Chapter 8
Mapping Potassium Availability from Limited Soil Profile Data in Brazil

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Abstract Brazilian soils are generally acidic with low base saturation and low plant available potassium (K). Potassium fertilizers play important role in production costs and farmers receive no governmental subsidies. Strategies are needed to improve potassium fertilizer delivery to different regions in Brazil and to establish affordable prices and balanced potassium consumption. For such strategy, it is necessary to take into account the different soil classes with its varying K levels. The purpose of this study was to map soil K in Brazil considering the different biomes and applying techniques to reduce problems caused by limited soil profile data. A soil profile data set was constructed from the soil archives of Embrapa Soils, Rio de Janeiro, Brazil. Descriptive statistics was performed on K levels in different soil classes and biomes. The different soil K levels were grouped in intervals and mapped using ArcGIS 9.1 tools from ESRI. Brazil's soil map and biome map at 1:5,000,000 scale were used in the geoprocessing. Our results showed that mapping soil K levels based on soil survey reports at the regional scale is difficult because of limitations in georeferencing and spatial distribution of soil profiles. However, this mapping would help fertilizer distribution planning in Brazil.

8.1 Introduction

In 2005, Embrapa Soils and the International Potash Institute (IPI) started to organize soil data for mapping the plant potassium availability of several soil surveys of the National Soil Archives of Embrapa Soils. There was a need for optimum regional distribution of K fertilizers in Brazil, which are mostly imported. Optimized fertilizer distribution would help fertilizer delivery to farmers at lower costs. Presently, up to 40% of the total production cost of grain crops is due to inorganic fertilizers

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(Bernardi et al., 2002). Brazilian farmers receive no governmental subsidies and the prices of inorganic fertilizers inhibit them to apply adequate and balanced amounts of fertilizer.

Mapping soil K availability is relevant because potassium is the second largest plant nutrient taken up by the main crop plants grown in Brazil such as soybean, coffee, common beans, cotton (Bernardi et al., 2002). Thus, balanced potassium fertilization of soils is essential to avoid both plant and soil degradation. In Brazil, crop plants are mostly grown in the Mata Atlantica and Cerrado biomes, whose soils are originally K deficient.

Since 1990s, compared to other plant nutrients the consumption of potassium fertilizer has been the largest in Brazil, and the recent growth of agribusiness have promoted potassium fertilizer use, particularly in the Cerrado region (Mascarenhas et al., 2004). Also, Lopes (2005) has estimated an increase of K_2O consumption in Brazil from 3.65 million t in 2003 to 5.2 million t in 2010 leading to US$ 6.08 million for importation expenditures in 7 years.

One of the main reasons for the change in agricultural production is the change in the consumer patterns combined with environmentally friendly technologies because of social and environmental concerns (Poulisse, 2003). There is a clear need for environmental sound techniques and food security with low environmental impact (Sanchez, 1997).

The use of geotechnologies in scientific studies may help to transform agriculture. Reliable data acquisition, organization in a georeferenced data base, and mapping are efficient tools. Plant nutrient mapping has been used at the farm level as part of precision agriculture (Bernardi et al., 2002). However, a regional approach is often needed for both governmental and private business purposes.

Available soil fertility data are sparse and collected at different scales. Interpolation is often difficult because of unreliable georeferencing. Problems related to sparse data infrastructures is further discussed in Chapter 2. The purpose of our study was to map K availability of Brazilian soils using soil survey reports, considering different biomes and applying techniques to reduce problems caused by limited soil profile data.

8.2 Material and Methods

A soil profile data set was constructed from the National Soil Archives of Embrapa Soils, Rio de Janeiro, Brazil. Exchangeable potassium data set were collected from 2600 soil profile (8500 soil horizons) surveyed in different biomes between 1958 and 2001.

