+cowpea), the level of soil organic carbon was restored, at least in the superficial layers of the soil at the level as it was, before previous cropping systems were responsible for the loss of 8.3 t C ha-1.

For less intensive cropping systems this takes more time as shown in figure 4. However, also the cropping system containing maize/mucuna restored the carbon content after about 5∫ years. From 4th to 8th year this system had added an average of 1.6 t C ha-1 y-1 to the soil (Amado *et al.*, 2001). Other research indicate values of 0.9 to 1.6 t C ha-1 y-1 (Bayer *et al.*, 2000; Amado *et al.*, 2001). This high increase, compared to the other systems, is related to the high biomass production of which the mucuna contributed 44%, with an annual average biologic nitrogen addition/recycling of 140 kg ha-1.

Another experiment shows that 89% of the original soil carbon level of the soil layer 0-17.5 cm was restored thirteen years after the introduction of intensive cropping systems.Fifteen years of conventional agriculture were responsible for the loss of 12.2 t C ha-1 in relation to natural grass vegetation, in the same soil layer before the initiation of the experiment (Lovato, 2001).

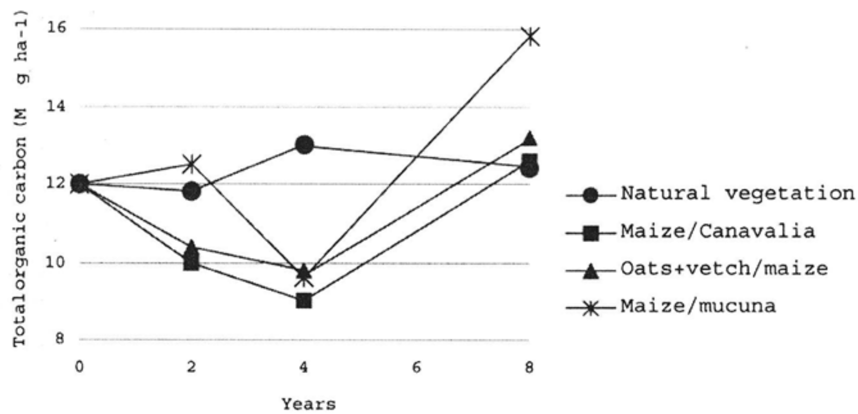

Figure 4. Dynamics of organic carbon (0-10cm) under different maize cropping systems (Amado et al., *2001)*

Another experiment carried out in Rio Grande do Sul, showed that during the initial years until establishment of the cropping system and the increase in soil aggregation, the increase in total organic carbon content was restricted to only the surface layers of the soil (0-2.5 cm) (Testa *et al.*, 1992). With time (fifth year), this effect reached also deeper soil layers (2.5-7.5 cm) (Bayer and Mielniczuk, 1997). At thirteen years this effect reached 7.5 to 12.5 cm (Lovato, 2001). Castro Filho *et al.* (1998) found a 29 percent increase of soil organic carbon in no-tillage compared to conventional tillage in the surface layer 0-10 cm of the soil, irrespective of the cropping system.

Compared to the cropping system winter fallow/maize, which was taken as a reference, soil carbon content increased with 47 percent in the system maize/lablab and with 116 percent in maize/castorbean cropping system. In systems were nitrogen was applied as a fertiliser the carbon content increased even more (Testa *et al.*, 1992).

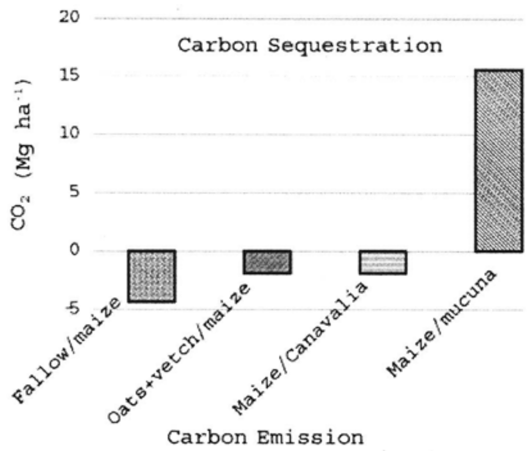

Figure 5. Estimation of emission and sequestration of CO2 under different maize production systems with cover crops under direct sowing compared to natural vegetation (Amado et al.*, 2001)*

The fact that agriculture can act as a sink for CO2 is shown in figure 5, in which the carbon stock in soils under natural vegetation is used as a reference (steady state C=0). During 8 years, the fallow/maize system liberated 4.32 Mg CO2 ha-1. Compared to fallow/maize system, all systems containing cover crops showed less CO2 emission. The maize/mucuna system showed a positive balance of almost 20 Mg CO2 ha-1 compared to fallow/maize (Amado *et al.*, 2001). Compared to soils under natural vegetation this means a sequestration of atmospheric carbon of more than 15 Mg CO2 ha-1 in eight years.

