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Mapping spatial and temporal potassium balances in Brazilian soils of south-west Goias

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Introduction
Brazil, is one of the main agricultural producers in the world ranking 1st in the production of sugarcane, coffee and oranges. It is also 2nd as world producer of soybeans and a leader in the harvested yields of many other crops. The annual consumption of mineral fertilizers exceeds 20 million mt, 30% of which corresponds to potash fertilizers (ANDA, 2006). From this statistic it may be supposed that fertilizer application in Brazil is rather high, compared with many other countries. However, even if it is assumed that only one fourth of this enormous - 8.5 million km2 - territory is used for agriculture, average levels of fertilizer application per hectare of arable land are not high enough for sustainable production. One of the major constraints is the relatively low natural fertility status of the soils which contain excessive Fe and Al oxides.

This paper is based on data from research project carried out under coordination of A. Naumov and R. B. Prado, with the contribution of M. Benites Vinicius, Bernardi, M.A., Ferreira, C., Menezes, C., Oliveira, R.P., Polidoro, J.C., Machado, P.L.O.A and R.O. Dart.

Agriculture is also often practised on sandy soils so that the heavy rainfall causes large losses of nutrients through leaching. In general, nutrient removal by crops such as sugarcane and tropical fruits is much more than the average nutrient application via fertilization, especially in regions with a long history of agricultural production. In the recently developed areas, especially in the Cerrado (Brazilian savanna) where agriculture has expanded since 1980, soils are even poorer than in the "old" agricultural regions, and high costs of mineral fertilizers have become a significant input factor in determining soybean, maize and cotton planting.

The consumption of mineral fertilizers throughout Brazil is very uneven. According to the 1995/96 Agricultural Census, only in eight of the total of 26 Brazilian states, were 50 per cent or more of the farms treated "systematically" with mineral fertilizers; in many states it was less than 25 per cent, and in five states even less than 12 per cent (Brazilian Institute for Geography and Statistics; Censo Agropecuario1995/96, Instituto Brazileiro de Geografia e Estadistica; IBGE, www.ibge.gov.br). The geographical application distribution pattern of mineral fertilizers may be considered as an important field of research.

Understanding geographical disparities in fertilization level requires a complex approach. This includes evaluation of the availability of nutrients in the soil (and related soil properties e.g. CEC and texture), the input of nutrients with fertilizer application, and the removal of nutrients by harvested yields. When all these data are compiled, it is possible to evaluate the balance of particular nutrients for certain areas, and make conclusions as to where agricultural practices should be optimized. This kind of research is somewhat complicated, because it relies on completely different sources of data, usually from incomparable data sources, e.g. soil characteristics attributed to soil type areas, in contrast to yields by administrative regions, or farms. A priority tool in this case is the Geographical Information System (GIS), which enables attribution of data from different fields to the same territorial units, and makes possible integration of these data in an "inputoutput" model, where "input" is the natural availability of a nutrient in the soil plus fertilization, and "output" - export of the same nutrient with the removed harvested yield.

The project
In 2002, IPI Coordination Latin America, working jointly with the GIS Lab of the National Soils Research Center of Brazilian Enterprise for Agricultural Research or Empresa Brasileira de Pesquisa Agropequaria (EMBRAPA Soils) began a research project titled "Regionalization of potash balance in Brazilian soils". This was aimed at mapping and evaluating geographical differences in the balance of the nutrient potassium at a national level. It began with analysis of potash removal by 17 different crops, based on yearly data statistics on agricultural production collected by IBGE. The analysis of the amount of potash, removed with yields, was applied to approximately five thousand territorial units (municipios), covering the whole country (Fig. 1). As the map shows, higher levels of potash removal correspond to a relatively minor number of areas, where commercial

agriculture is concentrated. These areas are: the principal sugarcane and orange producing region in the interior of the state of Sao Paulo, the soybean and maize producing regions in the Cerrado (states of Mato Grosso and Mato Grosso do Sul, south-west of the state of Goias, west of the state of Bahia), the old soybean producing region in the state of Parana, the tropical fruits producing region of Petrolina-Juazeiro on the Sao Francisco river in the north-east, and the coastal strip of north-eastern states, the cradle of Brazilian sugarcane and cotton plantations.

