DIAGNOSIS OF SOIL NUTRIENT CONSTRAINTS AND RECOMMENDATIONS FOR LIME, NITROGEN, AND PHOSPHORUS IN THE BRAZILIAN AMAZON REGION

Manoel da Silva Cravo

General Information on the Brazilian Amazon Region

The Brazilian Amazon occupies an area of approximately 4.9 million km^2, or about 2/3 of the Brazilian territory. The Amazon is located in the northern part of Brazil and contains the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, western Maranhão, and northern Mato Grosso. Vegetation varies from savanna to tropical rain forest (Kitamura, 1994).

A tropical rainy climate with a well defined dry season encompasses 52% of the region, 20% has a tropical rainy climate without a distinct dry season, and 28% has a tropical rainy climate with a predictable dry period of up to 90 days a year. The annual precipitation varies from 1,500 mm to 3,000 mm, with an average of 2,100 mm. The rainiest period occurs from May to October. The temperature varies from 25 °C to 27 °C and the regimes of soil humidity, according to Dematê (1988), are ustic (52%), udic (28%) and perudic (20%).

In the Brazilian Amazon, two great ecosystems exist: "terra firme" and "várzea". Terra firme is a generic term used to designate upland areas. This ecosystem covers the greatest part of the region, where the main soils belong to the orders of Oxisols and Ultisols, which are generally characterized as having low fertility and high acidity.

The term "várzea" is used to designate areas subject to periodic flooding. Those areas are distributed along the margins of the rivers and are subject to annual floods, through which new contributions of sediments are deposited (Cravo and Smyth, 1991). The várzeas soils are Entisols and they are characterized, by their high fertility and low acidity due to the sediment deposits that are derived from calcareous rocks of the Andes.

a) Predominant soils in the Brazilian Amazon

The predominant soils used for agriculture in the Amazon are Latossolos (Oxisols) and Podzólicos (Ultisols). These two soil orders cover approximately 75% of the region (Nicholaides *et al*, 1983).

The Oxisols, Psamments, Aquepts, Aquults, Entisols (várzeas), and Inceptisols occur in flat to slightly undulating terrain, which facilitates mechanization for agricultural use. These soils are not subject to great erosion risks (Table 1). On the other hand, Ultisols, Alfisols and some Entisols occur in undulated to strongly undulated terrain. These soils are prone to erosion and they must be tilled carefully to minimize soil loss.

Table 1. The major soil orders in the Amazon region of Brazil (4.98 million km^2).

Soil Collection System			
US. Soil Taxonomy	Brazilian	Amazon %	Relief
Oxisols	Latossolo Amarelo + Latossolo Vermelho-Amarelo	34	Flat to slightly undulating
Ultisols	Padzólico Veremelho-Aamarelo	39	Undulating to strong undulating
Alfisols	Padzólico Vermelho-Amarelo eutrófico Terra Roxa Estruturada	6	Undulating to strong
Entisols (Psamments)	Areia Quartzosa + Podzol Hidromórfico	5	Flat
Alfisols/ Inceptisols (Aquepts; Aquults)	Plintossolo	4	Flat
Entisols	Litólico + Cambissolo	6	Strong undulating to mountainous
Entisols; Inceptisols	Gley + Aluvial	4	Flat
Others		1	

Source: Adapted from Dematê & Dematê, 1997

Most Amazonian soils, except from Acre and Rondônia, have low fertility and high acidity, since they are old and, highly weathered soils. (Tables 2 and 3).

The main chemical limitations are deficiencies of P, K, S, Ca, Mg, Zn, P fixation, high Al toxicity, and low CEC (Table 2) (Dematê & Dematê, 1997).

The content of Ca + Mg rarely surpasses 2.0 cmol/kg. The aluminum saturation, in the great majority of the soils, surpasses 50%, which is considered toxic for most cultures. The base saturation is normally below the critical value for most crops, and together with high aluminum content, these soil problems represent the largest obstacle for crop root development (Dematê & Dematê, 1997).

The major physical problems for perennial and semi-perennial cultures in Amazonian soils are low water holding capacity and subsequent drought (Table 2).

Table 2. Major limiting factors to the agricultural uses of Brazilian Amazon soils.

