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Soil Fertility of Tropical Intensively Managed Forage System for Grazing Cattle in Brazil

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1. Introduction

In Brazil the predominant beef and dairy cattle production systems are based mostly on grazing and rely on native and cultivated pastures, which are grazed by continuous stocking all year round and are the main source of animal feed. About 90% of the nutrients required by the ruminants are obtained directly through grazing and supplemental forage feeding is only utilized in intensive dairy production systems and feed-lot systems (Euclides et al., 2010).

Most of the Brazilian cattle are maintained on pastures grown on acidic and low fertility soils that do not receive any lime or fertilizer. This lack of lime and nutrient input in the establishment and the maintenance phases, and the inadequate management of grasses are the main causes of pasture degradation in Brazil (Cantarella et al., 2002). Estimates indicate that approximately 80% of the 50 million hectares of pastures are degraded or under degradation process in the Cerrado (Savannah) region. Pasture degradation is the main cause of low productivity in the Brazilian livestock sector. In these low-input forage systems, lack of regular nitrogen (N) supply plus declining soil P levels are expected to eventually necessitate a reduction in stocking rate and animal production (Macedo, 2002).

The average stocking rate of Brazilian pasture is less than 1.0 animal per ha per year (Carvalho, 2002) with an annual productivity of meat and of milk around 50 and 2,000 kg per hectare, respectively. On the other hand, using appropriate technology in cultivated pastures it is possible to improve animal production significantly. Well established pastures that are properly managed and fertilized are the main source of food for cattle and most practical as the least costly source of feeding (Camargo et al., 2002). In intensive cattle production, well managed pastures allow for increased rates of stocking and productivity (Corsi and Nussio, 1993; Primavesi et al, 1999; Lugão et al., 2003) based on replanting with better grass varieties, grazing rotation, forage availability in the dry season, regulation of stocking densities, genetic improvement of cattle herds and building up soil fertility by balanced fertilization supply and improving soil organic matter (SOM) content.

In the intensive cattle production system, pastures are mainly composed of *Brachiaria* and *Panicum* species (C4 grasses with high herbage dry matter yield potential). These grass

forages are used in the summer season, and in the winter, feed is based on chopped sugarcane (corrected with crude protein or nitrogen) or silage (corn or sorghum), due the decrease in forage yield. This feeding system leads to increasing stocking rate up to 6 to 12 cow ha⁻¹ in pasture for about 200 days year⁻¹ without irrigation, with higher stocking rates possible when pastures are irrigated during the dry season (Corsi et al., 2001; Santos et al., 2003). Crop-pasture rotation and the tropical grass pasture management intensification increases animal production to more than 25,000 kg of milk per ha per year and 900 kg of liveweight gain per ha per year (Corsi et al., 2001).

Carvalho and Batello (2009) pointed out that as stocking rate is increased, individual animal performance decreases, while production/unit-area increases to some maximum and then declines as a result of concurrent process controlling plant production and utilization by the grazing animal. Increasing grazing intensity decreases plant solar energy capture because of the negative impact on leaf area index. The harvest efficiency is increased with increasing grazing intensity because the forage intake per unit area is increased. Conversely, with increasing the number of animals, the competition for forage decreases the individual animal intake, which diminishes the assimilation efficiency.

Of the controllable factors determining forage yield and quality, soil fertility including fertilizer application is one of the most important. On these tropical acid soils naturally poor in plant nutrients, soil liming and a balanced nutrient supply of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), boron (B), copper (Cu), molybdenum (Mo), manganese (Mn) and zinc (Zn) are therefore essential to ensure high yielding and high quality forage (Corsi and Nussio, 1993; Primavesi et al, 1999; Camargo et al., 2002). In order to intensify cattle production and reach high animal productivity, the main point to be considered is the correction of soil acidity and the balanced supply of mineral nutrients.

Maintenance of soil fertility depends on the nutrient recycling and inputs to the system. In extensive systems, natural rates of nutrient cycling may be sufficient, since it works with very low stocking rates, requiring plenty of waste returned to the soil, but it presupposes the need for large areas. In the case of intensive production, which is carried out in small areas, requiring high stocking rate, and thus higher biomass productivity of the grass, is essential to correct soil acidity with lime and fertilizer use.

However, the used rates of fertilizer in Brazilian pastures are still extremely low, around 5 to 6 kg per ha of NPK. In intensively managed pastures, the maximum doses of nutrients for technical and economical response are quite high. Research results point to economic doses around 800 kg per ha per year of N and K₂O in irrigated pastures, applied as 8 to 9 split applications, and 500 kg per ha per year of these nutrients in non-irrigated pastures (Martha Júnior et al., 2004; Sousa et al., 2004; Primavesi et al., 2004; Primavesi et al., 2003; Oliveira et al., 2003).