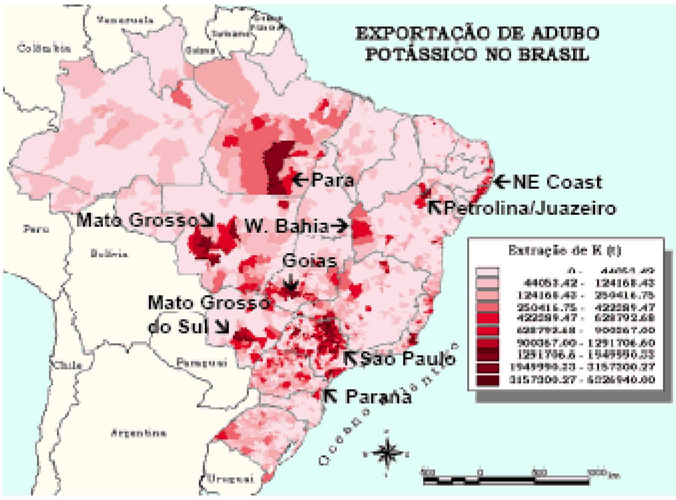

Fig 1. Brazil: Potash uptake by harvested yields of 17 main crops,
mt per municipio (2002/2003 agricultural year).
Source: Oliveira *et al.*, 2005, adapted from IBGE 2003.

The geography of potash removal is by itself a very important feature, but additionally we simulated a map showing the full balance of the nutrient, which also included potash availability in soil, and potash input with fertilizers. This was obtained from data on potassium availability in soil, from approximately 300 soil profiles all over Brazil, collected by EMBRAPA Soils since the 1970s, and stored in this center in Rio de Janeiro. Despite this large number of profile distributions within Brazil they are, however, not representative of all the regions of the country, with only a small portion of profiles being allocated in the Cerrado (Fig.2).

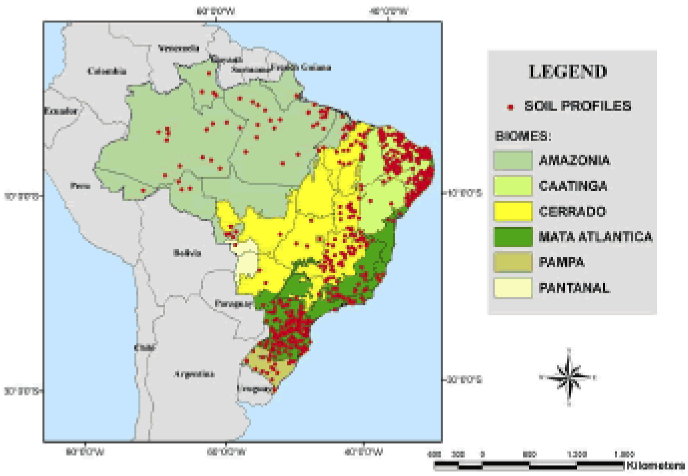

Fig 2. Brazil: soil profiles of EMBRAPA distribution and main biomes.
Source: EMBRAPA Soils.

For analysis of a nationwide potash input/removal ratio, the Cerrado region is particularly important. Cerrado landscapes in Brazil occupy approximately 200 million ha, 70 per cent of which are still as yet uncolonized for agriculture. Moreover, the Cerrado region recently became the most important biome in Brazil by the volume of soybean, maize and cotton production. The huge area of the Cerrado is not homogeneous and it is characterized by sharp differences in potash availability (Fig. 3). Primarily, the most fertile parts of Cerrado have been colonized, and now agricultural expansion has shifted towards the marginal areas, with poorer soils. Extrapolation of scarce soil profiles characteristics could cause serious errors and we came to the conclusion that much more detailed data are needed. Correct georeferenced data on application of fertilizers is the other problem, as official institutions do not collect statistics on fertilizer application by municipios. The Brazilian Association of Fertilizers Industries and Dealers (ANDA), publishes only data on fertilizer sales by states and these data cannot be applied to detailed geographical analysis. As the spatial and extent of available data for the whole nation i s insufficient for creating a GIS database, we decided to focus on the most important agricultural regions of Brazilian Cerrado - the south-west of the Goias state (Fig. 4).

