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Mapping Soil Fertility at Different Scales to Support Sustainable Brazilian Agriculture

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***Abstract*—**Most agricultural crops cultivated in Brazil are highly nutrient demanding. Brazilian soils are generally acidic with low base saturation and available nutrients. Demand for fertilizer application has increased because the national agricultural sector expansion. To improve productivity without environmental impact, there is the need for the utilization of novel procedures and techniques to optimize fertilizer application. This includes the digital soil mapping and GIS application applied to mapping in different scales. This paper is based on research, realized during 2005 to 2010 by Brazilian Corporation for Agricultural Research (EMBRAPA) and its partners. The purpose was to map soil fertility in national and regional scales. A soil profile data set in national scale (1:5,000,000) was constructed from the soil archives of Embrapa Soils, Rio de Janeiro and in the regional scale (1:250,000) from COMIGO Cooperative soil data set, Rio Verde, Brazil. The mapping was doing using ArcGIS 9.1 tools from ESRI.

***Keywords*—**agricultural sustainability, fertilizer optimization, GIS, soil attributes.

I. Introduction

BRAZIL is one of leading countries in the production of the main commodities (Fig. 1). Tropical savannas, locally known as Cerrado, occupy approximately 204 million ha, mostly in the Center-West region of Brazil, and partly in the South-East, North-East and the Amazon regions of this country. Reference [8] during last three decades of the 20th century, some 20 million ha in the Brazilian Cerrado were colonized for commercial crops planting.

In general, brazilian soils are poor in nutrients like K, N and P, then along with agricultural colonization of Brazil, consumption of mineral fertilizers was growing. Specifically in Cerrado, the soil properties, which predominate in the are high acidity (pH 4–5), low cation exchange capacity, low base saturation, high levels of Al^{3+} and ions of Fe and Mn are obstacle to agricultural practices. Only after liming and application of mineral fertilizers for supply necessary amounts of macro and micronutrients, these soils become suitable for continuous planting of grains, oilseeds, and other crops. Brazil already became one of the major consumers of mineral fertilizers, importing 4.1% of the world total of nitrogen, 10.1% of phosphorus and 11.7% of potash fertilizers [4].

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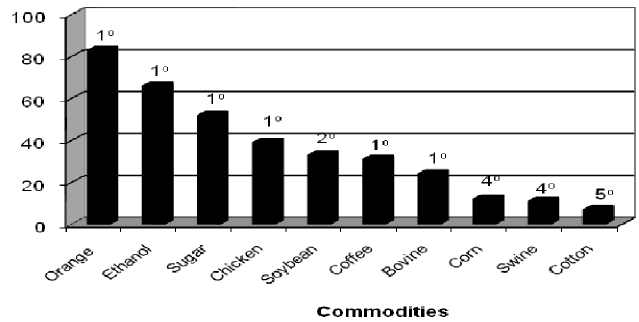

Fig. 1 Percentual of main brazilian commodities exportation related to total production (2009) and its position in the mundial ranking Source Modified from [4]

However, the application of nutrients in the crops is not suitable.The use of inputs in agriculture depends on factors such as demand and efficiency in implementation, and distribution logistics [2]. Data provided by [4] show that the cultures that most used fertilizers in Brazil were soybeans (24%), corn (23%) and sugarcane (21%), followed by other cultures, remembering that these cultures are prevalent in the southwest Goias. The environmental impact of this can be observed by the levels of nitrate contamination and heavy metals in soils and water. According [1] in systems where the production tillage is practiced, for example, one high efficiency can be observed until 100% of soil nutrients used by crops, compared to conventional growing systems involving plowing and disking.

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 [9]. In this context, in 2005 Embrapa Soils with cooperation to the International Potash Institute (IPI), Magnesita S.A. and COMIGO Cooperative started to organize soil data for mapping the soil nutrients availability [10]. The motivation was the need for optimum regional distribution of nutrients fertilizers in Brazil, which are mostly imported. Optimized fertilizer distribution would help fertilizer delivery to farmers at lower costs.

II. Methods

A. Study area

At 1:5,000,000 scale the study area was Brazil. The main soils in Brazil are Acrisols, Luvisols, Ferralsols and Arenosols (FAO Classification). On the other hand, the study area at 1:250,000 was southwest Goias (SW), that has approximately 10 million ha inserted mainly in Cerrado biome – Brazilian Savanna) (Fig. 2). The predominated soils in the Cerrado are Ferralsols (56%) and Arenosols (20%) (FAO Classification).

