IMPROVEMENT AND FERTILIZATION OF THE SAVANNAS IN BRAZIL *

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Summary

The Brazilian savanna covers an area of about 180 million ha. The predominant soils are Oxisols commonly deep, well drained and well structured. They are highly acid, very low in nutrient status and susceptible to erosion. The rainfall distribution is an other problem for agricultural production in the region. Any soil management scheme to minimize these problems should aim to: (a) improve the natural low soil nutrient status and neutralize part of the effects of soil acidity; (b) minimize the risks related to dry spells and (c) protect the soil against erosion.

Introduction

Essentially there are two alternatives to increase food production: one is by increasing productivity and another is expanding agriculture into new areas. As the increase in productivity is a slow process, on a short-term basis, agricultural expansion seems more important. Defining technology for rational occupation of savannas is a real challenge for the scientific community. A lot of research is still needed to develop adequate technology with special emphasis on soil management practices. The aim of this paper is to characterize major soil problems of the savanna area of Brazil and discuss alternative solutions based on present research experience.

Characterization of the savanna region

The acid savannas occupy about one fifth of the tropical zone with a strong dry season of three to six months. In Brazil the savanna area is about 180 million ha (Fig. 1), Oxisol and Ultisol are the predominant soil orders with a typical savanna or cerrado vegetation. The population density varies from low to medium and the infrastructure is quite good in many parts. Agriculture is expanding rapidly.

Some climatic data of two locations in savanna are presented in Fig. 2. Average temperature and total rainfall are high in all regions. The rainfall distribution pattern shows a long dry season in the savanna. There is literally no rain for two to three months. These average figures, however, can be very misleading. Short-term droughts or dry spells commonly occur during the rainy season and may have a detrimental effect on crop growth mainly due to low available water in the soil, adverse chemical conditions for root development, and high evapo-transpiration rate.

Red Yellow Latosol and Dark Red Latosol (Ustox or Orthox) are the dominant soils under savanna vegetation. They are deep and well drained soils with high aggregate stability that favors agricultural mechanization. Their texture varies, but most are clayey soils. They are acid and aluminum saturation is usually more than 50%, even though the absolute amount of exchangeable aluminum is not high. In some profiles, Al saturation is high in all horizons, but in others only in the surface layer (Table 1). This fact is important in terms of soil management aimed to improve conditions for root growth. Exchangeable bases are very low and available phosphorus is, for practical purposes, almost inexistent.

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* This paper is part of a paper on Management of Tropical Soils and World Food Prospects which will be presented at the 12th. ICSS – New Delhi, India.

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Soil management

The soils from savanna areas present several common characteristics. In general, any soil management scheme for savanna soils should aim at:

(1) building up the soil fertility;
(2) decreasing or minimizing the risks of short-term-droughts;
(3) protecting the soil against erosion.