8.2.1 Selection of Soil Profiles and Horizons

The predominant soil classes in Brazil are Acrisols, Luvisols, Ferralsols and Arenosols and soil K data were grouped for different depths (0–10, 0–20, 0–30, and 0–40 cm). On average accumulated soil K varies (>20%) with depth, particularly at 0–10 and 0–20 cm. Soil profiles selected were with soil horizons to 30 cm. Those soil horizons over 30 cm depth were considered up to 40 cm (i.e. 25–35 cm, 25–40 cm) and in soil profiles where the final depth was labeled 30 (i.e. 25–40 cm was considered 25–30 cm). Soil horizons deeper than 40 cm were excluded (e.g. 25–45 cm, 25–80 cm). Soil K concentration was restricted to a depth of 30 cm because most of plant root system are up to this depth.

8.2.2 Calculation K Level for Each Selected Soil Profile Data

For soil profiles showing two or more horizons the calculation of K level was as follows:

$$Kp = ((e_1^* K_1) + (e_n^* K_n)/30)$$

where:

Kp = soil K in the profile (mg kg^{-1})
e = depth of soil horizon (cm)
K = soil K in the horizon (mg kg^{-1})
n = number of soil horizons until 30 cm depth

8.2.3 Verification and Data Exploratory Analysis

Prior to the exploratory analysis all data was verified and outliers were deleted. Values outside the limit of $X \pm 3^* SD$ (standard deviation) were considered an outlier. After the elimination of outliers a correlation analysis between K content and chemical and textural attributes was performed. A forward stepwise multiple correlation analysis was also performed to identify the attributes that showed strong influence over K content. Statistica 7.0 software was used in all analysis.

8.2.4 Map Units of Biomes and Soils

The single-part polygon was used as map unit and the polygon was generated from the intersection between soil class and biome type. It was assumed that soil K may vary as a function of soil class and biome. The Brazilian soil map (IBGE, 2001a) and Brazilian biome map (IBGE-MMA, 2005), both at the 1:5,000,000 scale, were intersected using the geoprocessing tool of ESRI ArcGIS 9.1. The area of the biome-soil unit was calculated using Albers Equal Area Conic projection and SAD69 datum of ESRI ArcGIS 9.1. Finally, two methods were applied to construct the soil K availability map.

The total number of map units from biomes and soil classes was 3332. Figure 8.1 shows the location of the 1764 K soil profiles. Most profiles are located in the

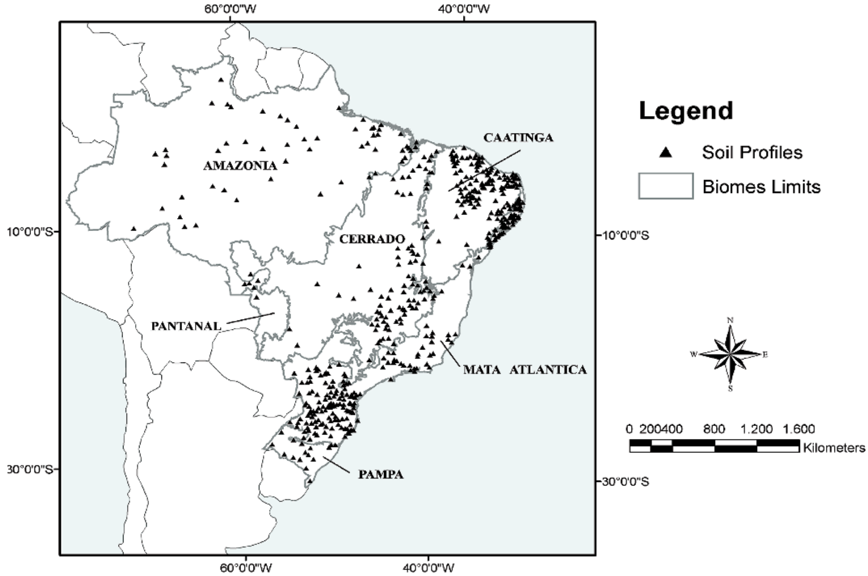

Fig. 8.1 Brazil's biome map at 1:5,000,000 and soil profiles distribution

northeastern, southeastern and southern Brazil and in the northern and central regions there were very few soil profiles available.

