Soil Fertility Evaluation and Control for Annual Crops in the Cerrado

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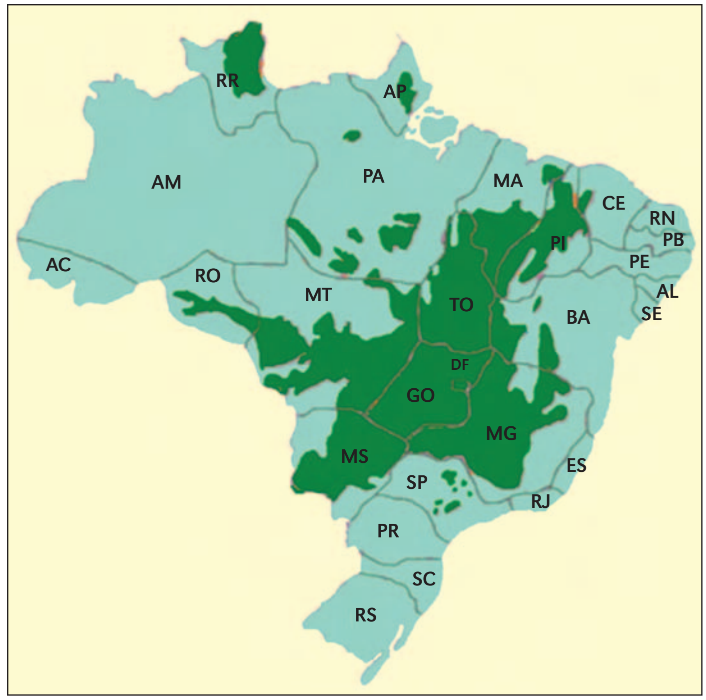
The authors review recommended practices for evaluating and managing liming and fertilizer use for high yielding annual crops growing under no-till (NT) cultivation within the Cerrado.

Brazil has increased its cultivated land area by 41% over the last 30 years, from 34 to 48 million ha. A great part of this land is located in the central savannah or Cerrado **(Map 1)**. Soils of the Cerrado are highly weathered, acid, and low in available plant nutrients. Until recently, past land cultivation in the Cerrado generally combined inadequate use of machinery plus monocrop cultivation of soybean. This has encouraged low soil quality, especially in terms of soil organic matter (SOM). No-tillage systems, as opposed to conventional tillage (CT), have now been implemented in about half of the Cerrado. This cultivation system has proven effective for improving soil quality, leading to more sustainable farming. This article focuses on NT soil fertility evaluation and control with macronutrients within the Cerrado. Extension of such management may be feasible to other tropical areas.



Map 1. Map of Brazil indicating (dark green) area of Cerrado region (Brazilian Savanah; 204 million ha = 20% of the country of Brazil). Source: IBGE, 2005.

Soil Organic Matter

Among soil components and properties, SOM more closely relates to soil quality, maximizing soil resistance to erosion, water infiltration and retention, soil cation exchange capacity (CEC), soil nutrient stocks, and microbiological activity. Experiments comparing CT and NT show a trend for higher SOM at the soil surface with NT **(Figure 1)**. About 90% of CEC in these soils is accounted for by the SOM pool. Thus, a good option to increase nutrient recycling and nutrient use is to increase SOM. Example data from a long-term pasture-annual crop rotation leading to higher SOM (Area A), compared to plots exclusively under annual cropping (Area B), found that a 3.0 t/ha soybean yield was possible in Area A with only 3 mg/dm^3 of Mehlich I P and 3.7% of SOM, versus Area B, which required 6 mg/dm^3 of P with 2.8% of SOM. Consequently, in the Cerrado it appears critical to adopt and manage its soils under NT to promote a high input of crop residues that can maintain, or increase, SOM. Several research projects have been established lately to verify the best cropping system options for each region of the Cerrado. In general, systems involving pasture crops lead to higher SOM and soil quality, which with time contributes favorably to soil nutrient management.

Soil acidity

Surface and subsurface soil acidity should be very well evaluated and controlled before establishing a tropical NT system. This will help to improve root development, increasing nutrient and water uptake by crops.

Surface soil superficial acidity (0 to 20 cm) is generally corrected to pH 6.0 in water, which in such soils relates to a base saturation[1] (BS) of 50%, by the formula:

$$Lime\ (\text{t/ha}) = \frac{(BS\ 2 - BS\ 1) * CEC}{ECCE}$$

where:
BS 2 = Ideal BS for specific crop systems.
BS 1 = Present BS obtained by soil analysis.
CEC = Cation Exchange Capacity at pH 7.
ECCE = Effective Calcium Carbonate Equivalent.