RECENT IMPROVEMENTS TO THE SYSTEM

In the majority of farms producing grains during summer and extensive grazing during winter in the same area, the preference for a particular species of green manure or cover crop, such as black oats, often associated with a specific subsequent crop such as soybean without rotation, has created some serious problems. These problems, like soil compaction, nutrient concentration in the surface soil, and certain pests, diseases and invading weed species, have resulted in an increased use of toxic pesticides.

For this reason it was not sufficient to maintain a minimum amount of residue on soil surface and to use tillage systems that cause minimum soil disturbance. The search for high biomass producing species, has motivated a lot of farmers to use a mixture of 3-5 different cover crops in winter season and rotate maize or sorghum with soybean in summer season. Some progressive farmers use radish oil during a small window between summer cash crop and winter cover crop, resulting in an extra addition of biomass to the system. The results are promising, especially with respect to nutrient recycling, reduction of weeds, pests and diseases and dry matter production.

In the integrated grain/livestock system, the best results for improvement were obtained through division of grazing areas, rotational grazing to allow the regrowth of pastures during 3-4 weeks, use of nitrogen fertiliser in grasslands, and especially the retraction of animals 30-45 days before planting of the summer crop. This interval permits an adequate biomass production before direct sowing of the next crop. Two critical points in livestock management are the retraction of animals during long periods of rainfall, when the soil is highly susceptible for compaction, and the maintenance of a permanent soil cover to reduce the effects of trampling.

Direct sowing has come to be considered as a system and not just a method of land preparation (Freitas, 2000). Direct sowing, with high addition of residues, through rotation of crops and cover crops has reduced the dependency on external inputs, such as mineral fertilisers, insecticides, fungicides and herbicides. The system has been optimised and become very efficient in small, medium as well as large farms. The adaptation of animal drawn and human operated machines in smallholder farms has brought a halt to the rural exodus in the southern part of Brazil.

CONCLUSIONS

With time, in systems with reduced tillage and high residue addition, soil life takes over the functions of traditional soil tillage, which is loosening the soil and mixing the soil components. In addition to that the increased biological soil activity creates a stable soil structure through accumulation of organic matter, and thus increases the levels of some soil nutrients and soil organic carbon.

The increase of soil organic matter transforms agricultural soils under the absence of soil tillage into sinks for carbon, reducing the atmospheric charge with greenhouse gasses like CO2. The figures presented confirm the potential of conservation agriculture for carbon sequestration, or at least reduction of the amount of carbon dioxide to the atmosphere. Assuming an average accumulation of 1.0 t C ha-1 year-1, an area like southern Brazil (Rio Grande do Sul, Santa Catarina and Paraná) under cultivation, applying the principles of conservation agriculture would have the potential to sequester 8 million tonnes of C annually, which corresponds with 29 million tonnes atmospheric carbon dioxide. Based on the figures of Landers *et al.* (2001) this would mean an estimated annual benefit of U$ 87 million.

A production system, which includes green manure, crop and cover crop rotation and no-tillage, can be regionally adapted and therefore can contribute to the sustainability of soil management in the region.

REFERENCES

Amado, T.J.C., C. Bayer, F.L.F. Eltz & A.C.R. de Brum. 2001. Potencial de culturas de cobertura em acumular carbono e nitrogênio no solo no sistema plantio direto e a conseqüente melhoria da qualidade ambiental. Revista Brasileira de Ciência do Solo, 25:189-197, 2001. Bayer, C. and J. Mielniczuk, 1997. Características químicas do solo afetadas por métodos de preparo e sistemas de cultura. Revista Brasileira de Ciência do Solo, 21: 105-112.

Bayer, C., J. Mielniczuk, T.J.C. Amado, L. Martin-Neto and S.V. Fernandes. 2000. Organic matter storage in a sandy clay loam Acrisol affected by tillage and cropping systems in southern Brazil. Soil & Tillage Research 54:101-109.