8.2.5 Mapping K Availability from Calculated K Soil Profiles with Associated Spatial Information

Most soil profiles of soil surveys were not fully georeferenced. Thus, the municipality central coordinates from the municipality grid map (IBGE, 2001b) at 1:250,000 scale were combined with the calculated K soil profile data, using the join tabular tool of ESRI ArcGIS 9.1. See also Chapter 29 for methodology used to convert printed into digital soil maps from the Amazon Region.

Soil profiles selected from the National Soil Archive were classified to the major soil group level (e.g. Ferralsol) whereas soil classification used in the 1:5,000,000 soil mapping was a third-order classification (e.g. Rhodic Ferralsols – Latossolo Vermelho distroferrico). Soil profile without representation at the 1:5,000,000 soil mapping were eliminated. This resulted in 482 calculated K soil profiles to be extrapolated to soil-biome units leading to 177 units with soil K data. Some units contained more than one soil profile and in these cases mean values were calculated for each soil unit.

Extrapolation of soil K from 177 soil-biome units to other units that were not mapped was done by the summarize tool of ESRI ArcGIS 9.1. A mean value of soil K was generated for each soil-biome unit group and this mean value was associated to other units not mapped using join tabular. In this step, the soil K of 1992 soil-biome units were estimated and used to map the K availability from soil profile data.

8.2.6 Mapping K Availability in the Third-Order of Acrisols, Luvisols and Ferralsols

At first, the percentage of Brazilian soil classes in different biomes was calculated. Only the K data of the Acrisols, Luvisols and Ferralsols were used because these major soil classes are dominant in Brazil (Acrisols and Luvisols 24% and Ferralsols 32% of Brazil area) and its agricultural suitability is generally high. The 296 (119 Acrisols and Luvisols, and 177 Ferralsols) profiles classified in the first-order were classified to third-order taking into account the humid colour of the first B horizon (10R-7.5R-5R-2.5YR = red; 5YR-7.5YR = yellow-red; 10YR-2.5Y-5 Y-7.5Y-10Y = yellow) and the base saturation percentage (<50% = dystric and >50% = eutrophic). Descriptive statistics for Acrisols, Luvisols and Ferralsols (third-order) K level and biome classes was calculated using Statistica. The results were associated by join tabular tool of ESRI ArcGIS 9.1 to the biome-soil units. In addition, 5 classes of interpretation of soil K were used to both mapping K availability, as suggested by Van Raij (1985). One more class was associated to no data related to biome-soil units with no associated soil K:

No data – biomes-soils units with no associated soil K
0–30 mg kg^{-1} soil – very low
30–60 mg kg^{-1} soil – low
60–120 mg kg^{-1} soil – medium
120–240 mg kg^{-1} soil – high
> 240 mg kg^{-1} soil – very high

8.3 Results and Discussion

Compared to Mata Atlantica, Caatinga, and Cerrado the soils of the Amazonia biome showed the lowest levels of available K. Results for both Pantanal and Pampa should be considered with care as the number of observations was low (Fig. 8.2).

All biomes and soil classes were considered in the map unit definition as climate and soil class strongly influence plant K availability. The soils from Caatinga soils have a high fertility and low annual rainfall (approx. 250 mm). Soils of the Amazonia biome have the lowest amount of available K because of high annual rainfall and intense leaching. In the Cerrado biome, the levels of plant available K ranged from low and medium but soil use of the extensive pasture systems may promote K depletion. In the Mata Atlantica and Caatinga there many smallholder farmers.