Note that the formula above takes into consideration properties of soil (BS 1 and CEC), crops (BS 2) and lime (ECCE), which leads to reasonably accurate rates of lime for each field situation. Calcium to Mg ratios should be in the range of 1:1 to 10:1, always with a minimum of 0.5 cmol$_c$/dm^3 of Mg. Before starting NT, lime should be uniformly incorporated in soil to a 20 cm depth. When feasible, lime should be incorporated at lower soil depths by correcting the amount showed in the formula above considering the analysis of 20 to 40 cm soil sample.

In general, soil acidification is slower under NT cultivation systems, as compared to CT **(Figure 2)**, where it occurs more intensively in the topsoil layer (5 cm) as a consequence

Abbreviations and Notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; B = boron; Cu = copper; Fe = iron; Mn = manganese; Zn = zinc.

[1]*Base saturation = BS = (K + Ca + Mg/CEC)*100, where CEC is the cation exchange capacity at pH 7.0.*

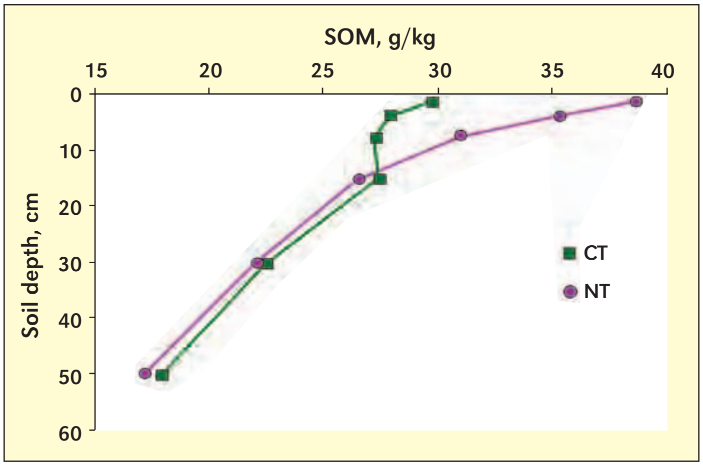


Figure 1. SOM contents of an Oxisol profile comparing CT and NT after 10 years of cultivation of corn and soybean.
Source: Nunes et al., 2008.

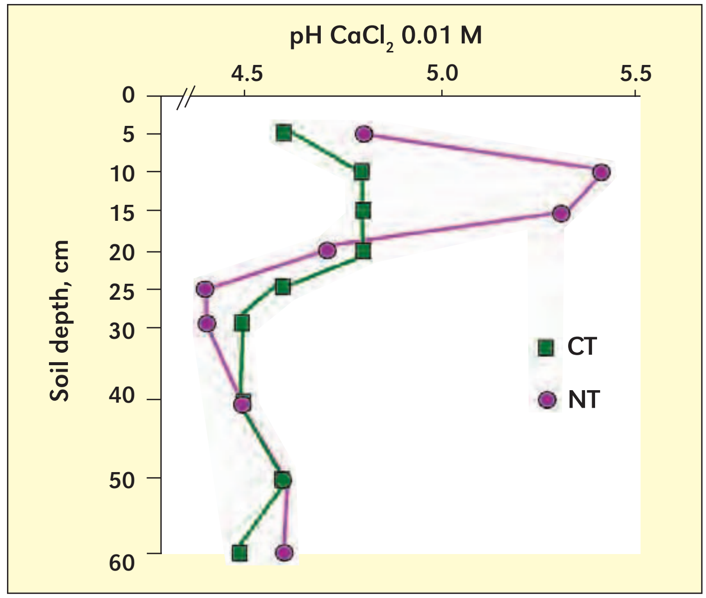


Figure 2. Soil pH in an Oxisol profile after 6 years of lime application as a function of cultivation system.
Source: Sousa and Lobato, 2004.

of nitrification after N mineralization of crop residues and use of N fertilizers. Some have observed reductions of up to 35% in the amount of lime necessary to maintain ideal BS in the top 20 cm under NT when both cultivations systems were compared. In a system already under NT, soil acidity evaluation is done by soil analysis, with application of lime to reach a BS of 50% recommended when present BS is under 40%. The distribution of lime in this case should be on the soil surface with no incorporation.

