GIS AS A TOOL FOR BALANCED FERTILIZATION AND SUSTAINABLE DEVELOPMENT OF AGRICULTURE IN THE SAVANNAS OF SOUTH AMERICA

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Abstract
Most of South American countries still own considerable land reserves for agricultural development. Huge areas of virgin lands and of extensive pasturing were recently colonized and suffer from increasing pressure of commercial agriculture. Growing demand for food in the world and attractiveness for capital investment drive colonization all further deep into the regions, which cannot be converted to commercial agriculture without serious, often catastrophic consequences for the environment. Development of agriculture in these areas neither can be considered sustainable economically, as high production costs, depending on chemical fertilizers, etc. sometimes surpass revenues from the harvest.

In most of cases, the regions of recent agricultural colonization in South America are those with savanna landscapes. In Brazil, tropical savannas, or *cerrado* occupy approximately 204 million has in the Center-West, and partly in South-East, North-East and the Amazon regions of the country. More than 20 million has of the Brazilian *cerrado* were colonized for commercial crops planting during the last two decades of the XX century. As the main constrains for agricultural use of the soils of the *cerrado* may be considered acidity and low natural contents of nutrients.

Understanding the problem of sustainability of agricultural development on huge areas of tropical savannas is impossible without geographical analysis and creation of specialized GIS. Spatial approach at different scales, including macro and micro levels, enables precise vision of weak points of recently established agricultural systems and helps to draw solutions for decrease the degree of their instability.

This paper is based on research, realized during 2004 – 2010 in one of the areas of the Brazilian savanna region with the purpose of study of efficiency of fertilizers use in agriculture. The research was supported by the International Potash Institute (IPI) and Brazilian Corporation for Agricultural Research (EMBRAPA), which cooperate in the Project "Fertilize Brazil".

Geographical analysis of balance of nutrients in agricultural systems showed, that for recently colonized savanna regions of Brazil it is typical the lack of adaptation of farmers practices of fertilization to local soil and climate conditions. Extensive growth of agriculture often makes it not sustainable environmentally, because of pollution of ground waters with chemicals, neither economically, because farmers spend more, than needed, for fertilizers. Thus, GIS for farmers, aiming to minimize production costs, becomes an important tool for increase efficiency of fertilizers use and enable farmers to approach more sustainable models of agricultural production.

Introduction

Most of South American countries still own considerable land reserves for agricultural development. Huge areas of virgin lands and of extensive pasturing were recently colonized and suffer from increasing pressure of commercial agriculture. Growing demand for food in the world and attractiveness for capital investment drive colonization all further deep into the regions, which cannot be converted to commercial agriculture without serious, often catastrophic consequences for the environment. Agricultural development in these areas neither can be considered sustainable economically, as high production costs, depending on chemical fertilizers, etc. sometimes surpass revenues from the harvest.

Understanding the problem of sustainability of agricultural development is impossible without geographical analysis. Spatial approach at different scales, including macro and micro levels, enables precise vision of weak points of recently established agricultural systems and helps to draw solutions for decrease the degree of their instability.

This paper is based on research, realized during 2004 – 2010 in one of the areas of the Brazilian savanna region with the purpose of study of efficiency of fertilizers use in agriculture. Observations, made during field visits to savannas of Paraguay and areas of recent movement of agricultural frontier in Uruguay (last ones out of the Tropics), also influenced the author's perception of the studied problem. The research was supported by the International Potash Institute (IPI) and Brazilian Corporation for Agricultural Research (EMBRAPA), which cooperate in the Project "Fertilize Brazil" (original title in Portuguese "Aduba Brasil"). The purpose of this project was to find solution for optimization of fertilizers use, mostly for agricultural regions in Brazilian savannas. Soils in these regions are not enough in nutrients for sustain intensive agriculture, which development requires increase of fertilizers application. 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 (FAOSTAT, 2010). Creation of special GIS for understanding regional differences in mineral fertilizers use and providing recommendations to farmers, for adjust fertilization practices to the local geographical conditions, was one of the main purposes of the Project "Fertilize Brazil".