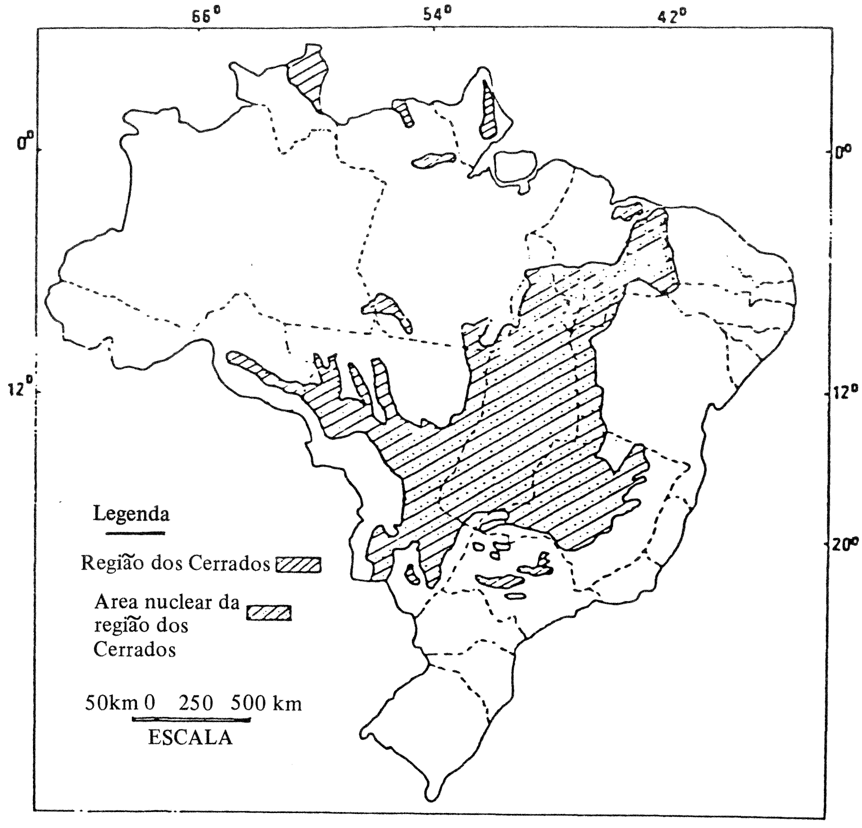

Fig. 1 The distribution of Cerrados in Brazil (EMBRAPA, 1978).

1 Improvement of soil fertility

1) Liming

A number of experiments have been conducted on Oxisols to study the influence of liming on yield of important crops. In one of those experiments, started in 1972 on a Dark Red Latosol (soil analysis shown in Table 1), limestone was applied at rates of 0, 1, 2, 4 and 8 ton/ha at two depths, 0 – 15 and 0 – 30 cm (9). Of the seven crops grown in the experiment, the first three, the fifth and the sixth were maize, the fourth was sorghum and the seventh was soybeans. A marked yield response to lime was observed for all crops (Table 2). This response shows evidence that, even at the lowest lime rates, the residual effects remained significant throughout the course of the experiment. Those treatments in which lime was incorporated to a depth of 30 cm consistently yielded more than those where lime was incorporated to a depth of 15 cm. It is evident though, that the differences between deep and shallow incorporation tend to decrease with time mainly due to Ca and Mg leaching. Enhanced root growth in the 15 – 30 cm layer and consequent nutrient, and water extraction from a greater volume of soil were associated with higher yields from the deep liming treatments (Goedert and Lobato, 1980).

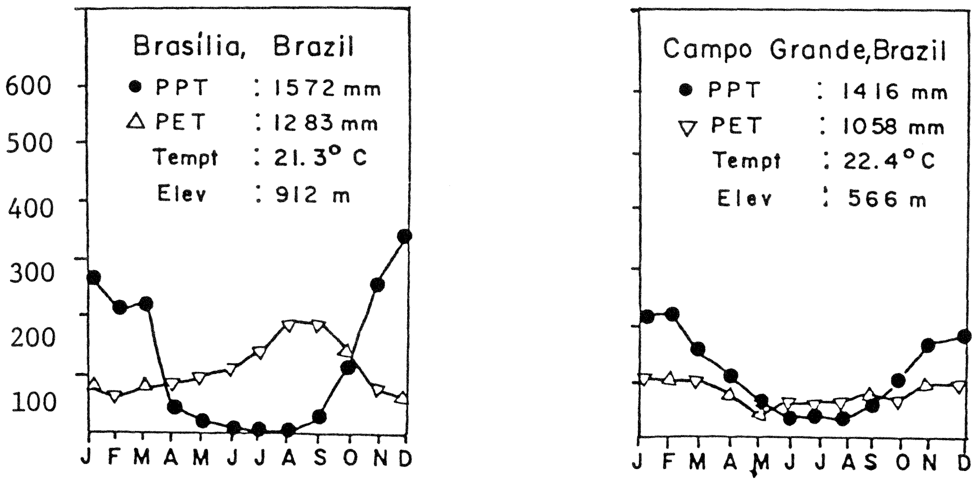

Fig. 2 Climatic data on two locations of Brazilian savanna (EMBRAPA, 1976).