Intensive management also contributes to turn to a more profitable and competitive livestock production because it reduces the pasture land area, reduces the potential deforestation of natural forests, increases the possibility of environmental conservation, and release areas for another agricultural land use (Kaimowitz and Angelsen, 2008). Moreover, it contributes to increase carbon sequestration, lower energy loss by animals that otherwise would take long walks in search of food and water, and generates less methane per unit of

product. So, intensification is a sustainable practice, since the recent development of Brazilian agriculture has been strongly based on productivity gains, and, to a minor extent, on land area expansion (Contini and Martha Jr., 2010).

This chapter provides information regarding the management of liming and fertilization of intensively managed pastures (based on soil analysis and requirement of the grass). Sources of information are scientific articles (mostly in Portuguese) and personal experience of experts.

2. Fertility of Brazilian soils

Brazilian tropical soils usually produce low yields due to the high Al saturation, low concentrations of most mineral nutrients that are essential for plant development, low organic matter content, leading to low CEC and high P fixation (Bernardi et al., 2002). A summary of the extent of soil-related limitations, both physical and chemical, in the acid infertile soils of the tropical Latin America region was given by Sanchez and Salinas (1981) and is presented in Table 1. Deficiency of N and P was shown to be the most severe limitation to crop growth. The list of major chemical constraints is completed by the toxicity of Al, deficiency of K, high P fixation, and low cation exchange capacity. Other physical hindrances are shown but they are of minor relevance.

Soil constraints	Tropical America		Acid soils	
	1.000.000 ha	% total	1.000.000 ha	% total
Nitrogen deficiency	1332	89	969	93
Phosphorus deficiency	1217	82	1002	96
Potassium deficiency	799	54	799	77
Calcium deficiency	732	49	732	70
Magnesium deficiency	731	49	739	70
Sulphur deficiency	756	51	745	71
Cu deficiency	310	21	310	30
Zn deficiency	741	50	645	62
High P fixation	788	53	672	64
Low CEC	620	41	577	55
Aluminum toxicity	756	51	756	72
Low water availability	626	42	583	56
High erosion risk	543	36	304	29
Flooding	306	20	123	12
Compaction	169	11	169	16
Laterization	126	8	81	8
Water stress (> 3 month)	634	42	299	29

Source: Adapted from Sanchez and Salinas (1981).

Table 1. Geographical extent of the major soil constraints to crop production in tropical America.

The most important function of organic matter in soil is as a reserve of nutrients required by plants (Craswell and Lefroy, 2001). Nevertheless, SOM also plays an extremely important role in tropical soils, since it affects soil properties such as electrical charge and nutrient supply (Sanchez, 1976). The main factor responsible for negative charges, and therefore the SOM which contributes 60 - 80% of total soil CEC (Raij, 1969). The organic matter content is affected by vegetation type, as well as the parent material from geological formations and increases with soil clay content and rainfall (Tognon et al., 1998).

SOM can be increased by addition of crop residues, cover crops, green manure crops, compost, animal manure, by reduced or no-tillage and by avoiding residue burning. Enhanced SOM increases soil aggregation, water holding capacity and P availability; reduces P fixation, toxicity of Al and Mn, leaching nutrients by adsorbing exchangeable Ca, Mg and K (Baligar and Fageria, 1997). SOM also provides a source of nutrients, as was shown by Pereira et al. (2000) who evaluated changes in chemical properties of a Xanthic Hapludox managed under pasture, using two rotational systems with *Brachiaria brizantha* and *Panicum maximum*. The organic material incorporated into the soil through vegetable and animal residues, influenced the chemical characteristics, increasing the levels of Ca, Mg, K, P, N, C, OM and pH, and decreasing the Al levels, indicating that SOM has a buffering effect and a complexing effect on Al.

3. Soil testing

Liming and fertilizer recommendations for pasture should be based mainly on soil analysis and expected yield. Potassium rates are recommended based on soil exchangeable K values. However P recommendation is based on two analytical methods: ion exchange resin-extractable P and Mehlich-1 P. Due to the differences between the analytical protocols used for P determination, there are differences in the interpretation levels as shown in Table 2 and 3. Soil analysis for micronutrients, extracted with hot water (B) and DTPA-TEA or Mehlich-1 (Fe, Cu, Mn, and Zn) is also used as criterion for fertilizer recommendation (Tables 4 and 5).

Fertility class	P resin			
	Forestry	Perennial	Annual	Horticultural
			mg kg ⁻¹	
Very low	0 - 2	0 - 5	0 - 6	0 - 10
Low	3 - 5	6 - 12	7 - 15	11 - 25
Medium	6 - 8	13 - 30	16 - 40	26 - 60
High	9 - 16	31 - 60	41 - 80	61 - 120
Very high	>16	>60	>80	>120

Source: adapted from Raij et al. (1996).

