Soils under Cerrado: A Success Story in Soil Management

By A. Scheid Lopes

Until the 1970s, the cerrado region of Brazil was considered marginal for crop production. However, the technologies developed by scientists of the Cerrado Research Center and other research institutions have completely changed the picture. The objective of this article is to present a summary of management technologies, already practiced by a great number of farmers, which remove low inherited soil fertility as a limiting factor for crop production. The goal is to achieve maximum economic yields (MEY) in a sustainable way in a period of 3 to 4 years.

The area under cerrado (savanna) vegetation in central Brazil occupies 2.04 million square km or 23 percent of the country. It is estimated that 50 percent of this area is arable land and two-thirds could be incorporated into agriculture/livestock/forestry production. Annual rainfall ranges from 900 to 2,000 mm, usually in the 1,000 to 1,400 mm range. The mean annual temperature is 22˚C in the south of the region and 27˚C in the north (Goedert, 1989). Most of the soils in this area are highly weathered Oxisols (46 percent), Ultisols (15 percent) and Entisols (15 percent), with serious limitations for crop production in terms of low natural soil fertility.

These soils are acid and have low availability of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), molybdenum (Mo) and zinc (Zn). They are high in aluminum (Al) saturation and possess high P fixation capacities.

Besides these chemical problems there are other production limitations (Lopes and Guilherme, 1994):

- typically a 5 to 6 month dry season (April to September);
- dry spells of one to three weeks, locally called “veranicos”, during the rainy season, generally associated with high evapotranspiration rates;
- low water holding capacity, even in clayey soils;
- limiting rooting depth of many crops as a function of Al toxicity and/or Ca deficiency in subsurface soil layers.

These points emphasize the need for appropriate management technologies to increase the probability of success when incorporating cerrado soils into the crop production process.

In spite of all these problems, a break-through in agricultural development has taken place in the area during recent decades, mainly involving food crops, pasture and coffee. Yield levels of some of these crops exceed national averages. Further, in 1992 they contributed nearly 20 million tonnes of grains (28 percent of Brazilian production), 43 percent of soybeans, 3 percent of the wheat, 14 percent of dry beans, 24 percent of the rice, 9 percent of

Table 1. Economic balance of the liming effect in three crops in Brazil.

Lime rate in first year tonnes/ha	Production increase after liming, kg/ha — First year	Period under review
	Five years of corn	
3.0	422	7,877
6.0	600	11,619
9.0	1,250	13,777
	Three years of soybeans	
1.5	473	1,746
3.0	513	2,357
4.5	645	2,610
	Four years of cotton	
1.5	32	1,072
3.0	245	2,609
6.0	442	4,092

Source: Raij & Quaggio, 1984

the sugarcane and 21 percent of the coffee, all on 10 million ha (FIBGE, 1993). Moreover, 35 million ha of improved pastures are producing 40 percent of Brazil's meat and 12 percent of its milk production. The potential of this region is considered by Norman Borlaug, Nobel Peace Prize winner in 1970, as the last great agricultural frontier of the world (Borlaug and Dowswell, 1993). Recent estimates suggest the area can produce 250 million tonnes of grains, 12 million tonnes of meat and 90 million tonnes of perennial crops (Macedo, 1995); (Lopes and Guilherme, 1994).

Liming

Liming is an essential management practice for non acid-tolerant crops to correct low pH and Al toxicity (Table 1). The average rates of aglime are 3 tonnes/ha (range 1 to 5), broadcast and incorporated as deep as possible to help increase rooting depth and, thus, tolerance to dry spells during the cropping (rainy) season. For established perennial crops, improved pastures and grain crops under no-till or minimum tillage, rates of lime are in general one-fourth normal rates.