B. Mapping soil fertility at 1:5,000,000 scale

Results of nutrients (Potassium, Magnesium and Calcium) contained in the data set were collected from 2600 soil profile (Fig. 3) surveyed in different biomes between 1958 and 2001 were used in this mapping. Soil profiles selected were only those with soil horizons to 30 cm. The consistence analysis of data was done and outliers were deleted. Because these soil profiles show two or more horizons the calculation of nutrients level was as follows (1):

$$Np = ((e1 * N1)+(en * Nn)/30) \quad (1)$$

Where:

Np = soil nutrient in the profile (mg kg-1)
e = depth of soil horizon (cm)
N= soil nutrient in the horizon (mg kg-1)
n= number of horizons.

The mapping unit was generated from the intersection between soil class and biome type maps. It was assumed that soil nutrients may vary as a function of soil class and biome. The Brazilian soil map [6] and Brazilian biome map [5], both at the 1:5,000,000 scale, were intersected using the geoprocessing tool of ArcGIS 9.1 from ESRI. A mean value of soil nutrients (K, Mg and Ca) was generated for each soil-biome group and after that, extrapolation of soil nutrients to soil-biome mapping units was done by the summarize tool of ArcGIS 9.1 from ESRI and the mean value was associated to the units using join tabular. In this case the projection applied was geographic (Lat Long) and datum WGS84. In addition, 3 classes of interpretation of soil nutrients (K, Mg and Ca) were used to mapping nutrients availability as suggested by [11] and Manual Fertilization: High, Appropriate and Low.

C. Mapping soil fertility at 1:250,000 scale

The soil nutrients (K, Mg and Ca) availability data were obtained from COMIGO Cooperative soil data set. This cooperative takes about 10,000 soil samples, yearly. At first, the consistence analysis of data was done and outliers were deleted. After the elimination of outliers, the statistic analysis was done for each municipality using the soil data set from 2003 to 2006 using a Statistical software. Southwest Goias has 86 municipalities associated with COMIGO Cooperative. But, in this step, only 51 of them were mapped because the others did not have nutrients information. The mapping unit was the municipality and the software applied was ArcGIS9.1 from ESRI. The projection applied was Universal Transverse of Mercator (UTM) and datum WGS84.

A textural soil classification was applied considering sand, clay and silt average percentage for each southwest Goias municipality [3]. In this step, COMIGO soil data set was used. These data are very important; they help the discussion about K, Mg and Ca. After that, the soil texture map was obtained by ArcGIS 9.1 for 51 municipalities southwest Goias.

In the K case four classes of interpretation of soil K were used to map K availability, as suggested by [11]. Besides, one more class was associated with no data related to municipalities without associated soil K:

- 0-30 mg kg-1 soil – too low
- 30-60 mg kg-1 soil - low
- 60-120 mg kg-1 soil - medium
- 120-240 mg kg-1 soil – high
- No data – municipalities without associated soil K

In the Mg and Ca case it was considered the relationship between Ca and Mg (Ca:Mg) and 3 classes were obtained in this map:

- Relationship less than 3:1 (>2,8) – No appropriate
- Relationship 3:1 (2,8 – 3,2) – appropriate
- Relationship more than 3:1 (> 3,2) - No appropriate