Table 2. Soil fertility classes and limits for interpretation of soil-P availability by the P resin method

Clay content	Soil fertility class				
	Very low	Low	Medium	Adequate	High
%			mg kg ⁻¹		
60-100	≤ 2.7	2.8 – 5.4	5.5 – 8.0	8.1 – 12.0	> 12.0
35-60	≤ 4.0	4.1 – 8.0	8.1 – 12.0	12.1 – 18.0	> 18.0
15-35	≤ 6.6	6.7 – 12.0	12.1 – 20.0	20.1 – 30.0	> 30.0
0-15	≤ 10.0	10.1 – 20.0	20.1 – 30.0	30.1 – 45.0	> 45.0

Source: adapted from Alvarez et al. (1999).

Table 3. Soil fertility classes and limits for interpretation of soil-P availability by the Mehlich-1 P method, considering soil clay content.

Soil fertility class	B (hot water)	Cu	Fe	Mn	Zn
			DTPA-extractable		
			mg kg ⁻¹		
Low	0 - 0.2	0 - 0,2	0 - 4	0 - 1,2	0 - 0,5
Medium	0,21 - 0,6	0,3 - 0,8	5 - 12	1,3 - 5,0	0,6 - 1,2
High	>0,6	>0,8	>12	>5,0	>1,2

Source: adapted from Raij et al. (1996).

Table 4. Soil fertility classes and limits for interpretation of micronutrient availability by the hot water (B) and DTPA (Cu, Fe, Mn and Zn) methods.

Micronutrient	Soil fertility class				
	Very low	Low	Medium	Adequate	High
			mg kg ⁻¹		
Cu	≤ 0.3	0.4 –0.7	0.8 – 1.2	1.3 – 1.8	> 1.8
Fe	≤ 8	9 – 18	19 – 30	31 – 45	> 45
Mn	≤ 2	3 – 5	6 –8	9 –12	> 12
Zn	≤ 0.4	0.5 – 0.9	1.0 – 1.5	1.6 – 2.2	> 2.2

Source: adapted from Alvarez et al. (1999).

Table 5. Soil fertility classes and limits for interpretation of micronutrient (Cu, Fe, Mn and Zn) availability by the Mehlich-1 extraction method

4. Foliar diagnosis

Leaves are the first and the principal part grazed by animals (Moraes and Palhano, 2002) so their chemical composition reveals their nutritional value. The principle of foliar diagnosis is based on comparing nutrient concentrations in leaves with standard values. Crops are considered to integrate factors such as presence and availability of soil nutrients, weather variables, and crop management. So plant tissue analyses are the best reflection of what the

plant has taken up. Traditionally, whole plant shoots are sampled for forage nutritional diagnosis (Monteiro, 2004). The range of levels considered adequate for forages in Brazil by Werner et al. (1996) are shown in Table 6.

Usually, forage value is based on its protein content however tissue mineral composition also plays an important role in animal nutrition. Gerdes et al. (2000) mentioned that the low nutritional value of tropical forage, often mentioned in literature, is associated with reduced crude protein and minerals, the high fiber content and low dry matter digestibility.

Forage	N	P	K	Ca	Mg	S
	g kg ⁻¹					
<i>Panicum maximum</i> cv Colonião	15 - 25	1.0 - 3.0	15 - 30	3 - 8	1.5 - 5.0	1.0 - 3.0
<i>Pennisetum purpureum</i> cv Napier	15 - 25	1.0 - 3.0	15 - 30	3 - 8	1.5 - 4.0	1.0 - 3.0
<i>Cynodon dactylon</i> cv. Coast-cross	15 - 25	1.5 - 3.0	15 - 30	3 - 8	2.0 - 4.0	1.0 - 3.0
<i>Cynodon</i> spp cv Tifton	20 - 26	1.5 - 3.0	15 - 30	3 - 8	1.5 - 4.0	1.5 - 3.0
<i>Brachiaria brizantha</i>	13 - 20	0.8 - 3.0	12 - 30	3 - 6	1.5 - 4.0	0.8 - 2.5
<i>Andropogon gaianus</i>	12 - 25	1.1 - 3.0	12 - 25	3 - 6	1.5 - 4.0	0.8 - 2.5
<i>Brachiaria decumbens</i>	12 - 20	0.8 - 3.0	12 - 25	2 - 6	1.5 - 4.0	0.8 - 2.5
<i>Medicago sativa</i>	34 - 56	2.5 - 5.0	20 - 35	10 - 25	3.0 - 8.0	2.0 - 4.0

Source: Adapted from Werner et al. (1996).

Table 6. Adequate shoot macronutrient concentrations for tropical forages and alfalfa.