Table 1 Some chemical an physical properties of 3 Latosols

Horizon	(Depth) cm	Clay %	OM %	pH (H_2O)	Exchangeable cations Al	Ca	Mg	K	ECEC	Al Sat. %	Available P ppm
					meq/100 g						
DARK RED LATOSOL from Brasilia/DF., Brazil											
A_1	(0– 10)	31	3.1	4.9	1.90	0.25	0.15	1.10	2.40	79	1.0
B_1	(10– 35)	48	2.0	4.8	2.00	0.12	0.08	0.05	2.20	89	–
B_2	(35– 70)	47	1.5	4.9	1.60	0.12	0.08	0.03	1.80	88	–
RED YELLOW LATOSOL from Brasilia/DF., Brazil											
A_1	(0– 20)	31	1.7	5.0	0.40	0.03	0.02	0.06	0.51	77	1
A_3	(20– 40)	34	0.9	4.9	0.07	0.02	0.01	0.03	0.13	50	nihil
B_2	(100–120)	29	0.5	5.6	0.01	0.02	0.01	0.01	0.05	7	nihil
RED YELLOW LATOSOL from Brasilia/DF., Brazil											
A_1	(0– 15)	46	3.4	4.7	1.50	0.60	0.40	0.08	2.58	58	1
A_3	(15– 37)	48	2.2	5.0	1.10	0.40	0.20	0.03	1.63	65	1
B_1	(37– 70)	49	1.0	5.0	0.90	0.60	0.30	0.02	1.82	47	1

If, on the one hand the existence of beneficial lime effects on yield is an unquestionable fact, much work still remains to be done in defining the range of soil conditions under which different crops respond to liming. The rate of lime needed will also depend on the kind of farming system. As an example, the traditional farming system in savanna areas of Central Brazil is to clear the area, grow upland rice for two or three years and then shift to pasture (mainly *Brachiaria decumbens)*. Both upland rice and *Brachiaria* are plants well known for their high tolerance to acid soil conditions. When rock phosphate is used as phosphorus source, liming is used mainly to supply Ca and Mg as nutrient. This is not true if crops like soybeans or maize are included in sequence.

On these acid soils where Al dominates the exchange complex, the amount of exchangeable Al provides a reasonable measure of lime requirement. Lime requirement has been defined according to the following formula:

Table 2 Grain yields of maize, sorghum and soybean on a Dark Red Latosol (Typic Haplustox) as influenced by rates of liming applied at 2 depths (EMBRAPA, 1979) Brasilia – Brazil

Lime rate and depth ton/ha	Maize			Sorghum (crop 4)	Maize		Soybean (crop 7)
	crop 1 '72–'73	crop 2 '73	crop 3 '73–'74	'74–'75 kg/ha	crop 5 '75–'76	crop 6 '76–'77	'77–'78
0	2,115	4,570	880	1,475	2,360	1,175	1,055
0–15cm							
1	3,425	5,280	1,475	3,525	4,280	1,940	1,966
2	3,530	5,690	1,865	5,585	4,320	2,005	1,862
4	4,005	5,905	2,265	6,225	4,620	2,705	1,889
8	3,725	5,960	2,050	6,875	5,410	2,455	2,113
0–30cm							
1	4,020	5,685	2,085	4,750	4,430	1,380	1,304
2	4,340	5,860	2,575	5,860	4,600	2,125	2,054
4	4,800	6,680	3,060	6,425	4,810	2,350	2,248
8	4,790	7,265	3,600	7,055	5,970	2,775	2,254

$$\text{t lime/ha} = (2 \times Al^{3+}) + 2 - \text{meq}(Ca + Mg)$$

The rates recommended by this formula usually increase the pH to around 5.3 and eliminate most of the exchangeable Al. This criterion is still a useful practice in spite of not taking into account the buffer capacity of the soil. The SMP method (to pH 5.5) has proved to be even more effective for predicting lime requirement of Oxisols.

2) Phosphorus

Phosphorus deficiency is probably the greatest constraint for agricultural production in savanna areas.