Subsurface soil acidity (20 to 60 cm) is also very common in the Cerrado region of Brazil. These soils are generally extremely low in Ca and may also be associated with high exchangeable aluminum (Al) or high Al saturation[2], which impose problems to plant root development. Consequently, soil sampling at these soil layers (20 to 40 cm and 40 to 60 cm or at least 30 to 50 cm) is extremely important. Either phosphogypsum ($CaSO_4 \cdot 2H_2O$; PG) or mined gypsum (gypsite) are generally utilized to ameliorate subsoil acidity. These products add Ca and S and can, in proper rates, minimize Al toxicity below the top 20 cm of soil. Application of PG is recommended when subsoil samples show Al saturation higher than 20% and/or exchangeable Ca is lower than 0.5 $cmol_c/dm^3$. In such cases, the amount of PG required to ameliorate sub soil acidity follows the formula:

PG (kg/ha) = *50 x SCC*

where:

SCC(%) = Soil Clay Content at soil depth of 30 to 50 cm or 40 to 60 cm

Due to higher solubility compared to lime and leaching of Ca and sulfate in the soil profile, PG is broadcasted over the soil surface with no incorporation necessary. Good responses to PG application have been noted for annual crops, especially for corn, wheat, soybean, beans, and cotton. **Table 1** presents some examples for PG responses in soils of the Cerrado. It is expected that similar responses may happen in similar soils of the world. The response to PG is due not only to the addition of S, but also to better root development **(Figure 3)**, which leads to higher nutrient and water uptake **(Table 2)**.

Table 1. Effect of phosphogypsum (PG) application on yields of cotton and soybean cultivated under NT.

PG Rate	Cotton	Soybean
	t/ha	
0	1.8b	3.3b
3	2.6a	4.0a

Averages followed by the same letter in the column do not statistically differ by the t test at 5% probability. Source: Sousa et al., 2008.

Soil Nutrient Management for High Yields

Studies have shown that fertilizer requirements in NT should be similar (initially) compared to CT. Definitions of fertilizer requirement in the Cerrado are based on soil analysis, nutrient source, and expected yield. Maintenance fertilizers are generally applied in the seed row, but in some situations (i.e. soils with medium to high levels of available nutrients) they can be broadcast on the soil surface. Broadcast applications are sometimes important to farm operations as they can allow the planting of large areas within the best planting period. However, the lack of soil disturbance under NT does leads to soil stratification in terms of SOM and nutrient bioavailability.

[2]*Al Saturation = (KCl-extractable Al/Effective Cation Exchange Capacity)*100.*

Table 2. Cottonseed nutrient contents as a function of PG rate in an Oxisol under NT.

PG Rate	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg/ha						g/ha				
0	32 b	7 b	12b	1.0 b	3.0 b	1.8 b	15 b	7 b	48 b	11 b	37 b
3	50 a	11 a	18 a	1.5 a	4.8 a	3.0 a	23 a	10 a	69 a	18 a	55 a

Averages followed by the same letter in the column do not statistically differ by the t test at 5% probability.
Source: Sousa et al., 2008.