5. Pasture fertilization

The pasture productivity is determined by many factors as species, climatic and soil conditions and management practices. Research in tropical and subtropical regions has highlighted the need to supply the pasture system with macro- and micro-nutrients, as well as soil amendments, since fertilization is one of the factors that most contribute to increase forage dry matter (DM) productivity and quality (Primavesi et al., 1999; Cantarella et al., 2002).

Pastures fertilization consists of two phases: fertilization during the establishment period, which aims to provide nutrients for the development of fresh established pasture and correcting deficiencies in the soil nutrient supply; and maintenance fertilization, which aims to provide or restore nutrients extracted or lost during grazing. Table 7 based on Macedo (2004) summarizes the N, P and K recommendations for pastures from three sources: Werner et al. (1997), Cantarutti et al. (1999), and Vilela et al. (2002). These actual lime and fertilizer recommendations for forage in the published literature are adequate for semi-intensive forage management systems, but do not capture the whole production potential of the tropical forage.

Bernardi et al (2008) carried out a survey with 232 farmers and rural extension workers who adopted the intensive managed forage system. Questions about the adoption of technical soil conservation and fertility, leaf and soil analysis, irrigation, use of fertilizers and limestone and costs of these techniques on production were made. The results pointed to an usual use of soil analysis, lime, micronutrients and soil conservation practices by 96%, 97%,

78% and 99% of interviewees, respectively. Regardless of the soil test, most used a N, P₂O₅ and K₂O formulation (NPK) for pasture fertilization of 400 kg ha⁻¹ of 8-28-16 at planting or seeding, and 700 kg ha⁻¹ of 20-5-20 at topdressing. However, 93.8% of the producers do not perform leaf analysis. The approximate relationship between fertilizer use and animal production for this group of interviewees was 1 ton fertilizer to 1000 liters milk and 1 ton fertilizer to 195 kg meat.

Recommendation	Grass-based forage phases			
	Establishment		Maintenance	
	N (kg ha ⁻¹)	Criteria	N (kg ha ⁻¹)	Criteria
Werner et al. (1996)	40	20-40 days after germination	40 to 80 50	Nutritional need each grazing cycles
Cantarutti et al. (1999)	0 to 150	60% of soil coverage by pasture	50 100-150 200-300	Technological level: Extensive Medium Intensive
Vilela et al. (2002)	40 to 50	75% of soil coverage by pasture	40	Extensive
	P ₂ O ₅ (kg ha ⁻¹)	Criteria	P ₂ O ₅ (kg ha ⁻¹)	Criteria
Werner et al. (1996)	20 to 150	Nutritional need	20 to 50	Nutritional need (annual application)
Cantarutti et al. (1999)	15 to 120	Technological level	15 to 60	Technological level (annual application)
Vilela et al. (2002)	20 to 180	Nutritional need	20	Nutritional need (biannual application)
	K ₂ O (kg ha ⁻¹)	Criteria	K ₂ O (kg ha ⁻¹)	Criteria
Werner et al. (1996)	20 to 80	Nutritional need	20 to 60	Nutritional need (annual application)
Cantarutti et al. (1999)	20 to 60	Technological level	40 to 200	Technological level (annual application)
Vilela et al. (2002)	20 to 60	Nutritional need	50	K < 30 mg dm ⁻³

Source: adapted from Macedo (2004).

Table 7. Nitrogen, P and K fertilizer recommendations (levels and fertilization criteria) for establishment and maintenance of grass-based forage for grazing cattle in tropical pastures of Brazil.

6. Nitrogen

In general, N is the nutrient that is the most limiting for plant growth and affects the productivity of pastures (Jarvis et al., 1995). Many authors pointed out that an increment in N fertilization increases grass dry matter yield. Vicente-Chandler et al. (1959) found a positive response to the application of up to 1,800 kg N per ha per year. Growth response of 40 to 70 kg DM kg⁻¹ of applied N can be expected at fertilizer rates of as high as 400 to 600 kg N ha⁻¹ during the growing season (Vicente-Chandler et al., 1974; Minson et al., 1993).

Other authors, however, demonstrated that higher responses are obtained with doses of 300 to 400 kg N per ha per year (Werner et al. 1977; Olsen, 1972, Gomes et al., 1987). According to Cantarella et al. (2002) N use efficiency (expressed in kg of dry matter produced per kg fertilizer N applied), decreases with increasing dose of N applied.

Additions of N through the mineralization of SOM, atmospheric (wet and dry) deposition and biological-fixing activities in soils are uncertain and are generally inadequate to sustain high pasture productivity (Martha Jr. et al., 2004).