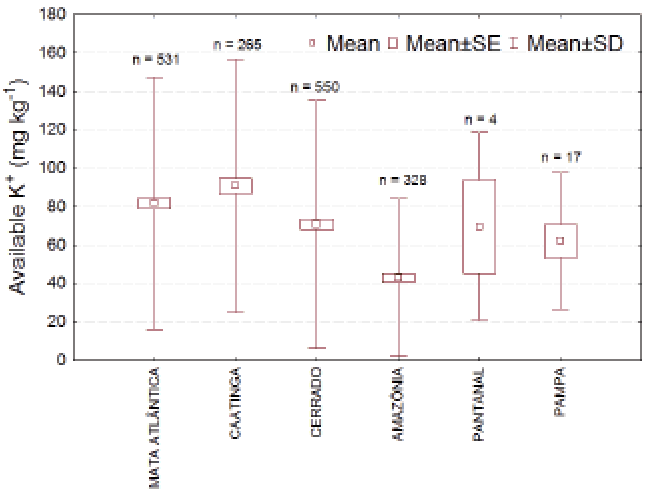

Fig 3. Potash availability in the soils of Brazilian biomes.
Source: EMBRAPA Soils.

This south-west area of the Goias state comprises approximately 10 million ha, mostly converted from savanna natural vegetation to agriculture. The main commercial crops are soybean and maize, planted in rotation. Cotton also plays an important role. Nowadays, sugarcane is gaining terrain, but local authorities are opposed to its expansion. No-till systems predominate in soybean and maize planting. Local farmers may be split into two groups according to fertilization practices. Those belonging to the first group apply insufficient rates of fertilizers, which limits yields and exhausts the soil. On the other hand farmers applying excessive fertilizer rates, induce the loss of a high proportion of nutrients by leaching and volatilization. Most farmers use the same NPK blends without taking in consideration differences of soil characteristics e.g. for soybean, farmers apply 400 kg of NPK 2-20-18, an equivalent of 72 kg of K_2O/ha(2), yet, among soils of the south-west of Goias there are some, naturally rich in potash, which do not require this high rate of application and vice versa. Excess potash, applied to sandy soil, is frequently lost by leaching.

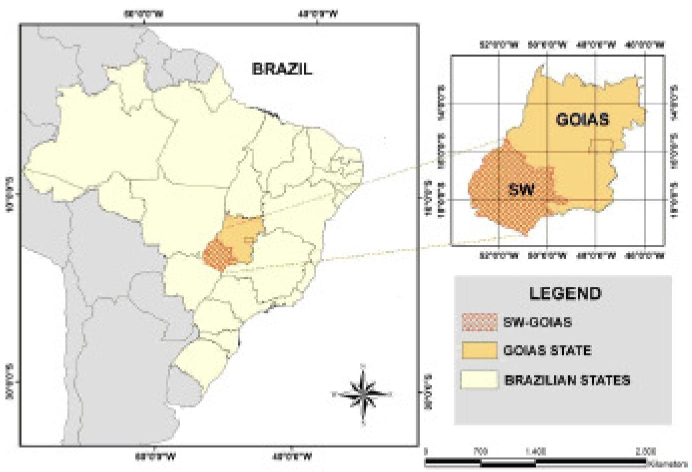

Fig 4. Study area localization map (south-west of Goias).