The authors acknowledge colleagues from The National Soils Research Center and other research units of EMBRAPA, local universities and agronomic research bodies in Goias, who were involved. The authors also acknowledge field workers – agronomists and farmers, who aim to practice sustainable agriculture.

Main arguments

South America, perhaps, is one of the last agricultural frontiers of the humanity. Since its conquest by Spain, Portugal and other European powers, agricultural development on this continent was going along with colonization. After the colonial period, it was followed by colonization in late 19^{th} – early 20^{th} centuries of the Argentinean Pampa, Southern Brazil, and some other regions in the inner parts of the continent. The last large-scale colonization campaign started in the 1980s, with massive colonization of Brazilian Center-West region. Later on, it also affected fringe of the Amazon region and neighboring areas of the North-East (Naumov, 2005). From Brazil, colonization spread to Paraguay and Bolivia. In Colombia and Venezuela, agricultural frontiers also started moving towards peripheral regions. These areas, together with some provinces of Argentina, became the ground for soybean production boom in Latin America (Melgar et al. 2011).

As most of South American countries own considerable land reserves, agricultural colonization on the continent is far from the end (table 1). E.g., in Brazil, according to USDA estimates, 170 million has are considered as “suitable” for agricultural colonization, including 65 million has of virgin lands in savannas, 10 million – in Amazon region, and 90 million has of pastures, if converted into fields (USDA, 2004).

Country	Land Area (LA) 1.000 has	Agricultural Area (AA)		Arable Land		Permanent Crops		Permanent Pasture	
		1.000 has	% of LA	1.000 has	% of AA	1.000 has	% of AA	1.000 has	% of AA
Argentina	273.669	128.747	47,0	27.900	21,7	1.000	0,8	99.847	77,6
Bolivia	108.438	37.087	34,2	3.050	8,2	206	0,6	33.831	91,2
Brazil	845.942	263.600	31,2	59.000	22,4	7.600	2,9	197.000	74,7
Colombia	103.870	45.911	44,2	2.293	5,0	1.557	3,4	42.061	91,6
Guyana	19.685	1.740	8,8	480	27,6	30	1,7	1.230	70,7
Paraguay	39.730	24.836	62,5	3.040	12,2	96	0,4	21.700	87,4
Suriname	15.600	89	0,6	58	65,2	10	11,2	21	23,6
Venezuela	91.205	21.640	23,7	2.600	12,0	800	3,7	18.240	84,3
S.America	1.753.237	584.285	33,3	107.105	18,3	13.645	2,3	463.535	79,3

Table 1. Land Use in Selected Countries of South America, 2003
Source: Calculated by the author, data from FAOSTAT, 2005

In most of cases, the regions of recent agricultural colonization in South America are those with savanna landscapes. As estimated by the authors, these landscapes occupy in Brazil approximately ¼, Venezuela and Colombia – 1/3, Bolivia – ½, Paraguay – ¼ of total land area. Some regions outside the Tropics, like Argentinean North, have similar physical-geographical characteristics. Until the end of the XX century, tropical savannas in these countries were almost no used for cropping. Leo Waibel, a German origin geographer, who lived in Brazil in 1930-50s, predicted for the savannas the role of the future “breadbasket of the humanity”. But during his life this forecast was considered science fiction (Etges, 2000).

In Brazil, tropical savannas occupy approximately 204 million has. These landscapes were earlier called in this country “*campos cerrados*” (“closed, or fenced fields” in Portuguese), nowadays the common name became “*cerrado*”, in singular. More than 20 million has of the *cerrado* areas were colonized for agriculture during the last two decades of the XX century (Manzatto, et al, 2002). The predominate soils in the *cerrado* are *Latossolos* (Brazilian soil taxonomy class, equivalent to U.S. *Oxisoles*, or FAO *Ferralsols*). Acidity and low natural contents of nutrients may be considered as the main constrains for agricultural use of these soils.