Limiting Factors	% of the Amazon Region
Chemical	
Phosphorus deficiency	96
Potassium deficiency	77
Aluminum toxicity	73
Sulfur deficiency	72
Calcium deficiency	70
Magnesium deficiency	70
Phosphorus fixation	65
Zinc deficiency	62
Copper deficiency	30
Low CEC	55
Without important limitation	7
Physical	
Low humidity retention	56
Poor drainage and risk of inundation	24
Drought (> 3meses) for:	
- Perennial and semi-perennial crops	53
- Annual crops	0
Shallow soils	8
Sloping areas (> 30%)	6
Laterites in the subsoil	4
Sandy soil up to 2m	5
Risk of erosion	8

Source: Dematê & Dematê, 1997

Cultivation of these soils for small farmers, who do not have resources for acquisition of fertilizers and lime, is only possible after burning primary or secondary forests. The ashes act as fertilizers and correct soil acidity (Table 4), allowing one or two years of cultivation under shifting cultivation (Smyth & Bastos, 1984). However, improvement of soil chemical characteristics after burning is ephemeral (Smyth & Bastos, 1984).

When the small farmers abandon their plots, the chemical characteristics of these areas are similar to those shown in Table 5. These poor soil chemical conditions are the main reason that farmers move to other areas to repeat the slash and burn process. Areas with soils having these chemical characteristics are considered degraded. (Table 5).

With appropriate management, with judicious fertilizer and lime applications, these soils have produced high grain yields at the experimental level (Cravo & Smyth, 1997) and in large scale cultivation (Dematê & Dematê, 1997). In the South of Pará, Rondônia, western Maranhão, northern Mato Grosso and, more recently, Roraima and southern Amazonas, high yields of rice, soybean and corn have been obtained, proving the effectiveness of the fertilizer and lime use in the Brazilian Amazon.

b) Degraded areas in the Brazilian Amazon

In the humid tropics, as in the Brazilian Amazon, abandonment of areas after a short time of cultivation is worsened by the fact that the predominant agricultural system does not take into consideration the need of adoption of effective management practices to avoid the

Table 3. Main chemical characteristics and clay content of selected soil profiles of the Brazilian Amazon.

Prof. (cm)	Clay (g/kg)	pH (H_2O)	C (g/kg)	Al	Ca	Mg (cmolc/kg)	K	CTCe	Sat. Al (g/kg)	P (mg/kg)
Manaus – (AM) – Latossolo Amarelo álico (Oxisol)										
0 – 8	76	4.6	3.0	1.1	1.7	0.3	0.19	3.2	33	2
8 – 22	80	4.4	0.9	1.1	0.2		0.09	1.4	79	1
50 –125	88	4.6	0.3	1.0	0.1		0.04	1.1	88	1
Santarém – (PA) – Latossolo Amarelo álico textura média (Oxisol)										
0 – 30	26	3.4	1.2	1.1	0.02	0.14	0.04	1.4	81	3
30 – 60	36	3.7	0.9	0.8	0.11		0.01	1.0	85	2
85 – 110	37	4.0	0.5	0.8	0.10		0.01	.93	85	2
Purus – (AM) – Latossolo Amarelo álico argiloso (Oxisol)										
0 – 10	41	3.5	2.7	2.2	0.43	0.02	0.11	2.9	80	4
10 – 30	51	3.9	1.0	1.6	0.18	0.17	0.04	2.1	80	2
50 – 100	67	4.2	0.4	1.2	0.18	0.14	0.02	1.5	77	1
Coari – (AM) – Podzólico Vermelho Amarelo álico, textura média/argilosa (Ultisol)										
0 – 5	16	3.0	2.5	6.5	0.12	0.33	0.20	7.2	90	6
5 – 25	27	3.2	1.2	6.4	0.22		0.06	6.7	96	2
80 – 110	47	3.9	0.3	6.2	0.14		0.03	6.4	97	-
Rio Branco – (AC) – Podzólico Vermelho Amarelo álico, textura média (Ultisol)										
0 – 6	14	3.9	1.6	1.8	1.2	0.6	0.39	4.2	43	30
6 – 20	9	3.6	0.8	3.2	0.2	0.3	0.15	3.9	95	10
50 – 110	32	4.2	0.8	5.8	0.3	0.3	0.06	6.6	88	4
Ouro Preto – (RO) – Podzólico Vermelho Amarelo eutrófico (Ultisol)										
0 – 12	18	6.5	1.3	0.0	6.5	1.6	0.31	8.4	0	6
12 – 32	22	6.3	0.9	0.0	2.6	1.6	0.24	4.4	0	-
70 – 112	34	5.7	0.2	0.0	5.0	1.9	0.28	7.1	0	-

Source: Dematê & Dematê, 1997

Table 4. Chemical characteristics of an Amazon Oxisol (Yellow Latossol), before and after burning.