In 2005, IPI, EMBRAPA and the Federal University of Rio Verde (FESURV) jointly initiated a research project devoted to mapping spatial and temporal potassium variability in the soils of south-west Goias with the purpose of optimizing fertilization practices. Data on potash availability in the soil (Table 1, GIS layer #2, Fig. 6) was obtained from the database of the COMIGO agricultural cooperative. This cooperative is the biggest in the Goias state, bringing together approximately four thousand affiliates, mostly from the south-west of the state. Agronomists of COMIGO collect over 10.000 soil analyses per year. Database, containing results of these analyses, was re-organized according to the requirements of our GIS model.

Table 1. Geo reference layers used in the project

GIS layer/ map	Variable	Data source	Unit of measurement
1 (Fig. 5)	Soil texture	COMIGO soil analyses	Clay, %
2 (Fig. 6)	Potash availability in soil	COMIGO soil analyses*	K_2O, mg/kg**
3 (Fig. 7)	Potash output with yields	Calculated on the basis of IBGE statistics on agricultural production, total 13 crops	K_2O, kg/ha

Notes: * COMIGO agronomists take over 10.000 soil samples for analysis each year.
** Classification according Raij et al. 1985

Statistical analysis was carried out for each municipio with soil samples data available from 2003 to 2006. Sample numbers greatly varied from only two for Perolândia municipio to more than 8,000 for Rio Verde. Of 86 municipios, which are affiliates of the COMIGO, 51 with 50 and more soil samples data were mapped because of reliability of information. These municipios were divided in four classes according to potash availability in the soil.

For data on potash removal, output values with the harvest were derived from agricultural productivity data (Table 1, GIS layer #3, Fig. 7).

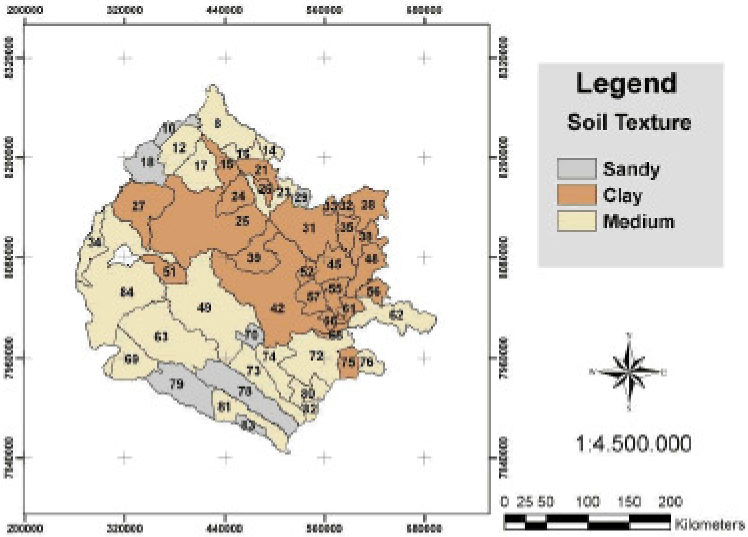

Fig 5. Soil texture classes in the south-west of Goias (numbers on the map are codes of municipios).

Calculations were based on average level of potassium concentration and actual production and expressed as kg K_2O/ha for 13 commercial crops of this region, (Yamada and Lopes, 1999). The crops, to which this calculation applied, were rice, cotton, coffee, sugarcane, lemon, orange, bean, soybean, corn, tomato, peanut, cassava and wheat. Estimated levels, multiplied by average agricultural productivity by municipio, registered by IBGE (2003) produced the required values estimating the potash removal per ha. This allowed the mapping of potash average output for 51 municipios. Both geo-referenced indicators (potash availability in soil and potash removal with yield) were calculated on a kg/ha basis (potash availability converted from mg/kg). These data layers were then converted from vector into raster format and overlaid, using tools of the ArcGIS 9.1. software. Using this approach values of potash balance were obtained for each of the municipios mapped.