Positive results of N fertilization on dry mass production of species of *Brachiaria* were achieved by Bonfim-da-Silva and Monteiro (2006), Primavesi et al. (2006), Rodrigues et al. (2006), and Benett et al. (2008), for *Cynodon dactylon* cv. coast-cross by Corrêa et al. (2007), for *P. maximum* by Lugão et al. (2003), Volpe et al. (2008) and for *Pennisetum* by Martha Jr. et al. (2004).

From a forage quality standpoint, N fertilization increased whole plant crude protein concentration (Alvim et al. 1998) but effects on other forage quality variables were less consistent. Results on the effect of N on *in vitro* dry matter digestibility (IVDMD) are conflicting (Monson and Burton, 1982; Gomide and Costa, 1984; Cáceres et al., 1989).

Urea has been the most used N-source in Brazil (ANDA, 2008), due to lower cost per unit of N. But N use efficiency of urea may be reduced because of losses from agricultural system by volatilization of ammonia to atmosphere. This is one of the main factors responsible for the low efficiency of urea, and may reach extreme values, with losses close to 80% of N applied (Lara-Cabezas et al., 1997, Cantarella et al., 1999; Martha Junior et al., 2004). Such results have been reported even in acid soils, since the liming increases soil pH and favors volatilization. Mulch present in no-tillage or pasture systems may also increase the amount of N lost by volatilization, especially when urea is applied on soil surface. Anjos and Tedesco (1976) compared the losses by N volatilization from N sources and reported values of 30% for urea and less than 1% for ammonium sulfate. In urea fertilized pastures, the volatilization of ammonia (NH₃) into the atmosphere is the most significant N loss (Whitehead, 1995). These losses are enhanced when the urea is applied in the topdressing and at the end of the rainy season (Martha Júnior et al., 2004, Primavesi et al., 2004), specifically with greatest losses (60%) when applied on wet soil (field capacity) followed by no rain or irrigation, and lowest losses (1%) when used on dry soil followed by around 10 mm rain or irrigation (Primavesi et al. 2001). These losses after N fertilization reduce pasture growth and consequently, the stocking rate and weight gain (Whitehead, 1995). In a Marandu grass (*Brachiaria brizantha*) pasture in Brazil, Oliveira et al. (2007) found gaseous losses of N fertilized with urea ranging from 14 to 38%, but the losses were much lower when urea was incorporated in the soil by a no-till double-disc soil cultivator.

Ammonia losses from N fertilizer can be reduced through the use of sources less susceptible to volatilization (nitrate-based fertilizers), or by soil incorporation of the urea (a process hindered by direct fertilization) (Primavesi et al., 2003). Slow urea liberation has also been observed with the addition of acids, salts of K, Ca and Mg, and by the choice of specific urea's grain size distribution (Allaire and Parent 2004). The urea-N losses can also be reduced using zeolites as additives in the fertilizers to control the retention and release of NH₄⁺ (Bernardi et al., 2009).

Teitzel et al. (1991) associated the use of N fertilizers in intensively managed tropical pastures with positive economic responses. Results from Euclides et al. (2007) showed that fertilizing *P. maximum* with N had significant responses on animal yield as weight gain and production per hectare.

Results from Primavesi et al. (2004) and Primavesi et al. (2006) indicated that the N fertilization doses of 500 kg ha⁻¹ year⁻¹ of N can be reduced in approximately 10% in subsequent years until stabilizing in the sixth or seventh year with maintenance dose, due the increased SOM levels.

Efficient pasture use in intensive production systems depends on the balanced mineral nutrition of the forage plant (Hopkins et al., 1994). Nevertheless physiological processes of plants are affected specially by high doses of N fertilizer. Data presented by Primavesi et al. (2001 and 2003) suggest that the maximum level of N in tropical forage grasses is 24 g kg⁻¹, from which starts the accumulation of nitrate in forage losses occur more intense and nitrate leaching. The forage protein content should be at least 70 g kg⁻¹ or higher to stimulate an animal intake and digestibility.

When N fertilizers are supplied to grasses, there may be increasing in levels of provided nutrient, but there may be side effects of this application, resulting in increases or reductions in levels of other nutrients. Primavesi et al. (2005) determined the uptake of cations and anions of coastcross grass fertilized with N from 0 to 1,000 kg ha⁻¹ (split in 5 applications during the rainy season). High doses of N fertilizer as urea or ammonium nitrate applied on coastcross grass favored absorption of cations and anions, although increasing rates of N caused higher K⁺ uptake in relation to other cations and in Cl⁻ among the anions. Batista and Monteiro (2010) evaluated changes in K, Ca and Mg concentrations of *B. brizantha*, cv. Marandu (Marandu palisadegrass) due N and S fertilizer inputs. N fertilization influenced Ca and Mg concentrations as well as the proportions of K, Ca and Mg in the above-ground part of Marandu palisadegrass.