The enormous agricultural area of Brazil equals 263 million has, including some 35 million has under tillage and 25 million has under no-till agricultural systems (FEBRAPDP, 2007). On this area, extremely sharp geographical differences between federal states in the level of mineral fertilizers usage may be noticed. According to the 1995/96 Agricultural Census, only in 8 from 26 federal states of

Brazil more than half of farmers were “regularly” using mineral fertilizers; in most of states it was below ¼, and in 5 states – only 10-12% (Censo agropecuario 1995/96, 1997). Same applies to potash fertilizers, containing one of the macronutrients, highly demanded by most of crops.

At the first two stages of implementation of the project “Fertilize Brazil”, potash balance in the soils was mapped on the level of states (in 2004) and municipalities (in 2007 – by more than 4.000 *municipios* with significant agricultural activities). Data on potash uptake with harvest was calculated by states, and afterwards – by *municipios* of the country. Data on agricultural production from the IBGE municipal statistical database were used (IBGE, 2003). Estimates were based on statistical indicators (annual yield), and average uptake of the nutrient with 1 tone of 19 main commercial crops: soybean, maize, sugar cane, coffee, cocoa, oranges, beans, etc., including planted eucalyptus (Oliveira et al. 2005).

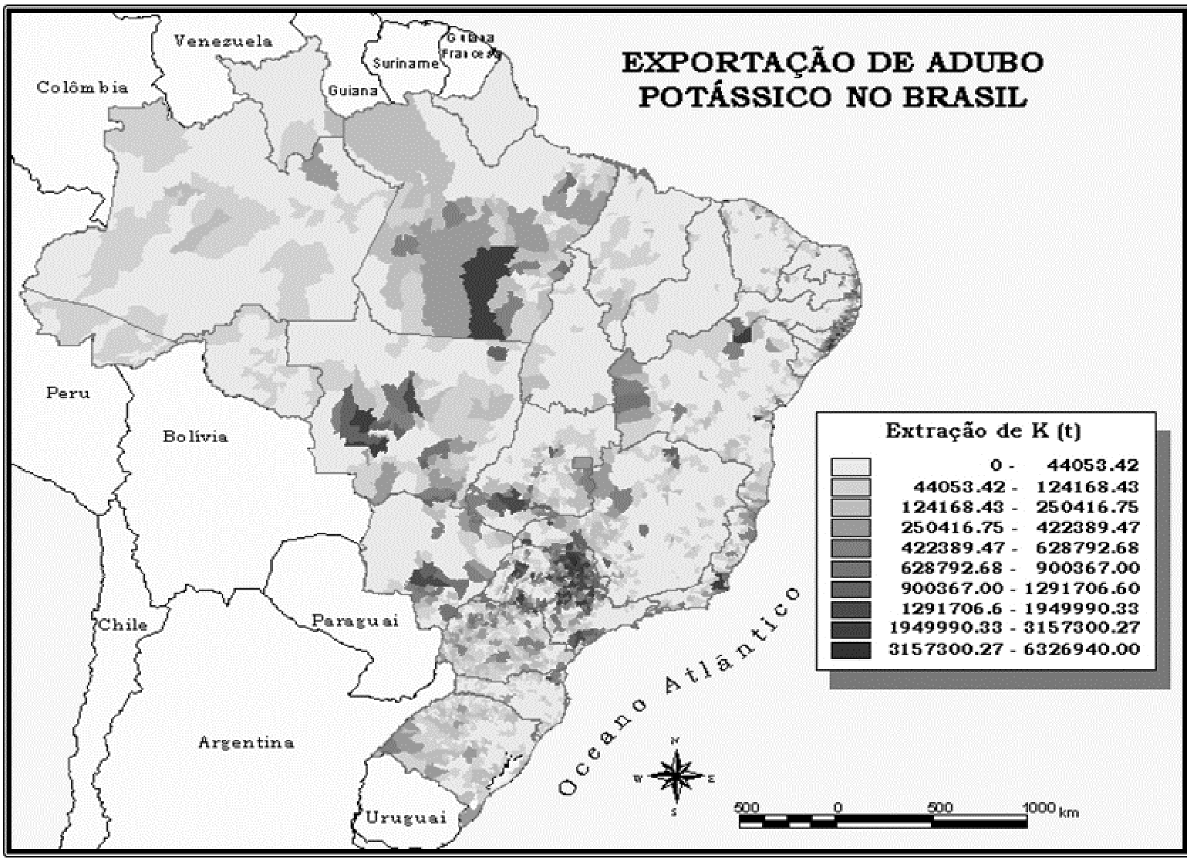

Figure 1. Potash uptake with commercial crops by *municipios* of Brazil (legend shows the quantity of annual uptake, Mt)
Source: (Oliveira et al. 2005)

As shown on the map (fig. 1), there were relatively few *municipios* with high levels of potash uptake. All of them are concentrated in the regions of commercial large-scale cropping, mostly oriented for exports. These are the clasters of sugarcane and oranges production in the inner part of São Paulo state; of soybean and maize in recently colonized states of the Center-West (Mato Grosso, Mato Grosso do Sul, Goias) and in the South regions (Paraná); of tropical fruits growing in the North-East region (Petrolina-Juazeiro pole on the São Francisco river and the coast). It is obvious, that the growing degree of clasterization of Brazilian agriculture strengthens rupture between large-scale commercial and smallscale peasant farms. The last ones have no access to modern technologies (e.g., mineral fertilizers) and cannot develop environmentally, economically, and socially sustainable agriculture.