To allow an evaluation of the influence of possible losses of potash by leaching on the potash balance, a map of soil texture classes for the study area was also produced. All municipios were divided in three classes (sandy, clay and medium texture), according to EMBRAPA (2006; Fig. 5).

Results

The main results of spatial variability of potash available in the soils in the south-west of Goias are as shown in the map on Fig. 6. Most of the area of SE Goias has a "Medium" level of K in soil (60-120 mg/kg), yet, large areas of the west of the state are classified as "Low" in K with only 30-60 mg/kg. Only in three municipios (marked as no. 45, 52, 56) where the highest positive values recorded are those located nearby the local center (the city of Rio Verde), where fertilizer industries and dealers are concentrated. In these areas, until the 1990s, cotton was the predominant crop, and high rates of potash fertilizers were applied.

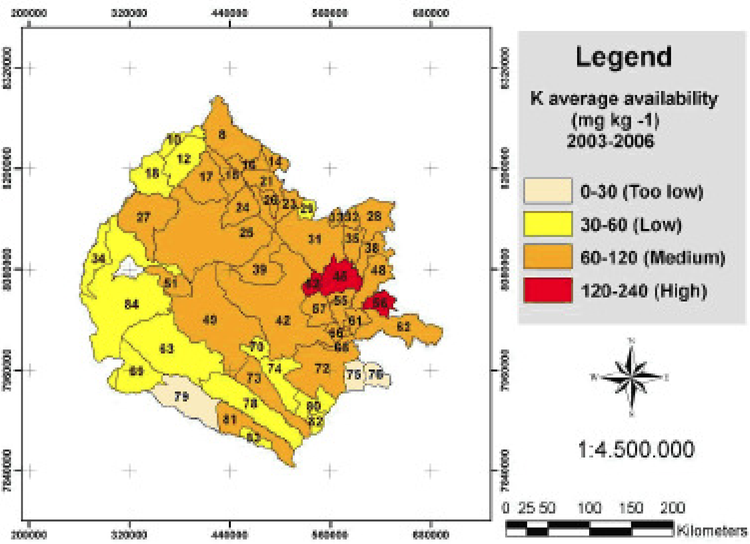

Fig 6. Potash average availability in the soils of the south-west of Goias, data derived from detailed soil map and soil profile data (numbers on the map are codes of municipios).

Comparing maps on Fig. 5 and Fig. 6 it is possible to observe that the high and medium classes of potash availability in soil are coincident with the areas with clayey soils. Clayey soils retain potash better than sandy soils, being characterized by smaller losses of potash by leaching. On the other hand, the areas of soils with low potash availability are coincident with sandy soils.

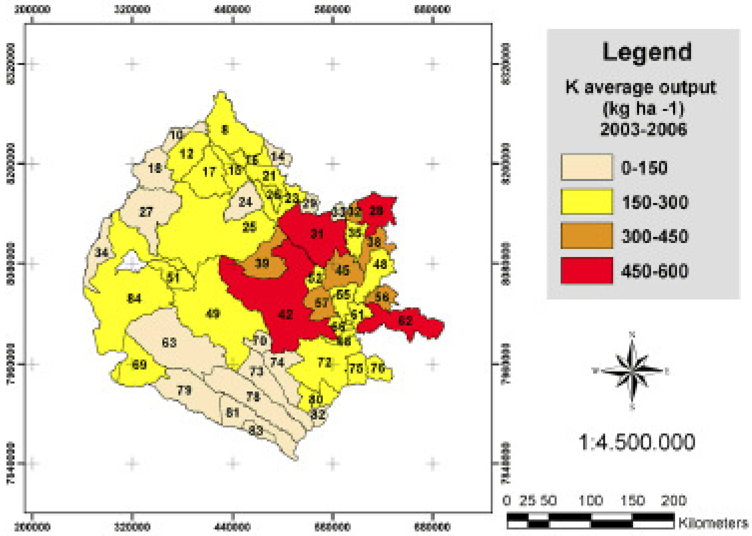

Fig 7. Potash average output with the harvest in the south-west of Goias, 2003-2006 (numbers on the map are codes of municipios).