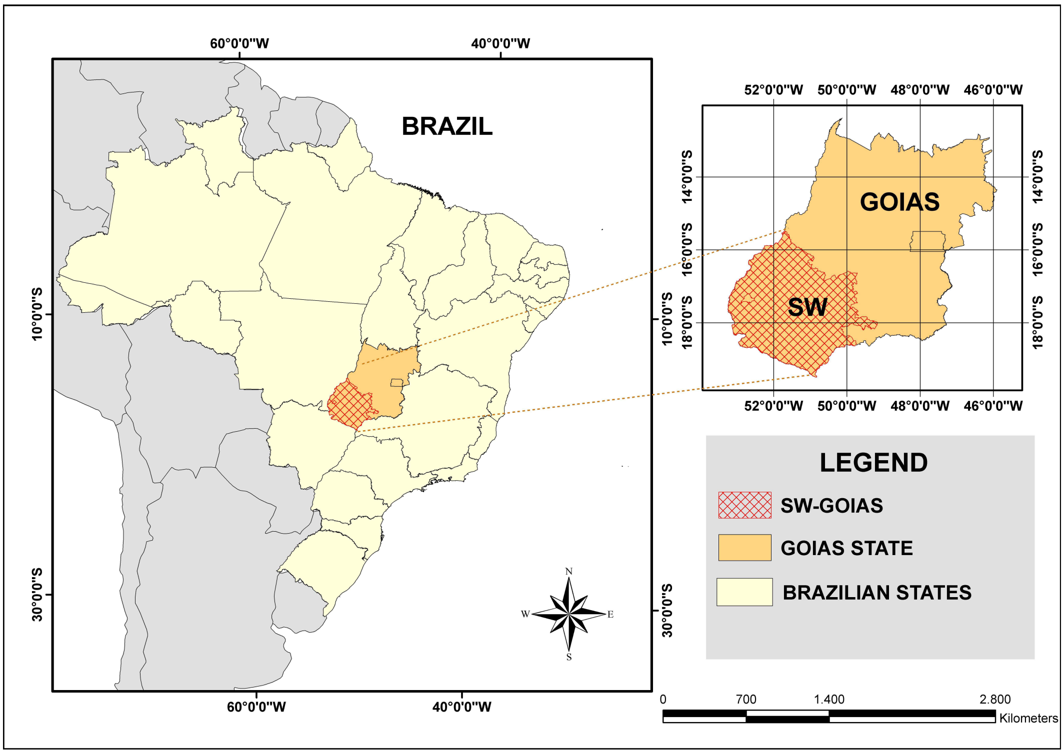

Fig. 2 Study area localization

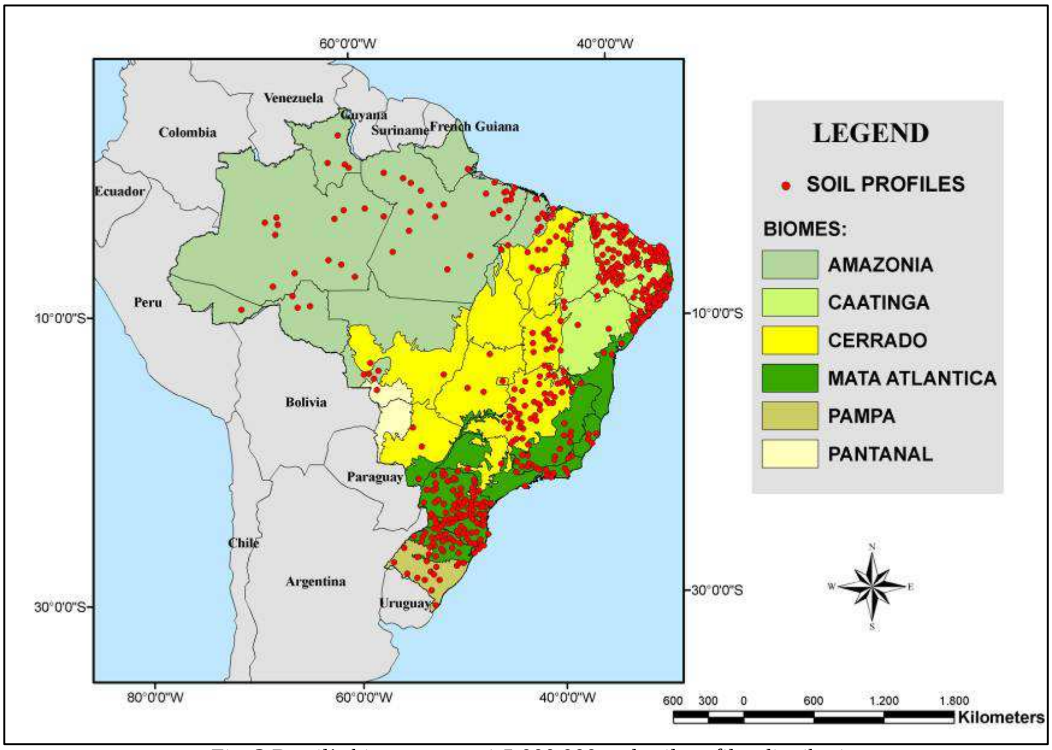

Fig. 3 Brazil's biome map at 1:5,000,000 and soil profiles distribution

III. RESULTS AND DISCUSSION

A. Maps of brazilian soil fertility at 1:5,000,000 scale

The maps obtained at 1:5,000,000 scale are presented in the Figs. 4, 5 and 6, respectively to K, Mg and Ca. All biomes and soil classes were considered in the map unit definition as both climate and soil class strongly influence nutrients availability. For example, the soils from Caatinga have a high fertility and low annual rainfall (approximately 250 mm). Soils of the Amazonia biome have the lowest amount of available K because of high annual rainfall and intensive 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 further K depletion in soils. In the Mata Atlantica and Caatinga there is a large number of smallholder farms. In terms of soil classes, Acrisols, Luvisols and Ferralsols are predominant in most biomes except for Pampa and Pantanal, in which the Planosols cover most of the areas.