Vegetation	Time of sampling	pH (H_2O)	Ca	Mg	Al	Effective CEC	Al Sat. (%)	P	K
			(cmol$_c$/kg)					(mg/kg)	
Primary Forest	Before	4.2	0.1	0.3	1.8	2.3	78	2	22
	After	5.3	2.1	0.8	0.6	3.7	16	6	106
Secondary Forest	Before	4.7	1.7	0.9	1.0	3.8	26	3	65
	After	5.2	2.3	0.8	0.3	3.8	8	6	151

Source: Smyth & Bastos, 1984

Table 5. Chemical characteristics of an area of Oxisol (Yellow Latossol) in the state of Amazonas abandoned after continuous cultivation.

Sampling Depth cm	pH H_2O	Exchangeable Cations Ca	Mg	K	Al	Al Saturation %	Organic Carbon g/kg
		(cmol$_c$/kg)					
0 – 20	4.6	0.54	0.19	0.08	1.13	58	21.3
20 – 40	4.3	0.14	0.06	0.05	1.10	81	9.0
40 – 60	4.3	0.13	0.07	0.04	0.90	79	7.0

Source: Smyth & Cravo, 1992

gradual impoverishment of the land, culminating with the decrease in crop or forage production (Alvim, 1990; Cravo & Smyth, 1997). These areas thus, are considered abandoned and/or degraded areas.

The term "degraded areas" has been used frequently in the past few years with different meanings, leading to a distorted estimation of its magnitude in the Brazilian Amazon. Botanist, agronomists, geologists and the social scientists each have their own concept of what constitutes a degraded area. For our purpose, the concept that will be used is one proposed by FAO/UNESCO in 1977. Soil degradation is the result of one or more processes that minimize the soil's capacity, current or potential, to produce goods or services.

Soil degradation then can be one of the following: a) excessive mobilization of the soil; b) deficient covering of soil surface; c) decrease of soil fertility and/or increase of soil acidity; d) compaction, and; e) erosion and reduction of the soil organic matter content.

Different degrees of soil degradation can exist. Dubois *et al,* (1996) proposed the following categories of soil degradation:

Category 1 — Area that presents a significant reduction of the productive capacity, without great alterations of the natural capacity of reforestation. These areas are represented by secondary forest in abandoned areas and abandoned pastures where the biomass of the forage is larger than the biomass of the weeds. These are areas with relative facility to restore initial productivity capacity.

Category 2 — Area that presents a significant reduction of the productive capacity, with drastic decrease of the natural capacity of reforestation. These areas are represented by abandoned pastures where the critical level of biological productivity is low, with the biomass of the forage being very inferior to the weeds. Lands in this category were submitted to successive agricultural uses, without fertilizer and lime use, and with short fallow duration. These areas generally, are located far from primary forests that would provide sources of seeds for the reforestation. These are lands degraded by incipient erosion and already present a certain degree of difficulty for restoration and need high economic investment for its recovery.

Category 3 — Total degradation of the productive capacity of the soil. In this case, reversibility demands true engineering works, long rehabilitation period and high economic investments.

As emphasized previously, soils of abandoned areas in the Amazon present chemical characteristics similar to those presented in Table 5, that represent highly degraded soils. Work carried out in Manaus (Smyth & Cravo, 1990; Smyth & Cravo, 1992; Cravo & Smyth, 1997) and in the Peruvian Amazon (Sánchez *et al,* 1983) show that soils with these chemical characteristics, cannot produce satisfactory crop yields.

Following are the main factors that cause low crop yields: high acidity (Cravo & Smyth, 1997); low Ca reservation and high Al saturation (Smyth & Cravo, 1992); low P availability (Smyth & Cravo, 1990; Cravo & Smyth, 1997), and; high cation and nitrogen leaching losses (Cahn *et al,* 1993). Research results from several crops produced on degraded soils demonstrated significant yield responses to fertilization (Sousa, 1997; Gasparotto & Schroth, 1997).