Benites, J., R. Dudal and P. Koohafkan, 1999. Land, the platform for local food security and global environmental protection. In: FAO. Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Caribbean. Proceedings of the IFAD/FAO Expert Consultation. Rome 15 April 1999. p. 37-42.

Burle, M.L., J. Mielniczuk and S. Focchi, 1997. Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification. Plant and Soil 190: 309-317.

Castro Filho, C., P.C. Corsini, D. Soares and W. Politano, 1993. Acceptance of soil and water conservation strategies and technologies in southern Brazil. Topics in applied resource management, Vol. 3: 341-361.

Castro Filho, C., O. Muzilli and A.L. Podanoschi. 1998. Estabilidade dos agregados e sua relação com o teor de carbono orgânico num Latossolo roxo distrófico, em função de sistemas de plantio, rotações de culturas e métodos de preparo das amostras. Revista Brasileira de Ciência do Solo, 22: 527-538.

Calegari, A. and I. Alexander, 1998. The effects of tillage and cover crops on some chemical properties of an oxisol and summer crop yields in southwestern Paraná, Brazil.

Advances in GeoEcology 31: 1239-1246.

Calegari, A., M.R. Darolt and M. Ferro, 1998. Towards sustainable agriculture with a notillage system. Advances in GeoEcology 31: 1205-1209.

Debarba, L. and T.J.C. Amado. 1997. Desenvolvimento de sistemas de produção de milho no sul do brasil com características de sustentabilidade. Revista Brasileira de Ciência do Solo 21, p. 473-480.

Eltz, F.L.F., N.P. Cogo and J. Mielniczuk, 1977. Perdas por erosão em diferentes manejos de solo e coberturas vegetais em solo Laterítico Bruno Avermelhado-distrófico (São Jerônimo). I. Resultados do primeiro ano. Revista Brasileira de Ciência do Solo, 1:123-127.

Freitas, V.H. de, 2000. Manejo de suelo en pequeñas fincas. Estrategiasy métodos de introducción, tecnologías y equipos. FAO Soils Bulletin 77, Rome. 66 pp.

Greenland, D.J. and Adams, 1992. Organic matter in the soils of the Tropics - From myth to complex reality. In: Myths and science of soils in the tropics. SSSA Special publication no. 29.

Lal, R., 1999. Global carbon pools and fluxes and the impact of agricultural intensification and judious land use. In: FAO. Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable land management with a focus on Latin America and the Caribbean. Proceedings of the IFAD/FAO Expert Consultation. Rome 15 April 1999. p. 45-52.

Landers, J.N., G. Sant'anna de C Barros, M. Theoto Rocha, W. A. Manfrinato, J. Weiss. 2001. Environmental impacts of Zero Tillage in Brazil – a first approximation. I World Congress on Conservation Agriculture, Madrid, 1–5 October, 2001

Lovato, T. 2001. Dinâmica do carbono e nitrogênio do solo afetada por preparos do solo, sistemas de cultura e adubo nitrogenado. Porto Alegre: UFRGS. 130p. Tese de Doutorado.

Pottker, D. 1977. Efeito do tipo de solo, tempo de cultivo e da calagem sobre a mineralização da matéria orgânica em solos do Rio Grande do Sul. Porto Alegre: UFRGS. 128p. Dissertação de Mestrado.

Reicosky, D.C. & Lindstrom, M.J. 1993. Effect of fall tillage method on short-term carbon dioxide flux from soil. Agron. J., 85:1237-1243.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas and P.E. Rasmunssen. 1995. Soil organic matter changes resulting from tillage and biomass production. Journal of soil and water conservation 50(3):253-261.

Roth, C.H. 1985. Infiltrabilität von Latosolo-Roxo-Böden in Nordparaná, Brasilien, in Feldversuchen zur Erosionskontrolle mit verschiedenen Bodenbearbeitungssystemen und Rotationen. Göttinger Bodenkundliche Berichte, 83, 1-104.

Testa, V.M., L.A.J. Teixeira and J. Mielniczuk, 1992. Características químicas de um Podzólico vermelho-escuro afetadas por sistemas de culturas. Revista Brasileira de Ciência do Solo, 16: 107-114.

Wünshe, W.A., J.E. Denardin. J. Mielniczuk, J. Scopel, P. Schneider and E.A. Cassol, 1980. Projeto integrado de uso e conservação do solo - Um esforço conjunto para a conservação do solo no Rio Grande do Sul. III Encontro Nacional de Pesquisa em Conservação do Solo. Recife, Julho de 1980. In: Trigo/Soja 51: 20-25, Porto Alegra.