Since most of these low pH soils are also deficient in Ca and Mg, dolomitic lime or Mg is most commonly recommended. The two methods commonly used to evaluate lime needs in this region are based upon Al and Ca + Mg levels and an increase in base saturation to a more adequate level for a given crop. Calculations for lime recommendation according to these methods are as follows:

1.0 Al and Ca + Mg method (Sousa et al., 1989)

1.1 Soils with > 20% clay and Ca + Mg < 2 meq/100 cm^3:
Rate of lime (t/ha)= (2 x meq Al/100 cm^3)+(2 - meq Ca + Mg/100 cm^3)

1.2 Soils with > 20% clay and Ca + Mg > 2 meq/100 cm^3:
Rate of lime (t/ha)=2 x meq Al/100 cm^3

1.3 Soil with <20% clay:
Rate of lime (t/ha)=2 x meq Al/100 cm^3 or
Rate of lime (t/ha)=2 - meq Ca + Mg/100 cm^3,
applying the higher of the two rates

2.0 Increase base saturation method (Quaggio et al., 1983)
Rate of lime (t/ha) = T (V2 - V1)/100 where T = CEC at pH 7.0;
V2 = base saturation adequate for a given crop, V1 = base saturation at pH 7.0.

The residual effects of these rates of lime, in general, can vary from 3 to 5 years. Lime should be broadcast and incorporated at least 60 to 90 days before planting or fertilization.

Amelioration of Subsoil Acidity

In most cases, the beneficial reactions of lime occur only in the incorporation layer. Low levels of Ca and Al toxicity can still restrict rooting depth in sub-surface soil layers (Lopes, 1983; Goedert, 1987). Under these conditions the use of agricultural gypsum, by-product of phosphoric acid production, has been shown to be an efficient management technology to increase rooting depth below the surface layer (Figure 1).

It is extremely important to evaluate acidity parameters (pH, Ca and Al levels) in the surface layer (0 - 20 cm), and to depths of 20 to 40 and 40 to 60 cm. For perennial crops, evaluations should also include the 60 to 80 cm depth. For areas with 0.3 meq Ca/100 cm^3 or less and/or 0.5 meq Al/100 cm^3 or more and/or more than 30 percent Al saturation of the effective CEC in these sub-surface layers, the use of agricultural gypsum at higher rates is recommended to move Ca down to these layers and/or to reduce Al toxicity throughout the soil profile (Lopes, 1983; Lopes, 1986).

The simplest soil parameter to evaluate rates of gypsum under these conditions is percent clay. Two approaches are most commonly used:

1. Rate of gypsum (kg/ha) = 300 + (20 x % clay), developed by Lopes et al., 1986, to improve the 20 to 40 cm layer.
2. Rate of gypsum (kg/ha) = 50 x % clay, developed by Sousa et al., 1992, to improve the 20 to 60 cm layer. For perennial crops, multiply the results by 1.5.

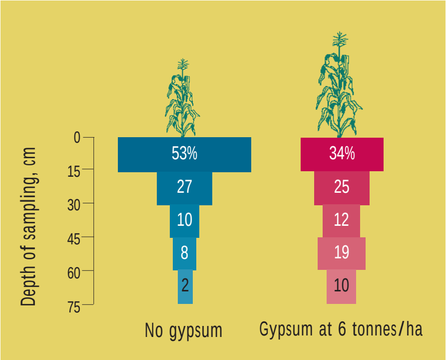

Figure 1. Relative distribution of a corn root system with and without gypsum in a clayey Oxisol in central Brazil. Source: Sousa & Ritchey, 1986

Improvements in yields from gypsum use in these soils, mainly due to increased rooting depth and more efficient use of subsoil water and nutrients, are reported as: 72 percent for corn, 59 percent for wheat, 14 percent for soybean, 30 percent for coffee, and 80 percent for lucerne. Significant responses have also been obtained for mango, orange and sugarcane (Sousa, Lobato and Rein, 1995).

The recommended rates of gypsum are generally surface broadcast at 60 to 90 days after liming. Residual effects last from 5 to 15 years.

Build-up Phosphate Fertilization

Build-up phosphate fertilization in these soils with extremely low levels of available P has been a crucial step to achieving adequate and economic yields in a short period of time (Figure 2). Average soil P content is 0.4 parts per million (ppm), and soil P fixation capacity is high. There is a well-defined relationship between clay percentage and rate of P needed to build levels of soil P in these low activity clay soils. According to Lopes (1983) 3 to 5 kg of soluble P_2O_5 for each one percent of clay, usually broadcast in the first year and incorporated by disking before planting, followed by small maintenance crop fertilization, are recommended to achieve the desired yield goal within 3 years of incorporation.