In general, Oxisols show low contents of total P and the amount of readily available P, extracted by routine methods, is insignificant (Table 1). Furthermore, the adsorption capacity of most soils is quite high. A substantial amount of data has been collected using the sorption isotherm method in order to estimate P requirements of these soils to achieve different levels of P in solution. Lathwell (1979) summarizes some data for Oxisols of Latin America. An average of 250

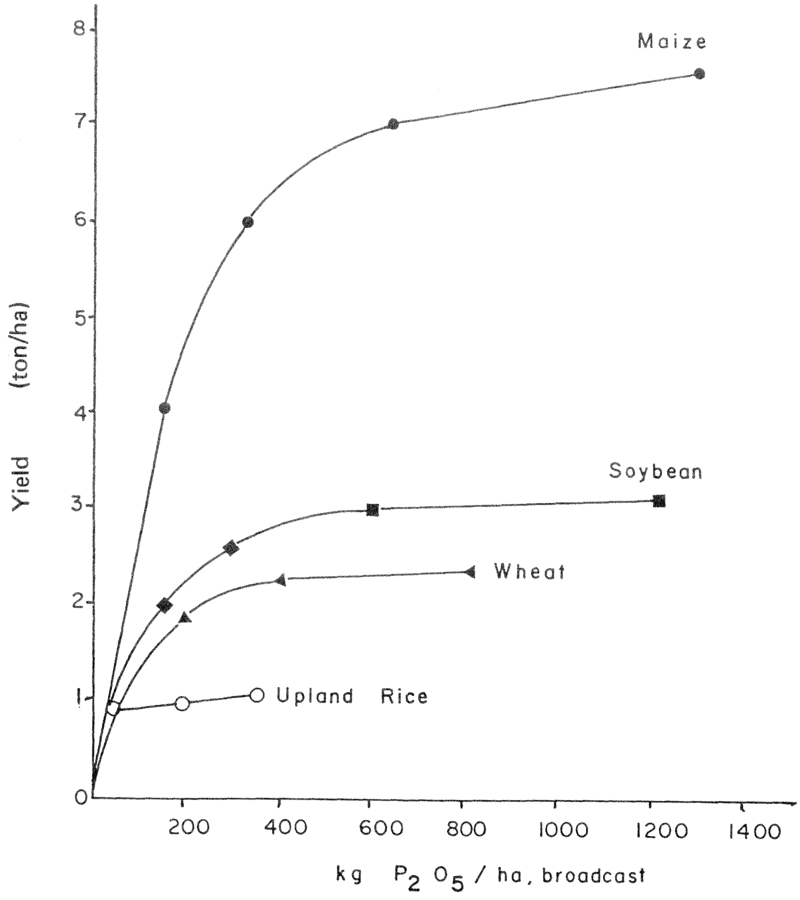

Fig. 3 Crop responses to phosphate fertilization, in savanna soils (Lobato, 1980).

ppm of P was required to give 0.10 ppm of P in solution, which represents a huge quantity of phosphates to be applied.

Plant response to applied phosphorus is excellent (Fig. 3) with a wide variation in phosphorus requirement to reach maximum yields for different crops and soils. These figures also demonstrate the high potential for food production in these soils when P deficiency is corrected.

Table 3 shows data from one long-term P fertilization experiment carried out in a Brazilian savanna soil. This experiment was started in 1972 and, so far, ten crops of maize have been harvested. The broadcast applications of phosphorus fertilizer were made only once, just before the first crop was seeded.

These results show clearly that band and broadcast applications on a long-term basis, present similar results, with the yields being a function of the total P applied. It was observed, though, that broadcast applications outyielded band applications for the first crops (Lathwell, 1979). The opposite was found after the third crop. This indicates the convenience of making an initial broadcast application in order to maintain an adequate P availability level.