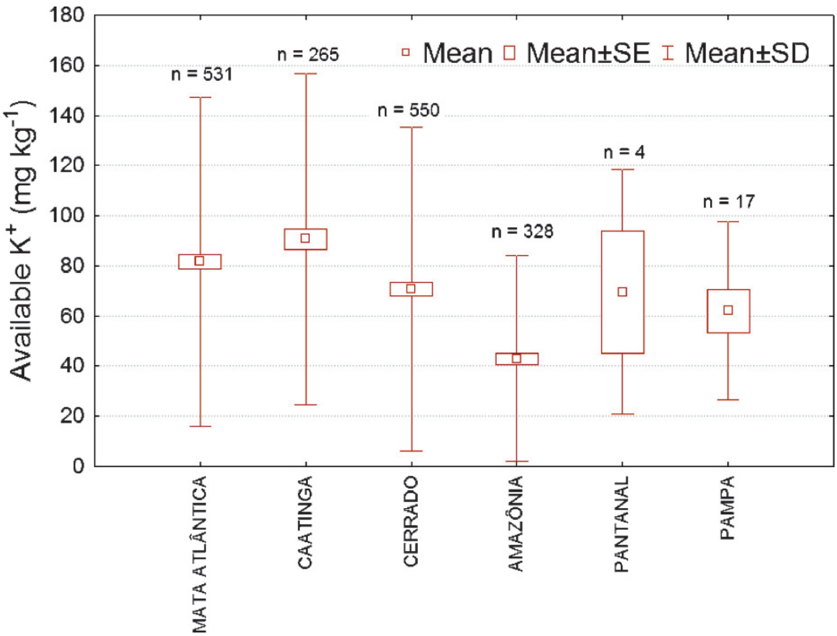

Fig. 8.2 The box and whisker plots of available K in Brazilian biomes. SD – Standard deviation, SE – Standard Error

8.3.1 Descriptive Statistics of K Data and Correlation with Other Soil Properties

Plant available K ranged from 3.90 to 456.3 mg kg^{-1} (mean = 79.0 mg kg^{-1}; SD = 79.6 mg kg^{-1}) showing a larger variability than the other soil properties such as Ca, Mg, Na, Al, and P (Table 8.1). This is probably due to larger and more frequent addition of mineral K fertilizers. Medium to low values of plant available K were also found by Silva et al. (2000) in a study on K forms in Ferralsols from the Cerrado biome. The authors reported that low K values are typical of highly weathered Ferralsols.

Sand content is negatively correlated with K, whereas silt values are positively correlated with K (Table 8.2). Sandy soils generally contain low K due to low nutrient retention capacity and high leaching. The silt fraction contains K-rich minerals, especially 2:1 minerals (Table 8.1).

As expected for acid tropical soils, plant available K is well-correlated with soil pH (both in water and KCl solution). Also, acid soils ($pH < 5.0$) rarely have high K levels (Fig. 8.3).

Calcium and magnesium levels were related to K levels (Fig. 8.4A), whereas soil Al is negatively correlated with K (Fig. 8.4A). This is due to soil liming (e.g. $Ca.MgCO_3$) which combined with K-fertilization increases the association. There was little relation between K and organic C levels (Fig. 8.4B).

Table 8.1 Descriptive statistics for soil properties at the surface depths ($n = 1976$)

Soil properties	Unit	Valid N	Mean	Minimum	Maximum	Std. Dev.	CV
sand		2496	463	0	980	264	57%
silt	$g\ kg^{-1}$	2530	195	0	650	137	70%
clay		2530	341	10	950	215	63%
silt/clay		2530	0.8	0.0	6.6	0.8	103%
water pH		2530	5.1	3.3	7.7	0.8	16%
KCl pH		2494	4.3	2.9	7.4	0.7	16%
Δ pH		2494	−0.8	−2.8	0.8	0.3	46%
Ca+Mg	$cmol_c\ kg^{-1}$	2530	3.5	0.0	24.6	4.6	131%
available K	$mg\ kg^{-1}$	2530	79.0	3.9	456.3	79.6	101%
Na	$cmol_c\ kg^{-1}$	2523	0.1	0.0	8.1	0.3	411%
Sum of bases	$cmol_c\ kg^{-1}$	2530	3.8	0.0	25.3	4.8	126%
Al	$cmol_c\ kg^{-1}$	2511	1.1	0.0	6.6	1.3	121%
H+Al	$cmol_c\ kg^{-1}$	2485	5.7	0.1	35.0	4.0	72%
P	$mg\ kg^{-1}$	1976	4.7	0.0	329.0	15.7	330%
Org.Carbon	$g\ kg^{-1}$	2530	14.6	0.4	69.1	9.5	65%
N	$g\ kg^{-1}$	2358	1.4	0.0	6.9	0.8	60%