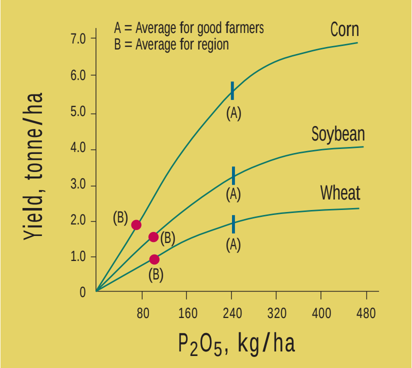

Figure 2. Corn, soybean and wheat yields under non-irrigated conditions, as a function of build-up rates of phosphate fertilization. Source: Wagner, 1986

Another common approach to gradually build P status in these soils is to apply a little excess P_2O_5 (20 kg/ha above normal maintenance crop fertilization) at planting. This rate should be applied for 5 to 6 years. After P soil levels reach medium to high, only maintenance fertilization is used (Sousa, 1989).

For grain crops, sugarcane and coffee, soluble P fertilizers (i.e. single superphosphate, triple superphosphate, thermophosphate or highly reactive rock phosphates), have been confirmed as the most efficient sources for use following liming. Due to the low reactivity of most Brazilian rock phosphates, these products are usually recommended for direct application only for opening new areas with pastures of acid tolerant species (Smyth and Sanchez, 1982; Goedert and Lobato, 1984; Goedert and Lopes, 1988). Since liming reduces the agronomic effectiveness of low reactivity rock phosphates even more, lime in these cases is recommended at one-fourth the normal rates (Lopes and Guilherme, 1989).

Build-up Potash Fertilization

Build-up of K is recommended in areas with less than 30 ppm of available K and more than 15 percent clay (Sousa, 1989). Rates normally vary from 50 to 100 kg K_2O/ha, depending upon soil texture, crop demand, etc. Rates can also be calculated to achieve 3 to 5 percent K saturation at pH 7.0. (Lopes and Guidolin, 1989). Potash fertilizers should be broadcast along with build-up phosphate fertilization.

Build-up Micronutrient Fertilization

The concept of build-up fertility of cerrado soils also includes micronutrients. Micronutrient fertilizers can be broadcast applied to those soils with naturally low availability (Zn, Cu, B and Mo). Several combinations of micronutrients are available for use according to specific problems in a given micro region of the cerrado.

Organic Matter Management

The great majority of the cerrado soils contain low activity clays, medium organic matter content and very low CEC, more than 70 percent of which is due to the organic fraction. Under management systems that include monocropping, conventional tillage and use of lime and fertilizers, organic matter depletion is fast and can reach unsustainable low levels after a few years of cultivation. Under these conditions it is extremely important to make use of a combination of more sustainable agricultural practices to avoid rapid declines in organic matter content. Practices such as crop rotation including improved pastures, green manure, minimum or no-tillage, cover crops, mulching for small farms, manure and adequate crop residues, are important management tools. The rapid increase in no-till in this region in recent years is certainly a key factor for future sustainable agricultural development. Common crop sequences used under minimum or no-tillage are presented in Figure 3.

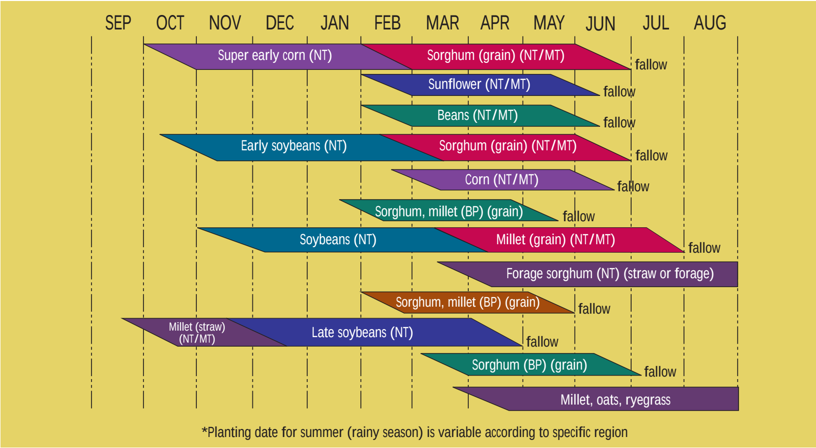

Figure 3. Commonly used crop succession for minimum (MT) or no-tillage (NT) in the cerrado region; BP = broadcast planting. Source: Sousa, 1995

Maintenance Fertilization

Following the build-up program, adequate and balanced maintenance programs are essential to maintain soil fertility and optimum crop production potential.