Table 3 Grain yields from 10 consecutive maize crops grown on Dark Red Latosol to measure influence of rate and placement of fertilizer phosphorus on grain yields (Lobato, 1980) Brasilia – Brazil

Treatment No.	Phosphorus applied broadcast	banded	Total P applied	Grain yields 10th	crop	total of 10 crops	
		(kg P_2O_5/ha)		(ton/ha)	(%)	(ton/ha)	(%)
1	160	0	160	0.35	6	17.06	28
2	320	0	320	0.55	10	27.85	45
3	640	0	640	1.47	27	42.67	69
4	1,280	0	1280	3.98	74	60.83	99
5	1,960	0	1960	5.38	100	61.64	100
6	0	80 (x4)+	320	0.88	16	30.09	49
7	0	160 (x4)+	640	1.90	35	44.05	71
8	0	320 (x4)+	1280	4.09	76	61.51	100
9	320	80 (x4)+	640	1.35	25	43.89	71
10	80	80++	880	4.81	89	49.77	81

+ Banded application was discontinued after fourth crop.
++ Banded was continued in all crops.

The data presented in Table 3 also give an idea about the good residual effects of P fertilization in high P adsorbing soils. Only after the tenth crop no longer was observed an effect on yield of treatment no 1, which consisted only of an initial broadcast application of 160 kg P_2O_5/ha. Furthermore, a complete calculation of the P extracted from the soils revealed that about 120 kg P_2O_5 were taken up by the plants, i.e. about 75% of the P applied turned out to be available to the plant on a long-term basis (Lobato and Ritchey, 1979). This figure contrasts with the numbers obtained through adsorption isotherms (Lathwell, 1979) and indicates that the well-known high sorption capacity of tropical soils may not be such a critical problem as described in the literature. In addition, this pronounced residual effect of P fertilization has to be considered in economic analysis for determining the best rates. A superficial economic analysis of the data from this experiment shows that if only yield of the first two crops were to be considered, the recommended rates would be around 350 kg P_2O_5/ha but if the yields for the first five crops are taken into account, the most economical rate would be about 1,000 kg P_2O_5/ha.

The soluble phosphates are mostly dependent on imported sulfur and phosphoric acid and prices are affected by the fuel supply situation. One alternative that has been studied is the possibility of using local sources of rock phosphates.

Most rock phosphates found in tropical areas are of medium to low solubility. In general the research data indicate that they can be used under the following conditions (CIAT, 1978; Goedert and Lobato, 1980):

(1) they should be preferentially applied in acid soil without lime or with a minimum application, just enough to supply Ca and Mg as nutrients to be cultivated with Al-tolerant species or varieties, such as upland rice and *Brachiaria.*

(2) Rock phosphates have to be broadcasted and used in conjunction with band applications of soluble P fertilizers.

(3) The price of one unit of total P_2O_5 as rock phosphate, has to be less than about 50% of one unit of water soluble P_2O_5, at the farm level.

Another important aspect in terms of soil management is the positive interaction between lime and phosphorus. The literature shows the importance of this phenomenon especially for acid soils with high exchangeable Al (CIAT, 1978; EMBRAPA, 1978; Goedert, 1979; North Carolina State University). One example is shown in Fig. 4 where soybean yield was not much affected by the application of phosphorus alone, but the application of both lime and phosphorus resulted in a spectacular crop response.

The research conducted in savanna areas indicates the necessity and convenience of making corrective application of phosphate. Rates varying from 100 to 400 kg P_2O_5 are recommended depending on soil P, soil texture, crop sequence and economic factors. The amount required can be applied over several years rather than as a single initial application. In one clayey soil, for example, 80 to 100 kg P_2O_5/ha band-applied annually for 4 to 5 years will build up the P availability to a critical level where only P maintenance is necessary to compensate P withdrawn by cropping.

A combination of an initial broadcast treatment (which in some cases may be done with rock phosphate) and subsequent band application on soils with a high adsorption capacity seems to be more efficient than either method of application alone. However, much work has to be done to define the most suitable long-term phosphorus fertilization practices on various soils for different crop combinations.