It is possible observe in the Figs. 4, 5 and 6 that the maps of K, Mg and Ca availability are similar, because depend of soil class and environment conditions, like climate. There are relatively few regions of Brazil with high levels of nutrients availability (signed in Figs. 4, 5 and 6). These are located in Northest, west Amazonia and south of Brazil. It is important to mention that the natural soil fertility is changing along the brazilian agricultural expansion. For example, primarily, some Cerrado areas (predominating in the central region of Brazil) had very poor soil fertility, but technologies allowed to improve soil fertility and to increase production of grains in these areas. Nowadays, Cerrado is one of the main regions of maize and soybean planting, also of cotton and sugarcane; cattle ranching and poultry industry develop fast in association with forage production.

B. Maps of brazilian soil fertility at 1:250,000 scale

Fig. 7 shows the map of soil texture and Fig. 8 shows the spatial variability of K average availability for municipality of southwest Goias. The municipalities 45, 52 and 56 presented too high K level because in this region predominated the cotton crop until 90's. And this crop needs high level of K application. Comparing the Figs. 7 and 8 is possible to observe that the high and medium classes in K average availability map are coincident to clay soils. These kinds of soils keep more K available than sandy soils and there is not large loss by leaching. On the other hand, the low and too low classes are coincident to sandy soils. In these kinds of soils the loss by leaching is more common due to K solubility. Fig. shows the relationship between Ca and Mg in sowthwest Goias.

The relationship Ca:Mg in the studied region points to a predominance of areas with relation <3:1. Although clayey soils tend to have closer relationship to the ideal, those most susceptible to degradation, sandy medium texture and tended to have the predominant relationship, <3:1. These results are interesting when compared with the survey conducted by Lopes (1983).

Based on 518 samples of areas under natural vegetation of the Cerrado (encompassing much of the region evaluated in this study) and considering the median of the frequency distribution of Ca and Mg cited by the authors, we could estimate the ratio of Ca: Mg of native soils of the region 2:8. Although this ratio was within what is called for as appropriate, the contents were reported as extremely low.

Reference [7] said that about 76% Ca and 90% of the Mg values were lower than 0.4 and 0.5 cmolc dm -3, respectively. That is, we can infer that changes in exchangeable cations of soils from the southwest Goias are occurring due to the use of fertilizers. And these changes could be grouped into two groups. The first, occurring in almost half of the study area and relate to the sandy soils and medium in which the management of inputs and culture culminates to a more negative balance in terms of Ca (ratio <3:1) and the second, quite representative of clay, about> 3:1 (eastern), with a predominance of Ca in the exchangeable cations.

To be correct inferences about the cause of this spatial distribution, data on the quantity applied and productivity and export of these elements by crops in the region would be needed, but it seems clear that the region west of the map needs more lime-based and that Ca areas to the east, the basis of Mg. The $MgSO_4$ and MgCl are good options for correction, but expensive. Thus, it is necessary to seek alternative sources to improve cost/benefit. In this sense, the Mg oxide appears as an interesting alternative for use in Cerrado, since it is quite soluble in water and have low price.