Present Land Use and Potential of the Cerrado Region

The present agricultural development of the cerrado region is the result of an integrated strategy, developed by the Cerrados Agriculture Research Center (CPAC), founded in 1975. It also involves other units of EMBRAPA (Brazilian Agriculture Research Enterprise), state research institutes, state and federal universities, as well as international institutes/universities such as CIAT, JICA, ORSTOM, CIRAD, TROPSOIL, Cornell University and North Carolina State University (Macedo, 1995).

A broad diagnosis of the major limitations for agriculture improvement was made in the 1970s, identifying the priority problems as a base to establish the research program:

- low knowledge of the natural resources
- irregular distribution of rain and dry spells
- low soil fertility
- soil degradation
- occurrence of pests and diseases
- inefficient production systems

Research projects were organized into three programs (Macedo, 1995):

- Natural Resource Evaluation
- Soil and Water Management
- Production Systems.

Table 2. Production of grain crops and beef cattle in the cerrado region.

Activity	Area, million ha	Productivity, t/ha/year	Production, million tonnes
Grain crops			
Rainfed	10.0	2.0	20.0
Irrigated	0.3	3.0	0.9
Beef cattle	35.5	0.05	1.7
Total	45.3		22.8

Source: Macedo, 1996

Table 3. Cerrado region production as a percent of totals for all of Brazil.

Output	% of total	Output	% of total
Soybeans	42.9	Coffee	21.2
Rice	24.4	Cassava	11.3
Corn	22.9	Cotton	12.1
Beans	14.2	Sugarcane	9.3
Wheat	3.1	Beef cattle	40.5

Source: FIBGE, 1993

Present Land Use

It is estimated that of the present 47 million ha (23 percent of the cerrado area) now cultivated, 10 million ha are grain crops under rainfed conditions, 0.3 million ha are grain crops under irrigation, 35 million ha are improved pastures mainly for beef cattle, and 2 million ha are perennial crops, including coffee, fruits and reforestation (Table 2). The 22.8 million tonnes of food produced in the region account for one-third of total Brazilian production.

Detailed information about specific crops and their production in relation to total Brazil production is presented in Table 3. It is of interest to note that soybeans, coffee and beef cattle account for 43 percent, 21 percent, and 40 percent of Brazil's production, respectively.

The present index of crop productivity in the cerrado region is a little above the Brazilian average, but is still below that obtained by farmers that use adequate available technologies. Average productivity in the cerrado region compared to the average for Brazil is shown in Figure 4. Some of the production is comparable to that obtained in the better soils of the world.

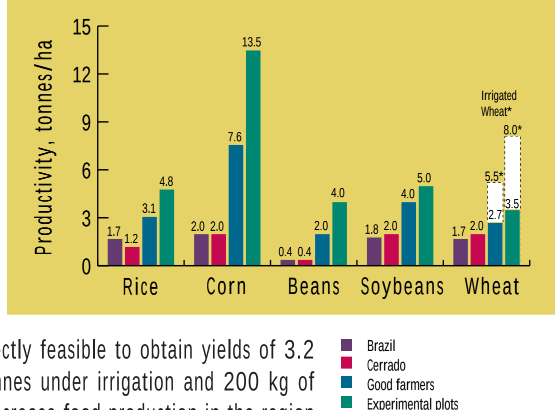

Figure 4. Average productivity and potential for selected crops in the cerrado region as compared to the average for Brazil. Source: Adapted from Macedo, 1995

Potential Use

According to Macedo (1995), if one considers the increase in productivity obtained by cerrado farmers who utilize the technologies already available, it is perfectly feasible to obtain yields of 3.2 tonnes of grain/ha/year under rainfed conditions, 6 tonnes under irrigation and 200 kg of meat/ha/year. This means that it would be possible to increase food production in the region to nearly 100 million tonnes, enough to feed a population of 250 million.