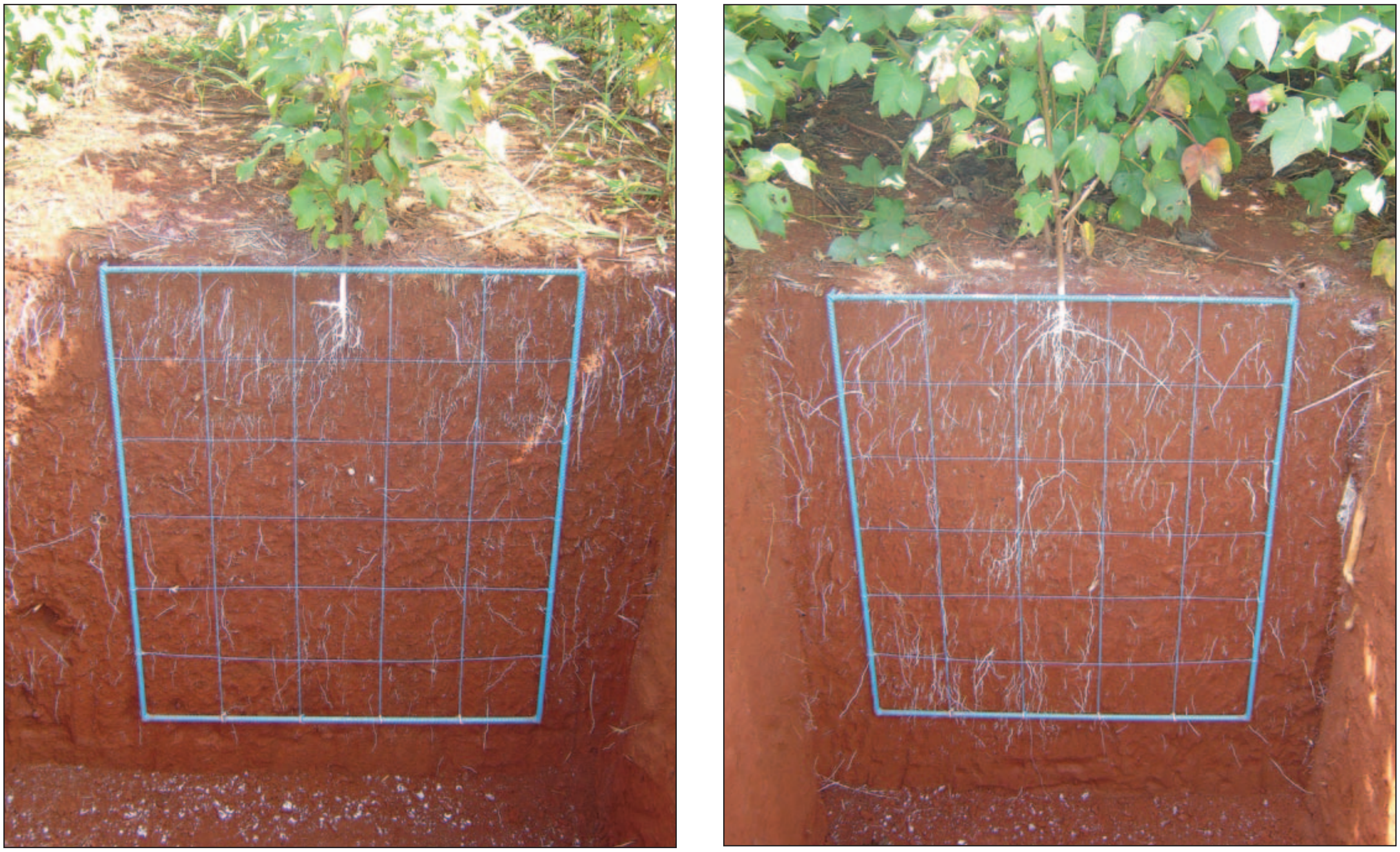


Figure 3. Cotton root development (at complete flowering) in the soil profile with (right) and without (left) PG application (grid of 15 cm x 15 cm). Source: Sousa et al., 2008.

Nitrogen

It is generally known that farmers should be careful in initial stages of NT cultivation regarding N because of lower rates of SOM mineralization and a higher possibility for N leaching due to reduced run-off and increased water infiltration through the soil profile. However, agronomic experiments in the Cerrado have shown similar yields without N application when comparing both cultivation systems. This should be related to higher rates of mineralization of crop residues in this environment, even under NT. Consequently, in the Cerrado, it is possibly not necessary to apply higher rates of N in crops planted within newly established NT fields compared to rates utilized in CT.

Nitrogen sources, when conveniently managed in well-drained soils, present similar agronomic efficiencies. It is important to note that urea should be incorporated to avoid higher N volatilization. It is recommended that N application rates be split, with 1/5 to 1/3 of the total N rate applied at seeding and the rest top-dressed during crop development (i.e. time and rate as a function of soil, crop, total rate, and irrigation, if applicable). For corn, in Oxisols with high clay content and medium to high base saturation status throughout the soil profile, up to 100 kg/ha of N can be applied at seeding, without topdress application. There are several criteria for defining N rates in the Cerrado (Sousa and Lobato, 2004). On average, to produce 1 t/ha of corn, wheat, rice, barley, and sorghum, it is necessary to apply 20 kg, 30 kg, 20 kg, 25 kg, and 30 kg of N, respectively. For soybean, no N is recommended due to biological N fixation.