Table 8.2 Correlation between K and other soil properties ($n = 1976$)

	sand	silt	clay	Ca+Mg	pH	OC	Na+	N	Al	P
available K	−0.30	0.37	0.14	0.63	0.47	0.13	0.05	0.29	−0.24	−0.07

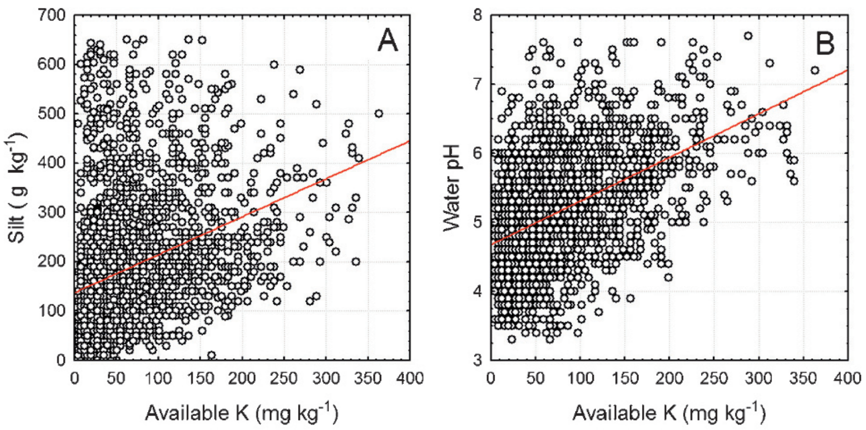

Fig. 8.3 Silt fraction (**A**) and soil water pH (**B**) in relation to available K

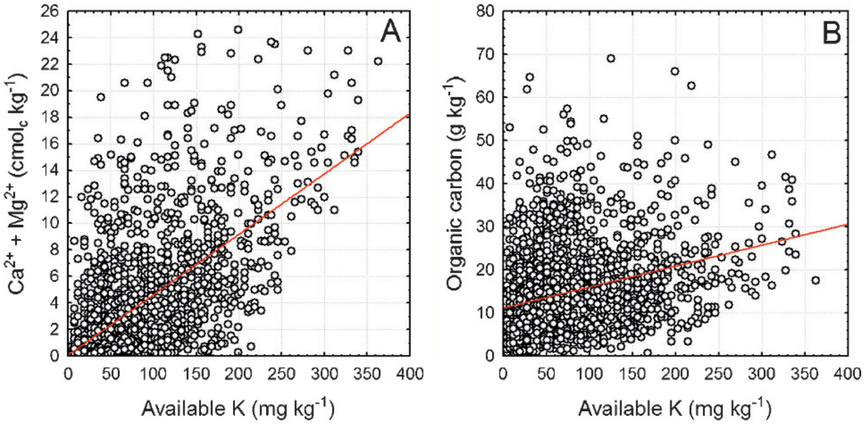

Fig. 8.4 Soil Ca+Mg (**A**) and organic carbon (**B**) in relation to available K

A multiple regression model for K estimation was performed based on Ca+Mg, water pH, organic carbon, and silt. The model explains about half of the K variation with a standard error of the estimate of 43.7 mg kg^{-1} (Fig. 8.5).