Fig. 7 describes potash average output with harvest in the research study for the years 2003-2006. High K output (removal) was concentrated in the eastern part of SE Goias, also for the reasons of well developed agriculture and the close vicinity to Rio Verde with its fertilizer production and trade centers. In most of the state, K output ranged between 150-300 kg K_2O/ha, or even less (Fig. 7). As proven by comparison of maps on Fig. 6 and Fig. 7, spatial variability of potash average output does not correspond exactly to potash average availability by geographical distribution. Fig. 8 describes the potash balance per municipio. Comparing soil texture and potash balance maps (Fig. 5 and Fig. 8 respectively), one can notice that high and medium values of positive potash balance are coincident with clayey soils areas, for which loss of this nutrient by leaching is not as high as for sandy soils. By contrast, the low and negative values are coincident with sandy soils areas. The high output classes are peculiar to the municipalities with higher yields, mainly of soybean (Fig. 7). In general, values of both potash availability and potash output with the yields decrease from the east to the west within the study area (Fig. 6 and Fig. 7). This can be explained by differences in soil texture and decreasing intensity of agriculture from the local center, situated in the NE (Rio Verde), to the periphery.

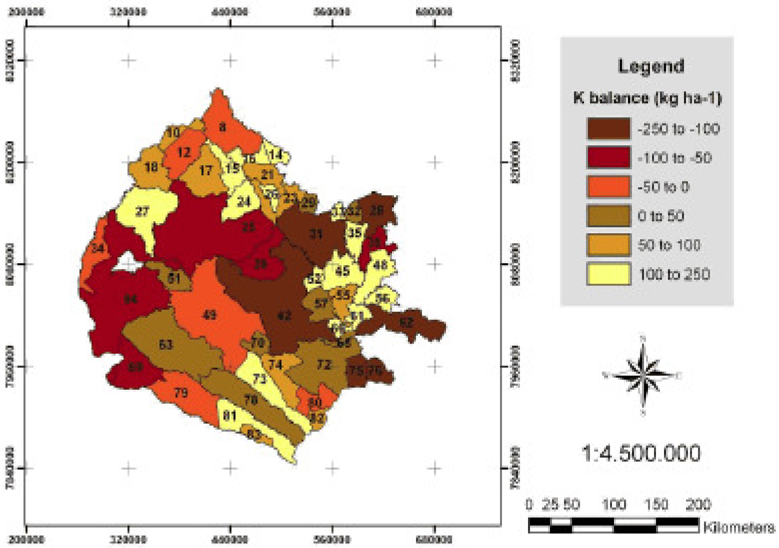

Fig 8. Mean potash balance map from 2003 to 2006 per municipo of southwest Goias (numbers on the map are codes of municipios).

To map potash balance, data from both layers as reflected on maps on Fig. 6 and Fig. 7, potash availability in the soil and potash output with yields were processed. As the result of overlay of these variables, the potash balance map for south-west of Goias was obtained (Fig. 8). The results show that on the negative balance, 17.26, 22.09 and 16.84% of the municipios were deficient by 250-100, 100-50 and 50-0 kg K_2O/ha, respectively, while on the positive balance, 16.19, 10.09 and 17.54% of the municipios had 0-50, 50-100 and 100- 250 K_2O/ha positive balance. All in all, 56 per cent of the trial area showed a negative K balance to various degrees.

Calculating that a 50 kg/ha of K_2O is a typical potash application for soybean planting in the Goias state, a negative K balance of 50 kg K_2O /ha and more means that potash fertilizers were not sufficiently applied. On the other hand, a positive may indicate that farmers can reduce rates of fertilization without causing loss of yield in the following year. Municipios, where the balance is near to zero, may be considered in an "ideal" situation where the applied potash accords to the real requirements.