Phosphorus

Soil P bioavailability is often extremely low in soils of the Cerrado. Fertilization with P is achieved in two different steps: (i) corrective and (ii) maintenance fertilization. A formula taking into account the soil P buffer capacity (SPBC) was developed to calculate the amount of P used to increase soil P status to the critical level (Sousa et al., 2006):

$$P_2O_5 \text{ (kg/ha)} = (DSPC - SPC) * SPBC$$

where:
DSPC = Desired Soil P Content (mg/dm^3)
SPC = Soil P Content (mg/dm^3)
SPBC = Soil P Buffer Capacity **(Table 4)**

Phosphorus fertilizer for corrective application should be broadcast and incorporated, before conversion to a NT system. If the soil P level is adequate (around the critical level), as shown in **Table 4**, maintenance P_2O_5 rates of 60 to 100 kg/ha should be enough for grain yields of 3 to 5 t/ha of soybean or 6 to 10 t/ha of corn. When the soil P level (Mehlich I) is above 6 mg/dm^3, 12 mg/dm^3, 20 mg/dm^3, and 25 mg/dm^3 for very clayey, clayey, medium-textured, and sandy soils, respectively, the maintenance fertilization can be reduced by half (Sousa and Lobato, 2004). For water-soluble P sources in NT, it is recommended to apply the fertilizer preferably in the row when soil P is below the critical level. In soils above the critical level, P fertilizers can be applied either way (i.e. in the row or broadcasted at soil surface). When P fertilizer is broadcast, special attention to soil and water conservation practices is required to avoid losing P-enriched topsoil or fertilizer P by erosion and runoff.

Potassium

Cerrado soils are low in exchangeable K and easily weatherable K-minerals. Potassium application in these soils can also be at corrective or maintenance levels. The corrective application is suggested when soil K (0 to 20 cm) is lower than 80 mg/dm^3 or 40 mg/dm^3 (Mehlich I), respectively, with CEC (pH 7.0) higher or lower than 4 cmol$_c$/dm^3. The amount of K applied follows the calculation below:

K_2O (kg/ha) = (DSKC – SKC) * 2.4

where:
DSKC = Desired Soil K Content (mg/dm^3)
SKC = Soil K Content (mg/dm^3)

Maintenance K fertilization is based on expected yield with the application of 60 kg/ha of K_2O for yields of 3.0 t/ha of soybean and 6.0 t/ha of corn. Once these soils generally have low CEC, it is recommended that application of rates of K_2O higher than 60 kg/ha should preferably be broadcast. For sandy or medium-textured soils with CEC lower than 4 cmol$_c$/dm^3, it is suggested to split the K rates, with 50% applied at sowing and 50% as topdressing. For corn, K topdressing generally takes place with the first N topdressing. For soybean, the recommendation is to apply K about 30 days after plant emergence.

With time under NT, the increase in SOM on the soil surface will lead to a reduction in K leaching. A study by Santos et al., 2008, has demonstrated that 89% of the K applied to a soybean-corn rotation in a clayey oxisol could be recovered after 8 years. Potassium recovered in this study considered K exported by plants plus exchangeable K in the top 30 cm of soil.

Conclusions

There are several management practices available to increase the effectiveness of lime and fertilizers in Cerrado soils or similar tropical soils. Practices such as cultivation under NT, crop rotation, inclusion of pasture and cover crops in the rotation to increase inputs of plant residues, maintenance of soil pH and associated BS at adequate levels, use of PG for subsoil acidity amelioration and adequate use of fertilizers, are essential to help farmers in the correct and effective use of fertilizers. Without adopting these practices, the general fertilizer efficiency, (defined here as proportion of the applied nutrient taken up by plants) is on average 55%. By utilizing such alternatives the efficiency can be as high as 85%. This translates into higher yields and, consequently, higher return on the investment for fertilizer. BC

Table 4. Soil P critical level in dryland annual crops cultivation systems and values of soil P buffer capacity utilized to calculate rates of corrective P_2O_5 application in Cerrado soils, as a function of soil clay content and method of P analysis.

Soil Clay	Soil P critical level in dryland cultivation systems[1]		Soil P buffer capacity (SPBC)[2]	
	Mehlich I	Resin	Mehlich I	Resin
%	------ mg/dm^3 ------		(kg P_2O_5/ha)/(mg/dm^3 of P)	
10-15	20	15	5	6
16-25	17	15	7	8
26-35	15	15	10	10
36-45	12	15	16	12
46-55	9	15	26	15
56-65	6	15	42	17
66-70	4	15	70	19

[1] For crops under irrigation, multiply by 1.4.
[2] Rate of P_2O_5 to increase soil P level by 1 mg/dm^3. Based on soil samples from 0 to 20 cm.
Source: Sousa et al., 2006.

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