The recovery of the productive capacity of these soils is dependent on the use of lime and chemicals or organic fertilizers. Special attention should be given to the use of green manures on degraded soils. Green manures fix N from the atmosphere and contribute to the recycling and storage of other nutrients (Macêdo *et al,* 1992; Smyth *et al,* 1991).

Agricultural Regions and Major Crops on the Brazilian Amazon

The regions of higher agricultural activity in the Brazilian Amazon can be divided by State and main crops (Table 6).

Table 6. Major agricultural activities by crop for State of the Brazilian Amazon.

State	Main crops
Acre	Soybean, corn, rice, beans, cowpea, cassava, coffee, peach palm for heart-palm, cattle for beef, cattle for milk, "pimenta longa", banana, brazil nut, rubber, regional fruits, "guaraná" and vegetables.
Amapá	Corn, rice, cowpea, cassava, banana, cattle for beef, brazil nut, vegetables and regional fruits
Amazonas	Soybean, corn, rice, beans, cowpea, cassava, vegetables, coffee, peach palm for heart-palm, cattle for beef, cattle for milk, brazil nut, regional fruits, "guaraná", citrus, coconut, pineapple, banana, oil palm, and rubber.
Pará	Soybean, corn, rice, beans, cowpea, cassava, coffee, peach palm for heart-palm, cattle for beef, cattle for milk, banana, brazil nut, regional fruits, vegetables, "guaraná", coconut, pineapple, oil palm, rubber, cotton, cocoa, citrus, sugar cane and "pimenta do reino".
Rondônia	Soybean, rice, cotton, corn, beans, cowpea, cocoa, coffee, citrus, pineapple, banana, cassava cattle for beef, cattle for milk, "guaraná", oil palm, rubber, peach palm for heart-palm, regional fruits, and vegetables.
Roraima	Soybean, rice, corn, beans, cowpea, pineapple, banana, cassava cattle for beef, cattle for milk, regional fruits, and vegetables.
Maranhão	Soybean, rice, corn, beans, cowpea, banana, cassava, cotton, cattle for beef, cattle for milk, regional fruits, and vegetables.
Mato Grosso	Soybean, rice, corn, beans, cocoa, banana, cassava, cotton, "guaraná", rubber, peach palm for heart-palm, cattle for beef, cattle for milk, regional fruits, and vegetables.

Challenges/Constraints and Opportunities for Improved Soil Nutrient Management

The main agricultural problem in the Brazilian Amazon is the soil chemical limitations. High acidity with high Al saturation and low natural fertility limits crop productivity. Moreover, the prices of fertilizers and lime in the region are very high, thus contributing to the increase of the production costs. For instance, in the State of São Paulo and in Central Brazil region, the price of lime is R$ 12,00 (US$ 7.00)/ton and the average cost of fertilizers is R$ 240,00 (US$ 140.00)/ton. Yet in the Amazon the lime costs R$ 120,00 (US$ 70.00) and the fertilizers R$ 720,00 (US$ 420.00) / ton. The higher price in the Amazon region is due to the increased transportation costs.

In the Amazon there are some natural lime deposits: Maués and Urucará, in Amazonas, Capanema in Pará, Pimenta Bueno in Rondônia and Cárceres in Mato Grosso. However, the natural deposits of Urucará and Capanema are for cement production. The lime deposit in Maués is a calcite lime and is very difficult to mine and, thus, the price of this material is about R$ 80,00 (US$ 46.70)/ton. The Pimenta Bueno deposit produces dolomite lime but is only used in the state of Rondônia and the northern Mato Grosso. The southern Pará and western Maranhão receive lime from states of the northeast of Brazil and from the states of Tocantins and Goiás. The remainder of the Amazon has limited lime deposits.

The state of Roraima could import lime from Venezuela, but the environmentalist imposed restrictions on the import of lime because the highway on which the lime would be transported in Venezuela goes by an ecological reserve – "La Gran Sabana". Thus, the State of Roraima does not have a lime source.

All fertilizers used in the Brazilian Amazon are imported from southern Brazil and, in the most cases, transportation is by truck contributing to the increase of the final cost of fertilizers. Some fertilizers are beginning to be shipped to Itaqui in Maranhão and are being used in Maranhão and southern Pará. Fertilizer imports to Amazonas may come with the ships that take soybeans from Itacoatiara as return freight, which would reduce costs. These import alternatives appear as the most promising for the rational use of fertilizers in the region as a whole, and offer the opportunity for Amazonas to experience sustainable agricultural development.