3) Zinc, potassium, nitrogen and sulfur

Acidity and P deficiency are, by far, the most important problems that require immediate solution to "reclaim" naturally poor soil of savannas. However, zinc and potassium often limit yield and may have to be included in a soil fertility build-up program. Zinc deficiency has been more apparent in crops such as rice and maize and on well limed soils (EMBRAPA 1976; 1978). A broadcast application of about 10 kg Zn/ha, in the form of zinc sulfate or zinc oxide, has been enough to solve the problem for a long period. A common practice also is to use N P K formula containing zinc, as maintenance fertilizer.

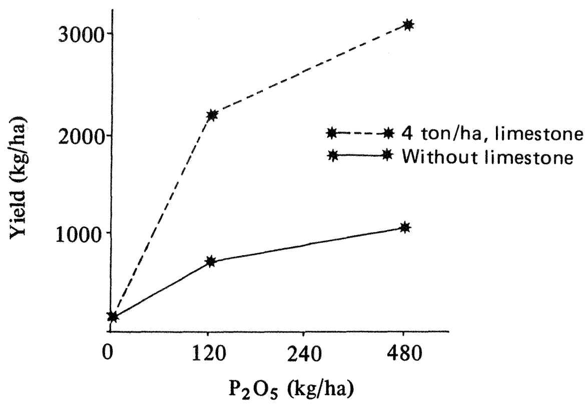

Fig. 4 Soybean response to liming and phosphate fertilization, in a Dark Red Latosol (EMBRAPA, 1976).

In many soils, if high yields are desired from the first year on, potassium should be included as corrective nutrient (Ritchey, 1979). In one soil in which the native K level was 23 ppm (Mehlich extractant) there was a significant response to the addition of 75 kg/ha K_2O, compared to the check. However, in practice, potassium is normally applied with the annual maintenance fertilization. The rate will depend on soil K status and the cropping system, but varies from 30 to 60 kg/ha of K_2O. An excessively high initial application may promote K leaching.

The nitrogen situation varies from soil to soil. Often considerable amounts of N are released from organic matter decomposition during the first years. A desirable situation should include legumes (bean, soybean, etc.) in the crop sequence. When N fertilizer is used, a small part is applied at planting time and the remaining side-dressed later to decrease chances of leaching.

Sulfur is expected to become a problem in many soils of tropical areas since S availability is not naturally high and the most common sources of N, P and K do not carry sulfur (urea, triple superphosphate and potassium chloride).

2 Decreasing risks of droughts

The rainfall distribution is quite irregular during the rainy season in savanna areas. When the dry spell coincides with a critical stage of crop development (reproductive stage mainly), significant yield losses may occur (Goedert, 1979). The significant damage caused by dry spells is mainly due to high evapo-transpiration rate, low soil available water and by poor root growth due to high subsoil acidity (high Al saturation and low Ca availability).

The complete solution to the water stress problem is very difficult, but there are several ways to minimize it, such as crop management, irrigation and soil management.

Several lines of soil management are potentially feasible. One way is to increase soil water availability through the incorporation of materials such as crop residues or green manure.

Perhaps the most promising alternative for drought control is to increase the soil volume exploited by roots, which, as a consequence, will increase the soil water reservoir. This can be accomplished by decreasing subsoil acidity with the incorporation of lime (and possibly phosphate) as deep as economically feasible and by the promotion of controlled leaching of Ca and Mg below the plow layer.

Deep incorporation of lime has shown very positive effects on yields (Table 2). Much of the yield increase shown can be accounted for by better use of water stored in subsoil layers (Bouldin, 1979; EMBRAPA, 1978; 1979; Lobato and Ritchey, 1979). Deep root growth, was shown to be enhanced when lime was deeply incorporated due to a decrease in Al saturation and increase in Ca and Mg status. However, deep lime incorporation at farm level, is limited by mechanical difficulties and the high cost of plowing deeper than 25 – 30 cm.

Leaching of exchangeable bases is traditionally considered as a problem in most temperate soils but when subsoil acidity and low Ca availability represent a constraint for root development, leaching can turn out to be a positive phenomenon. In savanna areas, where rainfall intensity is high, the soil is permeable and the CEC is low, leaching can easily be promoted. Two simultaneous steps have to be taken: addition of an adequate amount of Ca and Mg and provision of an anion which will serve as a "carrier" to allow downward movement of those cations.