The analysis of the yearly dynamics of potash availability and output (the temporal variation), was based on data from the farmers and COMIGO agronomists yearly surveys in 2003-2006. During this period, soybean prices dropped compared with fertilizers and fuel, and production costs increased because of the necessity of agronomic measures to control soybean rust. This explains why many local farmers in the first three years reduced or even stopped potash application. Nevertheless, potash uptake with yields of soybean, maize and other crops was high, and without replacement, potash availability in these soils consequently decreased. As shown in Fig. 9 for selected municipios, near Rio Verde city, potash output in 2003, 2004, 2005 and 2006 generally declined. This trend correlates with soybean yield oscillations, influenced by economic reasons, as mentioned above. Highest levels of potash output (above 450 kg/ha) were registered mainly in the municipios, with soybean yields of 3 mt/ha and higher (marked with numbers 31, 39, 42 and 45 on the map). Yet, from 2003 to 2006, the area under high K output was reduced. This does not necessarily mean that the potash balance improved, as potash availability also was not increasing.

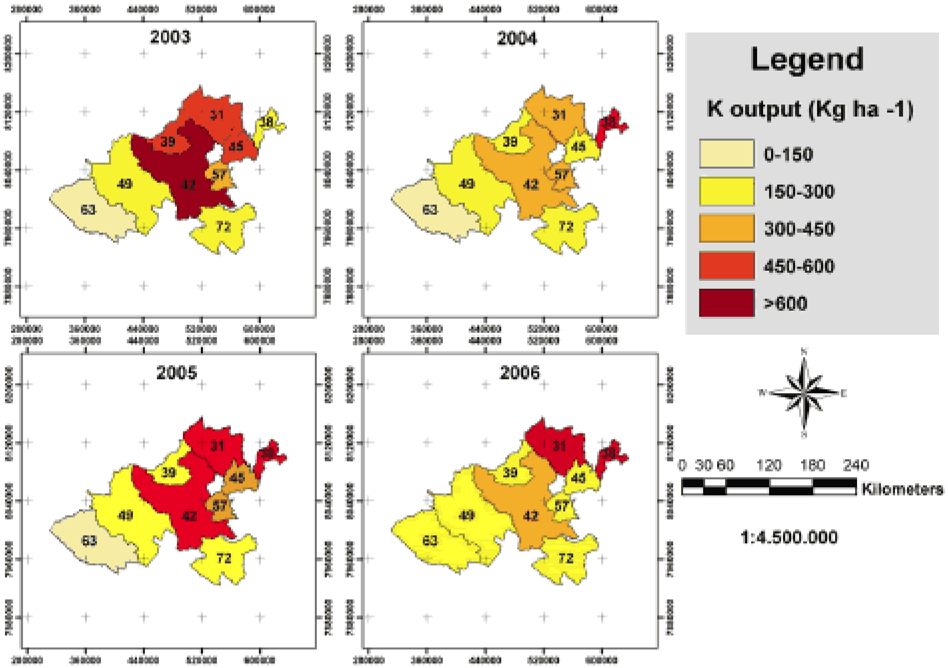

Fig 9. Dynamics of potash output with the yields in a few municipios in the south-west of Goias (near the city of Rio Verde), 2003-2006, data from the farmers and COMIGO agronomists yearly survey (numbers on the map are codes of municipios).

Conclusions

This research was a first attempt to link within unique GIS data on natural (soil) and social (agricultural productivity) phenomena for one of the main agricultural regions within the Brazilian Cerrado. Geo-referenced analysis of potash availability in the soil and potash output with yields showed sharp differences in spatial distribution and dynamics of both variables. These differences are caused mostly by soil properties, natural phenomena and are strongly influenced by economic factors (production costs). Approximately half of the municipios of the south-west of Goias presented a negative balance of potash because of intensive soybean planting together with insufficient fertilization. GIS tools can help to optimize fertilizing practices. For this purpose, it is important to build a consistent database, continuously adding information. For further development of GIS research, farms could be used as mapping units instead of municipios, which will provide better accuracy (average size of farm in the south-west of Goias is approx. 2,000 ha).

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