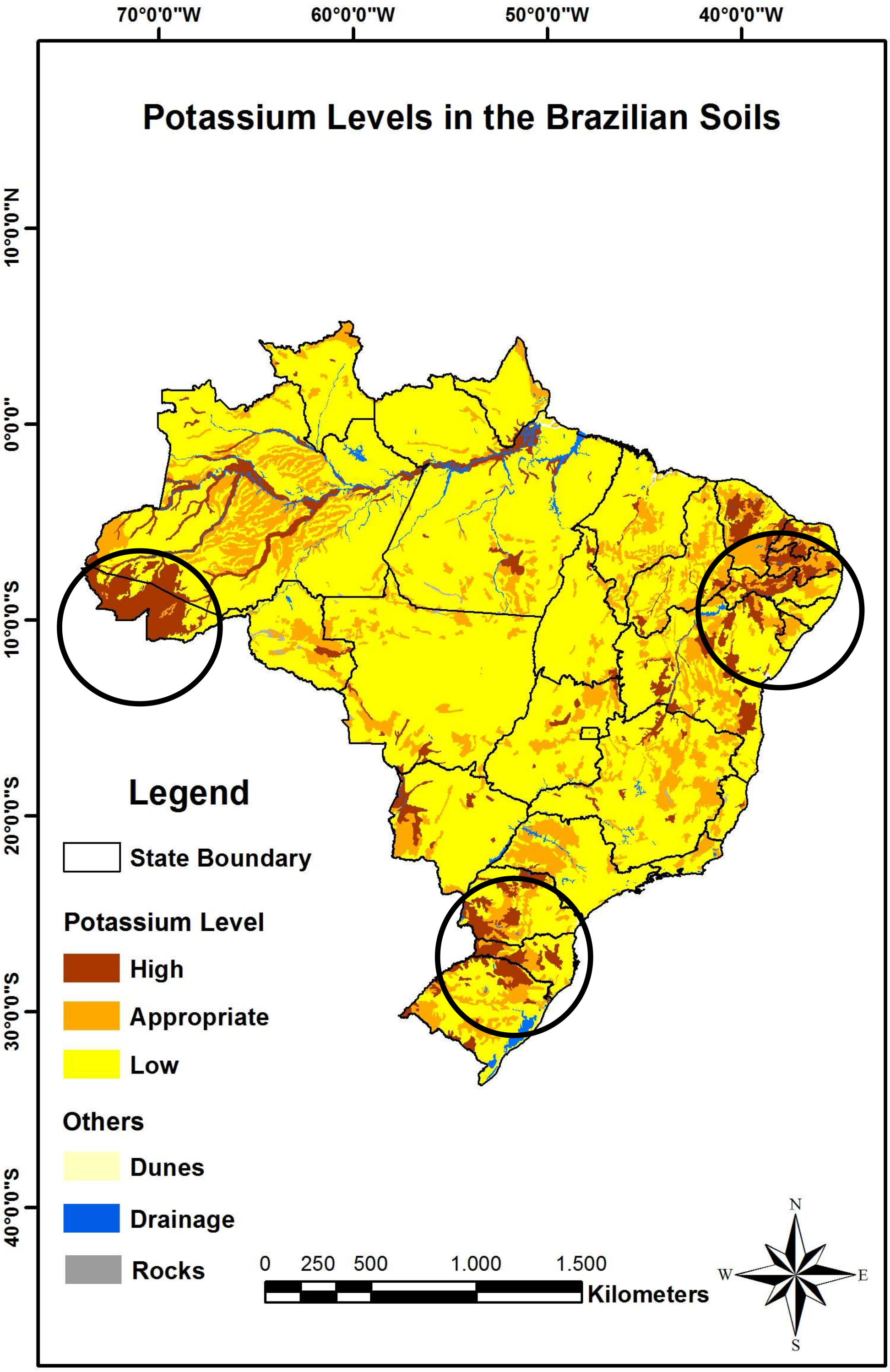

Fig. 4 Map of potassium level in brazilian soils

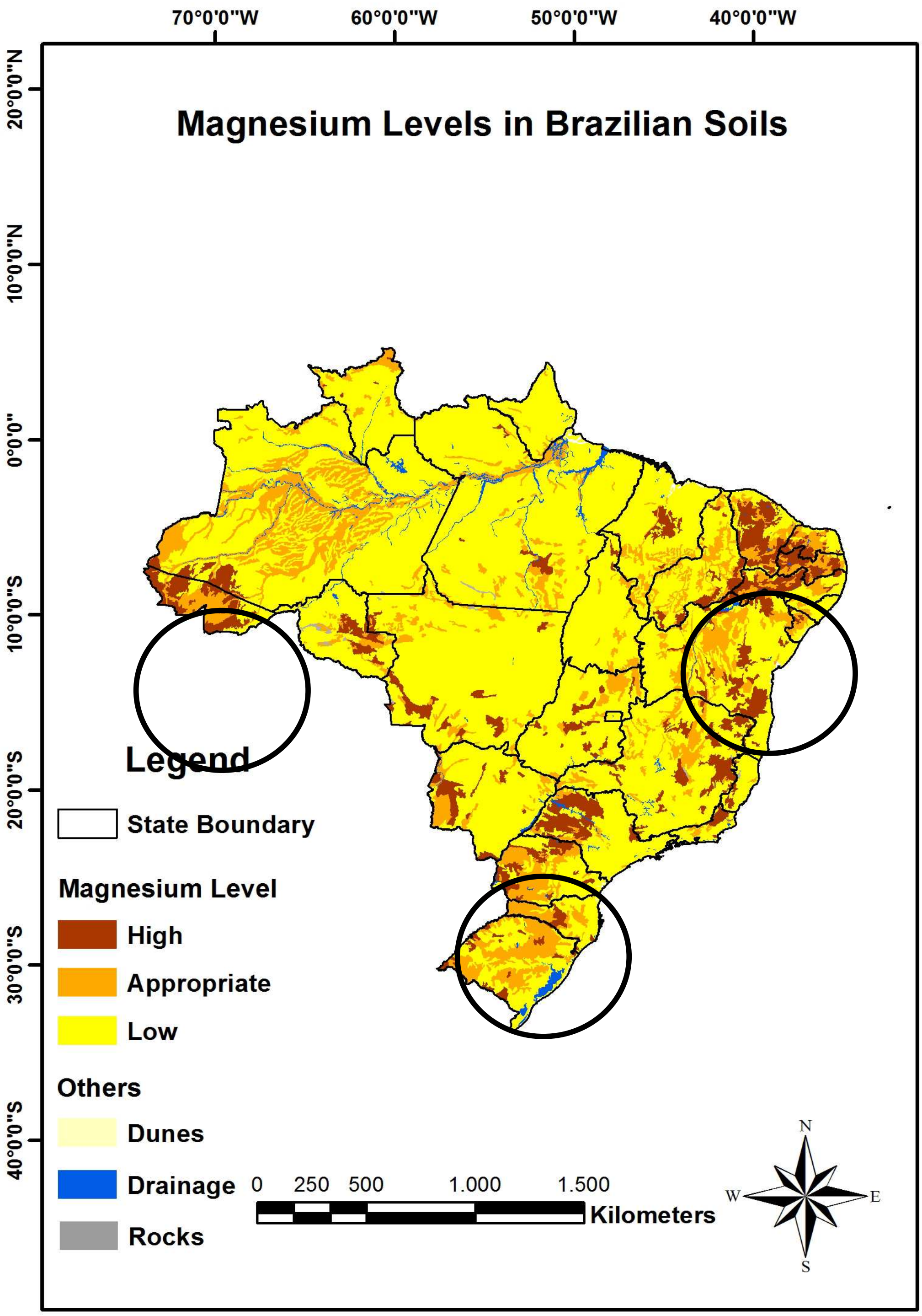