In the short term, the use of available technology to increase crop and beef cattle productivity in the area deserves the total attention of agriculturists. Technology is also a very powerful tool for use in environmental preservation. It diminishes the rate of deforestation of the more fragile ecosystems, helps to maintain biodiversity, and makes better use of the

Table 4. Food production using available technology in the potential area of the cerrado in Brazil.

Activity	Area, million ha	Productivity, t/ha/year	Production, million tonnes
Grain crops			
Rainfed	60.0	3.2	192
Irrigated	10.0	6.0	60
Beef cattle	60.0	0.2	12
Perennial crops	6.0	15.0	90
Total	136.0		354

Assumptions: One-third of the area (71 million ha) maintained for environment preservation; water availability to irrigate 10 million ha; average productivities would increase to levels compatible with available technology.

Source: Macedo, 1995

natural resources.

In the long term, however, one must consider the total potential of the cerrado region as an important and probably the last great continuous agricultural frontier to help to produce food to satisfy the future demand of the growing world population.

If 136 million of the 204 million ha of the cerrado region can be incorporated into a sustainable production system for the medium to long run, it would be possible to produce around 350 million tonnes of food in the area (Table 4). In reaching this production level, the cerrado agricultural frontier could be expanded by 89 million ha, while protecting 71 million ha for environmental preservation.

It should be stressed, however, that several factors concerning structural, economic and political aspects have to be considered in order for the cerrado region to achieve a more complete development for agriculture, livestock and reforestation activities.

The question is not only a matter of availability of sustainable technology for soil management in this region, but also the need for special programs to improve today's infrastructure of roads, railroads, storage facilities, electricity and water supply, among others. Special lines of credit mainly related to liming and build-up phosphate fertilization, as well as reduction of taxation for agricultural inputs and products, are essential to expand the rational development of the area.

Above all, a necessary political decision is to adopt medium to long-term agricultural policies as a part of a broad food security program for the country. The beneficial implications of such policies must not be considered only for the agriculture-livestock-forestry sectors. The development already reached in one-fourth of the cerrado region has demonstrated it is possible to reduce excessive migration of the rural population to big cities. Hundreds of small, well planned towns, less than 15 years old and built as a result of the development of these distant areas, have living conditions better than many old traditional towns near the coast. The social benefits of such development programs in the past extend to the cerrado region.

Finally, it is important to mention that under present conditions in the Brazilian economy, the philosophy for rural activities is to first increase productivity in the area already under cultivation by using advanced sustainable management. Only then is the agricultural frontier expanded.

It is now recognized that increased crop-livestock-forestry production in the cerrado region by using available sustainable technologies constitutes a very powerful environment preservation instrument. Such production contributes to reduced rates of deforestation, including the Amazon Forest and other more fragile ecosystems not satisfactory for intensive use, but with high potential for irreversible degradation. BCI

Dr. Lopes is Professor Emérito, Depto. de Ciencia do Solo, UFLA Caixa Postal 37, 37200-000 Lavras, MG, Brazil. Fax: 55-35-829-1251. Technical Consultant, ANDA, Associação Nacional para Difusão de Adubos e Corretivos Agricolas, Praça Dom José Gaspar 30, 9ª andar, Centro, 01047-901, São Paulo, SP, Brazil. Phone: 55-11-255-9277, Fax: 55-11-214-2831.

This article is adapted from a paper presented at the International Fertilizer Industry Association (IFA)/Potash & Phosphate Institute (PPI) Regional Conference for Latin America and the Carribbean, June 25-29, 1996, Mexico, D.F.

Bibliography

Borlaug, N.E. and C.R. Dowswell. Fertilizer: to nourish infertile soil that feeds a fertile population that crowds a fragile world. Keynote address at the 61st Annual Conference, International Fertilizer Industry Association (IFA), May 24-27, 1993, New Orleans, Louisiana, USA, 18 p.

FIBGE. 1993. Produção agrícola municipal. Fundação Instituto Brasileiro de Geografia e Estatística.