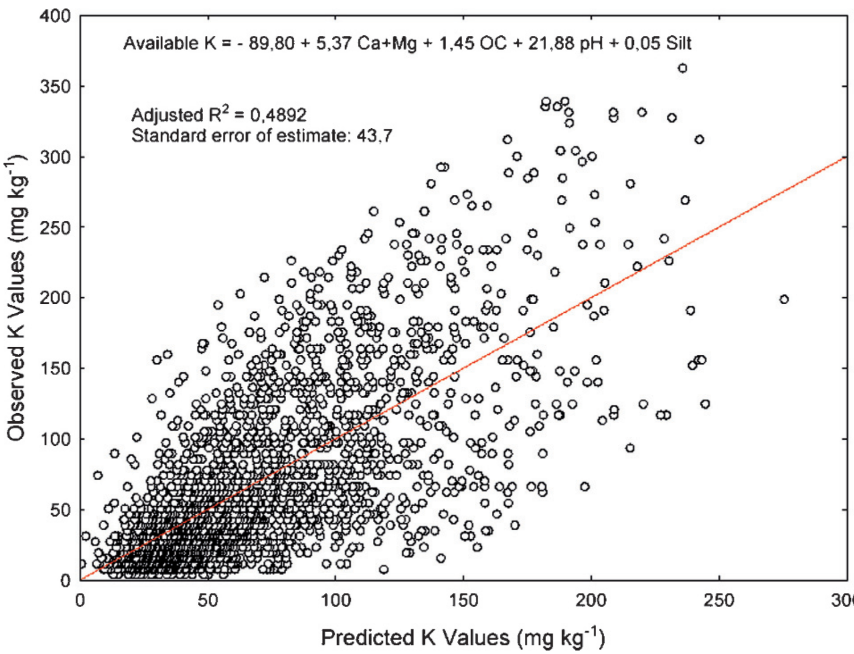

Fig. 8.5 Relationship between observed K and predicted K values using the model based on calcium, magnesium, organic carbon, water pH, and silt of Brazilian soils (n = 7072)

8.3.2 K Availability in Brazilian Biomes and Soils

Acrisols, Luvisols and Ferralsols are predominant in most biomes except for Pampa and Pantanal, in which the Planosols cover most of the areas (Table 8.3).

The results from mapping K availability from calculated K soil profiles with spatial information are shown in the Fig. 8.6. The 482 calculated soil K (mg kg^{-1}) were used to map 1992 soil-biome units. The legend presents the relative proportion of mapped area for each class.

The results from mapping the K availability in the third-order of Acrisols, Luvisols and Ferrasols are shown in Fig. 8.7. The legend presents the percentage area for each class. The most part of biome-soil units showed low amounts of K availability and the small biome-soil units were high. There was no biome-soil units associated with a very high K-levels. It seems that this results reflects better the

Table 8.3 Distribution of Brazilian soil classes in different biomes

Biome	Soil class	Percentage (%)
Amazônia	Acrisols and Luvisols	30.9
	Ferralsols	30.3
	Gleysols	8.0
	Others	30.5
Caatinga	Lithosols and Arenosols	28.8
	Ferralsols	21.0
	Acrisols and Luvisols	15.4
	Others	34.7
Cerrado	Ferralsols	40.7
	Lithosols and Arenosols	23.1
	Acrisols and Luvisols	12.0
	Others	24.1
Mata Atlântica	Ferralsols	35.5
	Acrisols and Luvisols	28.8
	Cambisols	15.5
	Others	20.0
Pampa	Planosols	26.0
	Lithosols and Arenosols	23.4
	Acrisols and Luvisols	22.3
	Others	28.2
Pantanal	Planosols	31.8
	Podzols	19.9
	Plinthic soils	18.7
	Others	29.4