Fig. 5 Map of magnesium level in brazilian soils

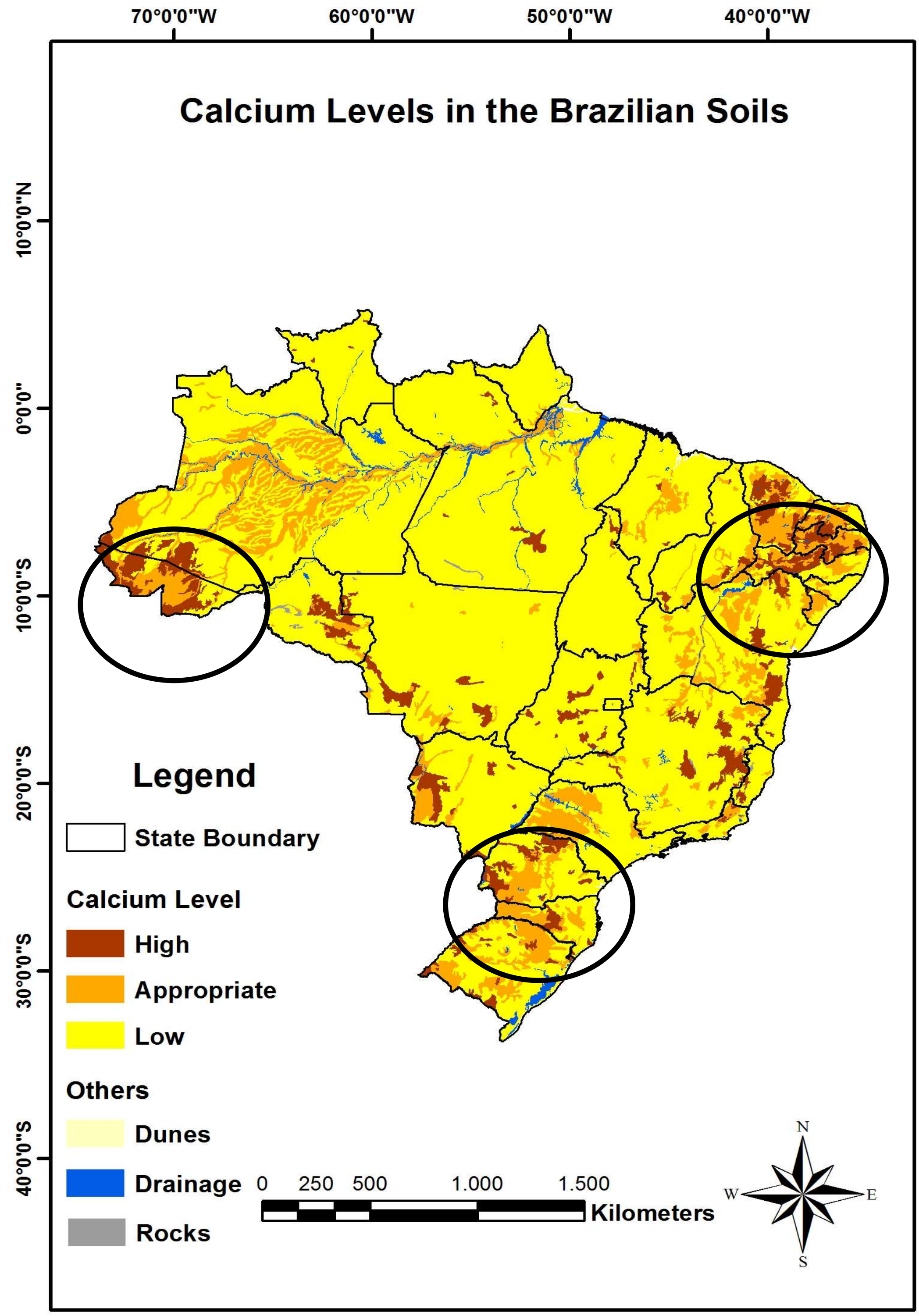

Fig. 6 Map of calcium level in brazilian soils

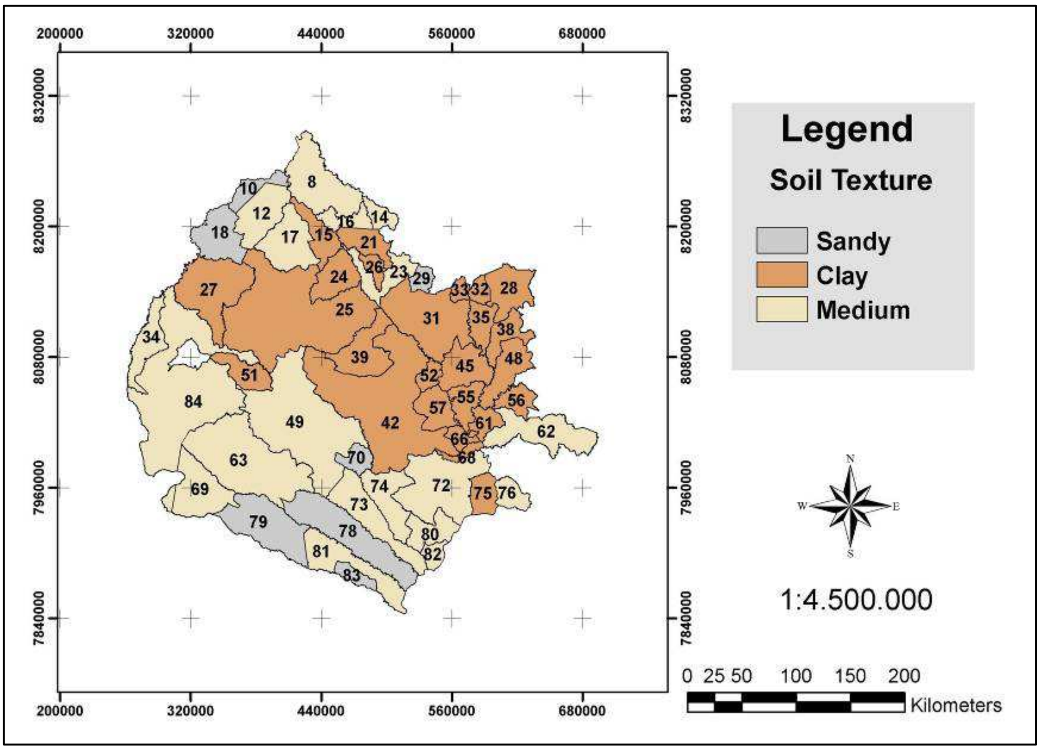