Lopes, A.S. 1983. Solos sob "cerrado": caracteristicas, propriedades e manejo. Associação Brasileira para a Pesquisa da Potassa e do Fosfato, Piracicaba, SP. 162 p.

Lopes, A.S. 1986. Calagem e gesso agrícola. Encontro técnico sobre gesso agrícola. Fosfértil/Petrofértil, Belo Horizonte, MG. 58 p. (mimeo).

Lopes, A.S. and J.A. Guidolin. 1989. Interpretação de análise de solos: conceitos e aplicações. ANDA, São Paulo, SP, Boletim Técnico N° 2, 3ª. edição. 64 p.

Lopes, A. S. and L.R.G. Guilherme. 1994. Solos sob cerrado: manejo da fertilidade para produção agropecuária. ANDA, São Paulo, SP, Boletim Técnico N° 5, 2ª edição. 62 p.

Macedo, J. 1995. Prospectives for the rational use of the Brazilian Cerrados for food production. Planaltina, EMBRAPA-CPAC. 19 p.

Goedert, W.J. 1987. Management of acid tropical soils in savannas of South America. p. 109-127. *In:* IBSRAM (International Board for Soil Research and Management). Management of acid tropical soils for sustainable agriculture: proceedings of an IBSRAM inaugural workshop. Bangkok, Thailand.

Goedert, W.J. and E. Lobato. 1984. Avaliação agronômica de fosfatos em solos de cerrado. R. bras. Ci. Solo, Campinas, SP, 8:97-102.

Goedert, W.J. 1989. Região dos cerrados: potencial agrícola e política para o seu desenvolvimento. Pesq. agropec. bras., Brasilia, DF, Brasil, 24(1):1-17.

Goedert, W.J. and A.S. Lopes. 1988. Eficência agronômica de fertilizantes fosfatados para culturas anuais, perenes, pastagens e reflorestamento. p. 24-29. *In:* Seminário sobre recuperação de fósforo. São Paulo, SP, IBRAFOS.

Quaggio, J.A. 1983. Critérios para calagem em solos do estado de São Paulo. Unpublished manuscript M.S. thesis. Escola Superior de Agricultura "Luis de Queiroz," Piracicaba, SP, 76 p.

Raij, B. van and J.A. Quaggio. 1984. Uso eficiente de calcario e gesso na agricultura, p. 323-346. *In:* Espinosa, W. and A.J. de Oliveira (ed.). Simpósio sobre fertilizantes na agricultura brasileira. Brasilia, D.F. Anais..., EMBRAPA-DEP.

Sousa, D.M.G. de. 1989. Calagem e adubação da soja no cerrado. Porto Alegre, DEAGRO/ADUBOS TREVO, S/A, p. 17.

Sousa, D.M.G. de, T.A. Rein, E. Lobato and D. Ritchey. 1992. Sugestões para diagnose e recomendação de gesso em solos de cerrado. p. 138-158. *In:* II Seminário sobre o uso de gesso na agricultura. Uberaba, MG. Anais..., São Paulo SP, IBRAFOS.

Sousa, D.M.G. de, E. Lobato, and T.A. Rein. 1995. Uso de gesso agrícola nos solos dos cerrados. p. 20. Planaltina, DF, EMBRAPA-CPAC, Circular Técnica N° 32.

Sousa, D.M.G. de and K.D. Ritchey. 1986. Correção de acidez subsuperficial: uso de gesso no solo do cerrado, p. 91-113. *In:* Decher, A.R. and Q.A. C. Carmelo de (ed.). Simpósio avançado de quimico e fertilidade do solo. Campinas, SP, Fundação Cargill, p. 91-113.

Sousa, W. de. 1995. Plantio direto. p. 32-45. Manchete Rural. Rio de Janeiro, RJ, N° 98, agosto.

Smyth, T.J. and P.A. Sanchez. 1992. Phosphate rock dissolution and availability in cerrado soils as affected by phosphorus sorption capacity. Soil Sci. Soc. Am. J., Madison, Wisconsin, USA, 46:339-345.

Wagner, E. 1986. Desenvolvimento da região dos cerrados. *In:* Goedert, W.J. (ed.) "Solos dos cerrados" Tecnologia e estratégia de manejo. São Paulo, SP, Editora Nobel, 19-31.