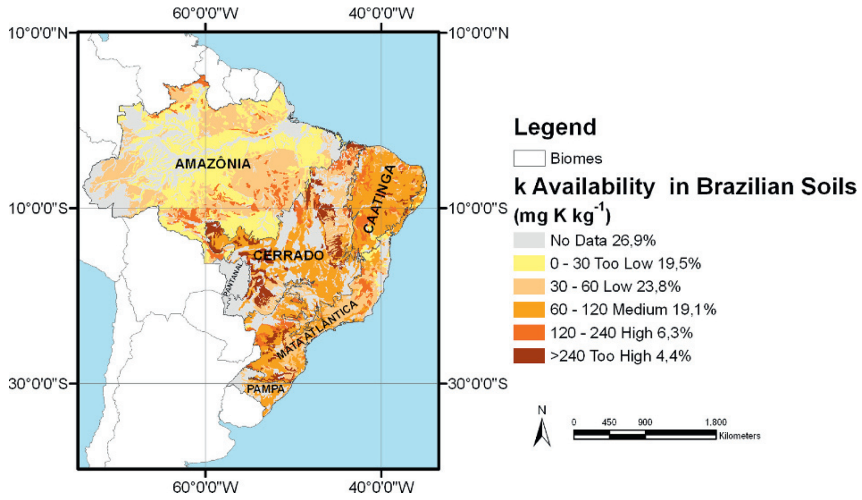

Fig. 8.6 K availability map from calculated K soil profiles with associated spatial information (See also Plate 8 in the Colour Plate Section)

reality because it was considered the soil classification in third-order. However, it is necessary to classify the other soil classes to third-order to map K under this method for all Brazil. The profiles ($n = 296$) used in this case were Xanthic Ferralsols in Amazonia, and Rhodic Ferralsols in the Cerrado and the Pampa and Pantanal biomes did not have K soil profile data.

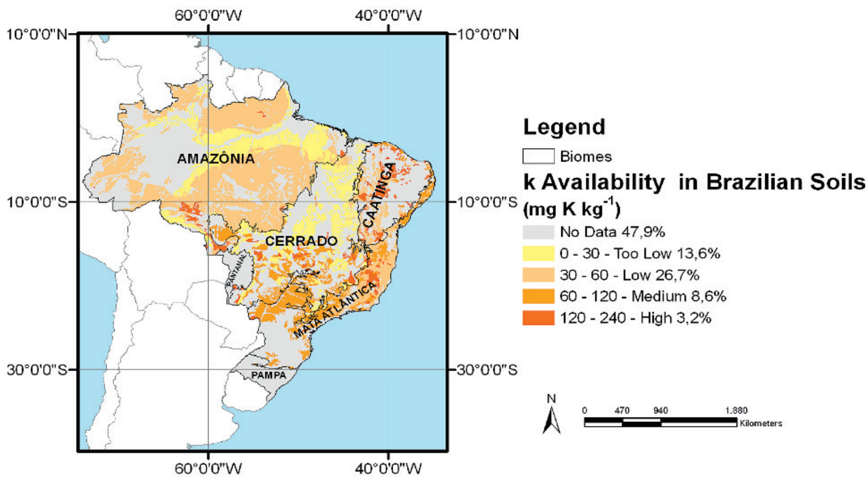

Fig. 8.7 K availability from descriptive statistics application to calculated K soil profiles in a third-order classification to Acrisols, Luvisols e Ferralsols (See also Plate 9 in the Colour Plate Section)

8.4 Conclusions

The biome and soil intersection used to obtain the mapping units of the soil properties may be more useful than municipality borders, because they have natural limits. Our results showed that the mapping of soil K levels based on soil survey reports, at a regional scale, is difficult because of limitations in georeferencing and spatial distribution of soil profiles. Than, it is necessary to test other methods to improve accuracy of K mapping using limited soil profile data in Brazil. For this, it is important consider other themes in the mapping like land use and terrain elevation. This kind of mapping would help fertilizer distribution planning but it is not suitable for fertilizer recommendation. Soil map scaling is also discussed in Chapter 17. For mapping soil K availability in a better scale, like 1:250,000, it is recommended to use georeferenced and more representative soil data set.

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