The distribution of Ca+Mg in a Dark Red Latosol, after liming, can be seen in Fig. 5. The deep movement of these cations increased with the amount of lime applied, and the extent to which Ca+Mg moves to subsoil layer is affected by the source of phosphate applied. The source containing sulfur (simple superphosphate) enhanced Ca+Mg leaching. A simultaneous decrease in Al saturation was observed in subsoil layers (EMBRAPA, 1978). An experiment carried out with a re-constructed soil profile in a column under controlled conditions showed that anions that are not specifically adsorbed, such as chloride and nitrate, promoted a too fast movement of Ca+Mg (EMBRAPA, 1979), not suitable for agronomic purposes, because Ca+Mg will move out of the root zone. Carbonate ions do not cause enough Ca+Mg movement, nor do phosphate ions since they are strongly and specifically adsorbed at the surface of Al and Fe oxides. Sulfate anions, on the other hand, promote adequate leaching under 1200 mm annual rainfall conditions. Leaching of Ca+Mg to a 45 – 60 cm depth seems suitable for most annual crops and the amount of water stored at this depth seems to be enough to overcome normal dry spells.

In addition to increasing the use of subsoil water, deep rooting also increases the uptake of subsoil nutrients including those nutrients easily leached such as potassium and nitrate that might, otherwise, be lost.

3 Soil conservation

The most important factor affecting erosion in tropical areas is the rainfall intensity. Thunderstorms of 80 mm/hour are common and even though the water infiltration rates in Oxisols and Ultisols are usually very high, there will be an excess of water.

Research on erosion and soil conservation in tropical areas is very scarce. Table 4 shows soil losses on a 5% slope in Brasilia. The annual loss in a bare soil is high, but it decreases as the surface soil is covered by vegetation, being insignificant under pasture.

The data presented in Table 4 indicate that any scheme for erosion control has to be concerned with soil coverage. During the period when the crop has a large amount of vegetative material, erosion risks are small. The major problem occur during and immediately after planting time and also after harvesting if crop residues are not left on the field.

Even though vegetative and cropping practices are, by far, the most important in a soil conservation system for Oxisols and Ultisols, mechanical practices are useful in most situations. Contour planting and leveled terraces are frequently used in tropical areas. A very useful procedure is to collect the vegetation, right after clearing, in contour bands spaced according to the slope. When this vegetation decomposes, a natural terrace is almost built.

Conclusion

The ecological conditions of savanna areas are adequate for almost any crop. For this reason, when soil acidity and low soil fertility are corrected, excellent yields can be obtained with crops such as soybean, maize, sorghum, edible beans, wheat, peanuts, sunflower, pea, potatoes, etc. With adequate technology, an average of 2.5 ton grain/ha/year can be obtained without irrigation.

On the other hand, the potential of savanna zones for perennial crops is also great. Research has indicated that the most adapted species are coffee, citrus, avocado, mango, papaya, banana, cashew, etc. In practice, it has been suggested that these crops should be preferentially cultivated in areas with more than 5% slope or in sandy soils. There are indications that yields are comparable

Table 4 Soil losses by erosion in a 5% slope Dark Red Latosol (EMBRAPA, 1979; 1980)

Treatments	Total loss (1977/78)		Total loss (1978/79)	
	ton/ha	%	ton/ha	%
Bare Soil	29.4	100	131.6	100
Upland Rice (Conventional)	4.0	14	64.9	49
Maize (Conventional)	5.2	18	57.8	44
Soybean (Conventional)	2.7	14	50.7	39
Soybean (Without Straw)	2.4	13	32.7	24
Soybean (No tillage)	1.9	10	1.5	1
Soybean (Contour)	2.4	13	29.5	22
Pasture of *Brachiaria*	0.8	3	0.2	–

with those obtained in traditional temperate or subtropical cultivated areas (EMBRAPA, 1980).

Even though many crops can be successfully cultivated in savanna areas, beef cattle raising will be, in short and medium run, the most important economic activity in these zones. The cultivated pasture should be well fertilized, mainly with phosphate, and include a legume with the grass.