Diagnosis of Soil Nutrient Constraints and Lime and Fertilizer Recommendations

a) Acidity

The criteria used for diagnosis of the soil acidity are based on soil testing data as well as the land use history and on the expectation of crop yield.

Factors considered in the diagnosis of soil acidity include: soil pH value, the level of aluminum, the level of Al saturation, and the content of calcium and magnesium. There are several methods used to recommend lime and fertilizers for the Amazon. The main methods used for lime recommendations for most of the region are those used for the Cerrado and states of São Paulo and Minas Gerais. They are described by Leo Nobre de Miranda in his document for this workshop.

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For the state of Amazonas, the Cochrane & Sánchez equation for lime recommendation is being used. This equation takes into consideration crop tolerance to aluminum saturation and soil CEC. Unfortunately, we do not have comparisons between this equation with other methods to verify if there are differences in the acidity correction and in crop yields.

In the region, the range of soil pH varies between 3.0 and 5.5. Most crops produced at these low pH's generally exhibit low yields, especially in the case of grains such as corn and soybean. Soils that usually do not have low pH's are "várzeas", the "terras roxas", and the so called terra "preta de Indio", but these soils occur on a small scale in the region.

The soil acidity diagnosis makes no distinction between H, Al, and Mn toxicity. For corn and soybean for instance, soil Al saturation up to 20% allows grain yields higher than 80% of the maximum.

The deficiencies of Ca and Mg are considered in the calculations of the lime rate recommendation, because the Cochrane & Sánchez equation considers the content of those elements in the soil. Cravo & Smyth (1997) defined the Ca and Mg saturation of 40% and 6.1%, respectively as adequate to obtain a production of 90% of the maximum for cowpea in a Yellow Latossol of the Manaus region.

The average lime rate recommended for several crops in the region, is around 2 tons/ha, needing to be reapplied every three to five years.

b) Nitrogen

The diagnosis and recommendation of fertilizer nitrogen application rates are not based on soil analyses. The idea is to replace the amount absorbed by the plants as well as the natural losses, which have been determined through field experiments, taking into account the fertilizer efficiency. Usually, the recommended amount of N for corn varies from 60 to 120 kg/ha. Half of the nitrogen is applied 25 days after planting, and the remainder at 55 days after planting. For rice, the first half of the fertilizer (between 40 to 80 kg/ha) should be applied 15 days after planting, and the remainder at 35 days after planting.

Nitrogen fertilizer rates for corn in regions of large scale agriculture (western Maranhão, northern of Mato Grosso, south of Pará, Rondônia) are recommended according to yield expectation and crop sequence.

For regional fruit crops, the amounts recommended vary according to the species, from 45 to 135 g of N/plant/year.

c) Phosphorus

As mentioned previously, the low P content in the soils of the Amazon region is one of the main problems for the development of a sustainable agriculture. Soil P contents rarely surpass 4 mg/kg, which is below the critical level for most crops.

Phosphorus diagnosis is made by soil analysis. In the soil test laboratories of the region, the main method used is Mehlich 1. This method is suitable for acid soils like Oxisols and Ultisols, but research has shown that this method to determine P levels extracts a very large amount of P from soils such as "várzea" (Entisols), "terra Roxa", and "terra preta de Indio". As these soils have a high content of calcium, it is possible that part of the P content is calcium phosphate, which is not available for the plants.

Smyth & Cravo (1990) defined critical levels of P in the soil on a Yellow Latossol (Oxisol) of the region of Manaus for corn, soybean, and cowpea. These results were tested successfully on similar soils in Pará (Dematê & Dematê, 1997). Cravo & Smyth (1990) also determined that a band P application of 22 and 44 kg/ha was necessary to cultivate corn and cowpeas, respectively.

The banded P applications would have the same effect as a single broadcast application of 88 and 176 kg/ha of P. Broadcast applications are incorporated to a depth of 15cm at the beginning of the corn and cowpea cultivation. The disadvantage of broadcasting is that the initial investment for purchase of fertilizers is very high.

For the regions in the Amazon where agricultural activity is high, the fertilizer phosphorus recommendations are based on soil analysis data. See Miranda's report for more details on soil test P.

However, one important factor that must be considered before deciding to apply fertilizer and lime, is the price of the products because transportation is very expensive and may reduce the profit of the agricultural activity in the Amazon region.

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