7. Phosphorus

Acid tropical soils normally contain a limited P reserve and often have a high sorption capacity (Novais and Smith, 1999). According to Sanchez (1976), there are two main processes responsible for P fixation in acid soils: (i) precipitation by exchangeable Al and; (ii) adsorption on the surface of sesquioxides. Phosphorus fixation tends to be high in acid soils where the Fe and Al-oxyhydroxides are ubiquitous. The reversibility of P sorption is important since desorption often is a limiting step in the uptake of P by crops. Hence, P is considered to be the most limiting nutrient in uncultivated tropical soils and frequently found only as a trace (below 1 mg per kg of soil).

Phosphorus plays an important role in plant metabolism as cell energy transfer, respiration and photosynthesis. The response to fertilization depends, among other factors, the availability of P in the soil, the availability of other nutrients such as N and K, the species and climatic conditions (Sousa et al., 2004). Phosphorus deficiencies limit pasture establishment and growth (Corrêa and Reichardt, 1995; Corrêa and Haag, 1993). Souza and Lobato (2004) and Macedo (2005) also verified is that P is the most limiting nutrient related to pasture establishment and pasture sustainability. Results from Werner (1986), Corrêa and

Haag (1993), Hoffmann et al. (1995) and Belarmino et al. (2003) pointed out that P fertilization significantly increased root and tiller growth. Once P is available in sufficient supply, N availability drives pasture production. Cultivars of *P. maximum* generally show high response to P fertilization (Gheri et al., 2000).

8. Potassium

Potassium is the cation in higher concentration in forage plants and has relevant physiological and metabolic functions such as enzymes activation, photosynthesis, photo-assimilates translocation, stabilization of internal pH, stomatal function, turgor-related processes, N absorption and protein synthesis. The addition of K increases its levels in plant tissue and reduces the Ca and Mg levels in equivalent quantities (Mattos et al., 2002).

Providing an adequate supply of K is important for plant production and is essential to maintain high quality and profitable yields. In order to determine the best time and way of supplying of a nutrient source, their dynamics in soil and role on plant metabolism should also be considered (Benites et al., 2010). Band application of K in the furrow or topdressing application on soil surface is possible due its uptake by mass flux and its high mobility within the plant (Benites et al., 2010). Proper management of K fertilizer in relation to doses and application methods (banding, broadcast and split applications) can minimize losses, avoid depletion of soil K, increase the soil available K pool for a beneficial residual effect of infrequent K fertilization and increase crop yields per unit of K applied to soil (Vilela et al., 2002). The most appropriate time and manner of application of K and of any other nutrient are determined according to plant requirement and element dynamics in soil. The strategy for K fertilization must be accomplished in two steps: first corrective fertilization and then maintenance fertilization.

9. Liming

Soil acidity is one of the most yield-limiting factors for crop production, since is a complex of numerous factors involving nutrient/element deficiencies and toxicities, low activity of beneficial microorganisms and reduced plant root growth that limit nutrient and water uptake (Fageria and Baligar, 2003). High amounts of Al, and sometimes Mn, and the low contents of Ca, Mg, and other nutrients frequently account for the low productivity of crops grown on the acid soils. High concentrations of Al inhibit root development and tend to limit absorption of other nutrients, especially of Ca and Mg since their uptake is directly related to root growth and plant development (Lathwell and Grove, 1986).

The clay fraction of Oxisols and Ultisols is usually dominated by sesquioxides, gibbsite, kaolinite and intergrade minerals. These compounds have low intrinsic amounts of negative charges and, therefore, most of the CEC of these soils depends on organic matter (see below) and depends on the soil solution pH. As a consequence, such soils exhibit a strong relationship between charge and pH. In some cases the soils may show net positive charge at low pH, which affects the availability of some nutrients (Sanchez, 1976). Cation exchange capacity is responsible for the equilibrium of ions in the solid/liquid interface in soils. So the usually low values of CEC combined with low pH lead to leaching of K, Ca, and Mg. Low concentrations of K, Ca and Mg, and the low CEC associated with high Al contents are

serious fertility constraints in acid tropical soils. Evaluation of these parameters in subsurface layers (below 0.2 m) should be undertaken.

Liming is a low-cost and effective way to neutralize soil acidity and to improve crop yields. Liming reduces Al and Mn toxicity, improves P, Ca and Mg availability, increases CEC, promotes N₂ fixation, and improves soil structure. Overall, liming improves soil capacity to supply needed nutrients and the ability of plants to absorb nutrients and water due to better root growth and activities of beneficial microorganisms. Also an increase in exchangeable bases and pH can stimulate decomposition and mineralization of organic matter by creating a more favorable environment for microbial populations (Sanchez, 1976; Havlin et al., 1999; Fageria and Baligar, 2008). The quantity of lime required depends on the soil type, quality of liming material, costs and crop species or cultivars (Fageria and Baligar, 2008).