Fig. 7 Map of soil texture to southwest Goias

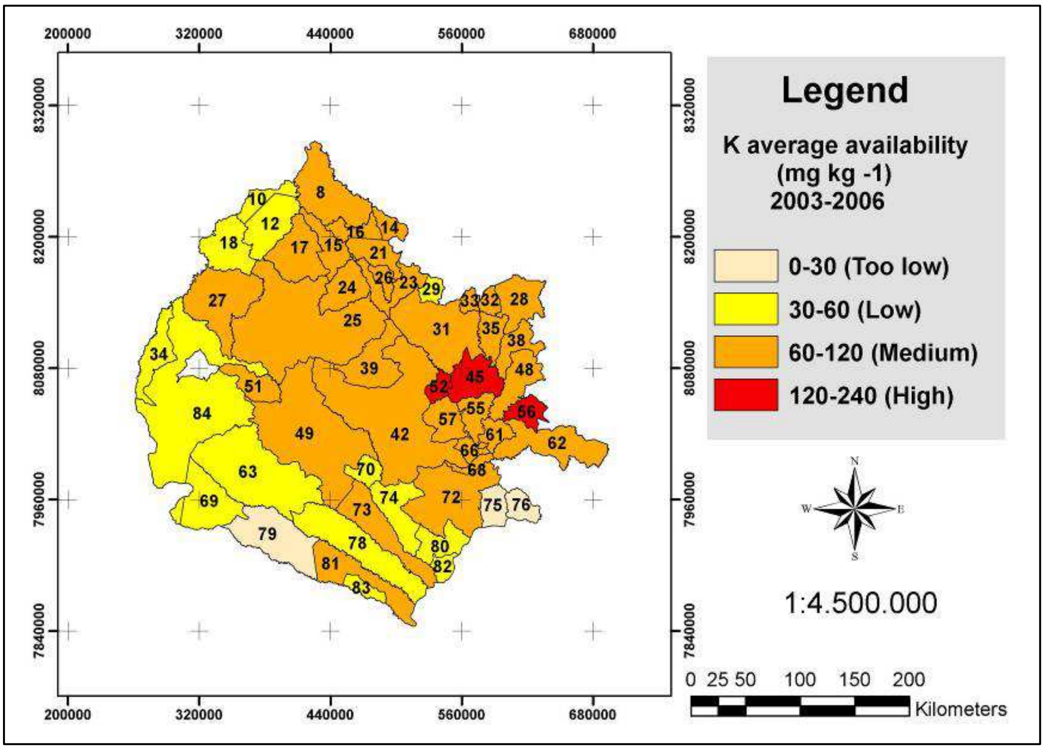

Fig. 8 Map of K soil availability from southwest Goias