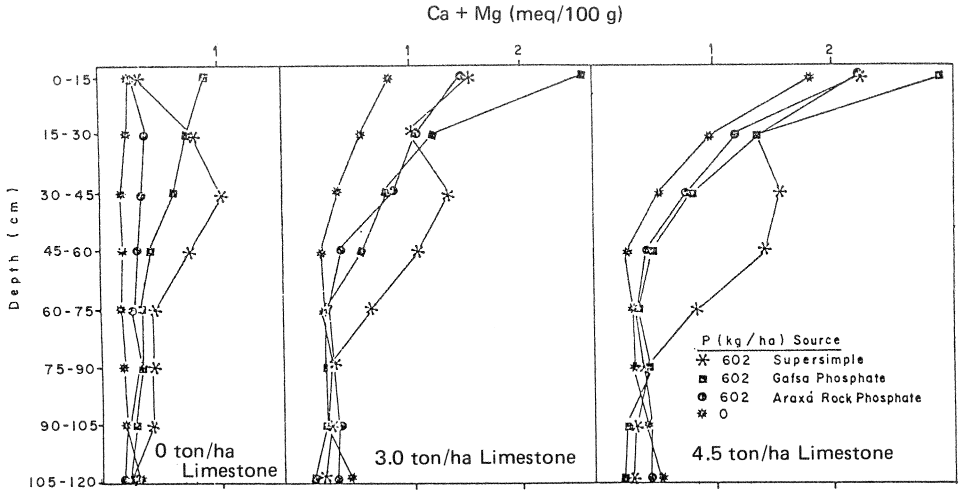

Fig. 5 Exchangeable calcium and magnesium distribution in a Dark Red Latosol profile, three years after top application of limestone and phosphates (EMBRAPA, 1978).

Present food production on savanna is rather low, probably insufficient to feed its own population. Soil management appears to be the most important factor for rational and intensive occupation of these areas.

However, for this potential to turn into reality, many things are necessary, especially technology development, soil amendments (lime and fertilizers, mainly), machinery, trained hand labor and infrastructure (transportation, credit, market, etc.). All of them are time demanding, which indicates that a full development of this zone will need 20 to 40 years. The speed and security of this occupation will be closely related to the capacity of the research to develop adequate farming for each ecosystem and to the availability of government programs for orienting this occupation.

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Discussion

Shoji, S, (Japan): 1) With reference to one of the tables you showed, I would like to know what is the pH value of the Dark Red Latosols which received various amounts of lime. Is there any possibility of overliming for this soil? 2) How about the aluminum tolerance of your test plants?

Answer: 1) To bring the pH to about 5.3, 4 ton/ha of lime is recommended depending on the exchangeable Al^{++}, Ca^{++} and Mg^{++} concentration. Zinc deficiency may appear as a result of overliming 2) Even though the maize variety (Cargill III) is one of the recommended varieties for the cerrado region, it is relatively susceptible to aluminum toxicity.

Goswami, N.N. (India): 1) You mentioned that the phosphorus recovery by the first crop from 160 kg P_2O_5/ha of applied phosphorus was 70%. This figure appears to be extremely high and radiotracer data indicate that only about 15 – 25%/ha applied phosphorus is utilized by the first crop. You also have a high percentage of aluminum saturation. 2) What is the relative efficiency of broadcast and band application of fertilizer? 3) Is the higher requirement of phosphate by maize, as compared to that by wheat, sorghum and upland rice, due to higher yields relative to the other crops?

Answer: 1) The 70% recovery of applied phosphorus did not apply to the first crop only but to the tenth. The high aluminum saturation recorded is due to the low level of nutrients and does not necessarily imply that aluminum content is high. 2) Broadcast application of 100 to 400 kg of P_2O_5 is recommended for the first year and band application of 80 kg up to the 5th year. Usually we combine broadcast and band application. 3) High phosphate requirement by maize is not only due to higher production but also to differences in the root system, mycorrhizal activity at the rhizosphere, etc.