Information on appropriate liming rates for tropical forages grown on acid soils in Brazil requires further studies, because the forage response to this practice have been differentiated (Cruz et al., 1994; Oliveira et al., 2003; Paulino et al., 2006), probably due to differences in soil properties and the variability of tolerance to soil acidity of tropical forage grasses. Macedo (2005) believes that the controversy lies in the Cerrado, since clays in these Oxisols affect their response to liming in a way that is quite different from other regions of Brazil. Besides, forages commonly used in this region have high tolerance to soil acidity. Limestone rates are calculated to raise soil base saturation as a percentage of the cation exchange capacity (CEC) of the soil at pH 7.0, to levels which vary with forage species. Werner et al. (1996) recommended a soil base saturation (BS) of 70% for planting and 60% for pasture maintenance, for *Pennisetum purpureum*, *P. maximum*, *Cynodon dactylon*, *Digitaria decumbens*, *Hyparrhenia rufa* and *Chloris gayana* pastures; 60% of BS for the establishment period and 50% of BS for the maintenance of *B. brizantha*, *Andropogon gayanus* e *Cynodon plectostachyus* pastures; and 40% of BS for the establishment and maintenance of *Brachiaria decumbens*, *Brachiaria humidicola*, *Melinis minutiflora*, *Paspalum notatum* and *Setaria anceps* pastures. *B. decumbens* pasture, which had the adequate basis saturation of 40%, after four years of intensive use of N and K fertilizer was observed high depletion in Ca and Mg levels in soil that could lead to plants death (Primavesi et al., 2004 and 2008).

Nevertheless, some intensive managed pastures appear to require more lime, with 80% of basis saturation being the optimum level. This apparent controversy can be explained by the fact that commonly used N, P and S fertilizers are acid-forming. The acidifying effect varies with the forms of these elements in the specific fertilizer used. For example, urea, ammonium nitrate and ammonium sulphate are soil-acidifying and require respectively 1.8, 1.8 and 5.4 kg of lime per kg of fertilizer to neutralize the produced soil acidity (Havlin et al., 1999).

Disking for lime incorporation in soil cultivated with pastures is a controversial practice (Arruda et al., 1987; Soares Filho et al., 1992; Luz et al., 1998). A slight increase in forage yield (130 kg ha⁻¹) was observed when lime was incorporated into the soil of a degraded *P. maximum* pasture by disking (Luz et al., 1998). On the other hand, disking decreased the dry aboveground matter of *B. decumbens* pasture (Soares Filho et al., 1992). In the recovery of degraded pastures, Primavesi et al. (2004 e 2008) showed that lime can be applied superficially especially when high N dose are used.

10. Sulphur

Sulphur (S) is an important macronutrient for plant metabolism and growth, being a component of essential amino acids (methionine, cysteine) and other organic compounds. The extraction of sulfur by forage plants may be around $50 \text{ kg ha}^{-1} \text{ yr}^{-1}$, considering yields of $20 \text{ t ha}^{-1} \text{ year}^{-1}$ of dry matter and S concentration in shoots of 2.5 g kg^{-1} (Werner et al., 1996). Since plants have a lower demand for S than N, it has been neglected in Brazilian pasture fertilization (Monteiro et al., 2004). In Brazil, as a result of the constant use of concentrated NPK fertilizers, besides some edaphic and climatic factors, S became a limiting nutrient for plant development. Moreover in intensive forage management system low response to N fertilizer may be associated to low levels of S in the soil (Cunha et al. 2001; Mattos and Monteiro, 2003, Oliveira et al. 2005; Bomfim and Monteiro-Silva, 2006).

Monteiro et al. (2004) suggested that S fertilization of pasture grasses should be recommended when these forages are well fertilized with N. Stevens (1985) emphasized that both N and S supply are directly related and they must be in plant tissues in adequate proportions and amounts for the optimal synthesis of protein. The N:S ratio is an important nutritional status index since it remains constant at different stages of grasses development (Vitti & Novaes, 1986). According with Scott (1983) to ensure proper development to forage plants, the optimum N:S ratio must be around 16.5:1. The uses of ammonium sulphate or simple superphosphate or gypsum are adequate sulphur sources.

11. Micronutrients

Micronutrients play important roles in plant metabolism, acting as a constituent of organic compounds or as regulators of the functioning of enzyme systems. Micronutrients, also known as trace minerals, which chiefly include boron (B), molybdenum (Mo), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe), are required in extremely small quantities by crops and cattle. Review articles related to micronutrients on tropical forages prepared by Gupta et al. (2001) and Monteiro et al. (2004) provide information about forage yield responses to these minerals.