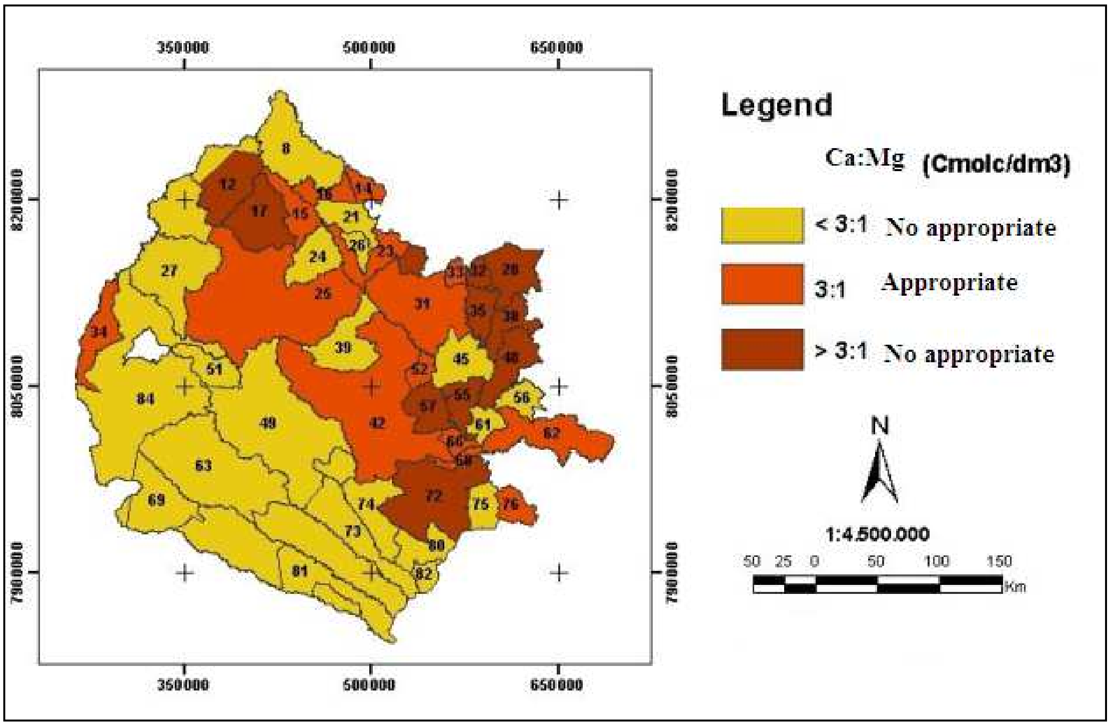

Fig. 9 Map of relationship Ca:Mg from southwest Goias

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