Soil acidity is one of the primary factors affecting the availability of micronutrients to crops (Sanchez, 1976). With the exception of Mo, the plant availability of other micronutrients, e.g., Zn, Mn, B and Fe decreases with liming (Gupta et al., 2001; Monteiro et al., 2004).

Micronutrients needs are assessed by soil testing and eventually supplied by fertilizers. In more intensive agricultural systems, such as intensively managed grassland with high productivity and high stocking rates, the tendency is a greater need for micronutrients. So an adequate supply is important to avoid a reduction in forage production. Positive response of grasses to zinc addition has been reported in Cerrado low fertility soil and for intensive managed pasture system with high N fertilization (Monteiro et al., 2004).

12. “Adubapasto” software

As presented in this chapter, the criteria for lime and fertilization recommendations for intensively managed pastures are not organized in a specific publication. Thus, there was a clear need to gather, organize, and make available this existing information to producers and agricultural extension agents. So, Embrapa Pecuária Sudeste made free, online software

Adubapasto 1.0 with remote access software by Web service. The structure of this software is based on: 1) architecture of the environment: CLIENT / SERVER, 2) Server Operating System: LINUX, 3) Web Server: APACHE, 4) Application Server: Zope/Plone; 5) Database Server: FIREBIRD and 6) Language development: PYTHON / JAVA SCRIPT.

Software is available at the site: <http://www.cppse.embrapa.br/adubapasto>. Based on the results of soil analysis, characteristics of a property and cattle schedule (stocking rates, number of days in pasture, supplemental feeds, etc), algorithms for lime and fertilizer recommendation were established, based on results of studies published in scientific and technical literature and experience of experts in soil fertility, fertilizer use, plant nutrition, animal nutrition and forage production.

The calculation routines include recommendations for liming, gypsum, N, P and K fertilizer for pasture establishment and maintenance periods, depending on the forage species, cattle management and stocking rate.

As a result, the software generates reports of recommendations for correction and fertilization, stocking rate expected and achieved. It is also possible to assess the historical evolution of soil fertility, since the data is stored in the database. This software operates as a management tool for agricultural technicians, extension workers, producers and researchers who can organize their information in the database.

13. Final remarks

The chapter showed that intensive pasture management practices can make cattle more profitable and competitive, and also conserve soil and water, thereby reducing the potential for deforestation and increasing the possibility of environmental preservation. So, High pasture productivity, leading to improve and high cattle production (milk and meat) is a sustainable practice that can meet societal demands for development without environmental degradation, better quality of life and improved resource availability with the opportunity to progressively combat social inequalities in all sectors and especially in the agricultural sector.

Soil chemical analysis is an important tool to know the soil fertility and make appropriate lime and fertilizer recommendations. There are differences between analytical protocols used for soil testing in Brazil, therefore, attention should be paid to the results to avoid any ambiguity in the interpretation and recommended doses.

Pastures need N to accumulate carbon, and also K, Ca, Mg, P, S and micronutrients for high yield and quality and profitability of cattle. Nutrient deficiencies and some soil chemical constraints can be avoided by regular monitoring of soil fertility. Careful attention to stocking rates to prevent overgrazing is also important.

The practices of soil amendment and fertilizer depend on the production system that farmer adopts and will always want to obtain satisfactory economic return with low environmental impacts. Table 8 summarizes the suggestions for liming and fertilization of intensive managed pasture systems on tropical acid soils in Brazil. Soil testing must be carried out every year.

Liming	Increase basis saturation to 70 or 80% (Ca: 55 to 60% of CEC*; Mg: 15 to 20% of CEC)
Nitrogen	Doses established as a function of forage species, animal stocking rate and soil organic matter: 40 to 50 kg ha ⁻¹ of N per AU** considering 3 to 7 AU** per ha. Reducing doses in 10% each year, from 6 or 7 th year just N fertilizer for replace the exportation. Foliar diagnosis for evaluation keeping N in shoots approximately 24 – 25 g kg ⁻¹ .
Phosphorus	Begin with 10 mg dm ⁻³ and increase until 30 mg dm ⁻³
Potassium	Begin with 3% of CEC* and increase until 6% of CEC*
Sulphur	60 - 90 kg ha ⁻¹
Micronutrients	B = 0.5 to 1.0 kg ha ⁻¹ Cu = 1.0 to 2.0 kg ha ⁻¹ Zn = 2.0 to 4.0 kg ha ⁻¹ , or FTE*** = 30 to 40 kg ha ⁻¹

*CEC = cation exchange capacity; **A.U. = animal unit = 450 kg of live weight; ***FTE = fritted trace elements (composition: Ca = 7.1%; S = 5.7%; B = 1.8%; Cu = 0.8%; Mn = 2.0%; Mo = 0.1% and Zn = 9.0%).

Table 8. Suggestions for liming and fertilization of intensive managed pasture systems in Brazil.

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