For evaluate potash input in the soil on the level of Brazilian states, the data of the National Association of Mineral Fertilizers Dissemination (ANDA) were used. This layer of the GIS resulted less precise, because of the quality of data source.

For mapping potash availability in the soils, data from 3.000 soil profiles, gathered by EMBRAPA Soil Center were used. Creation of the layer of GIS, containing these data, was technically obstacle by the necessity of linking soil profiles data to the maps of administrative-territorial division, soil types and landscapes of Brazil. Researchers had to visit sites of some of profiles, opened in the previous years, for verify geographical coordinates of their location, using GPS navigators.

The above mentioned soil profiles, described by EMBRAPA, are unequally distributed by Brazilian territory. Their network is very sparse in the *cerrado* regions. However, as soil profiles data comparison showed, soils of the Brazilian *cerrado* and similar savanna landscapes are not uniform, and vary by physical and chemical properties. E.g., potassium availability in the upper layers of the soil may differ from 15 to 150 mg kg^{-1}(Prado et al, 2008).

Primarily, the *cerrado* covered areas with more fertile soils were colonized, but nowadays agricultural frontier has moved towards marginal areas with poorer soils. Extrapolation of EMBRAPA data on soil profiles to all areas under *cerrado* vegetation for purposes of further evaluation of Potash balance in the soil and development of recommendations for farmers could cause significant discrepancies. Therefore, on the third stage of implementation of the project, we have decided to carry out more detailed research and create special GIS for determine potash balance in agricultural systems of one of the main grains and oilseeds producing regions of the Brazilian *cerrado* – South-West of the Goias state (fig. 2). Large-scale commercial agriculture stated to develop in this state in late 1970s, and nowadays Goias is one of the main regions of maize and soybean planting (8,1 million Mt, or 15% of the total national annual harvest and 7,5 million Mt, or 11%, respectively), also of cotton and sugarcane; cattle ranching and poultry industry develop fast in association with forage production (Projecções do agronegócio, 2010).

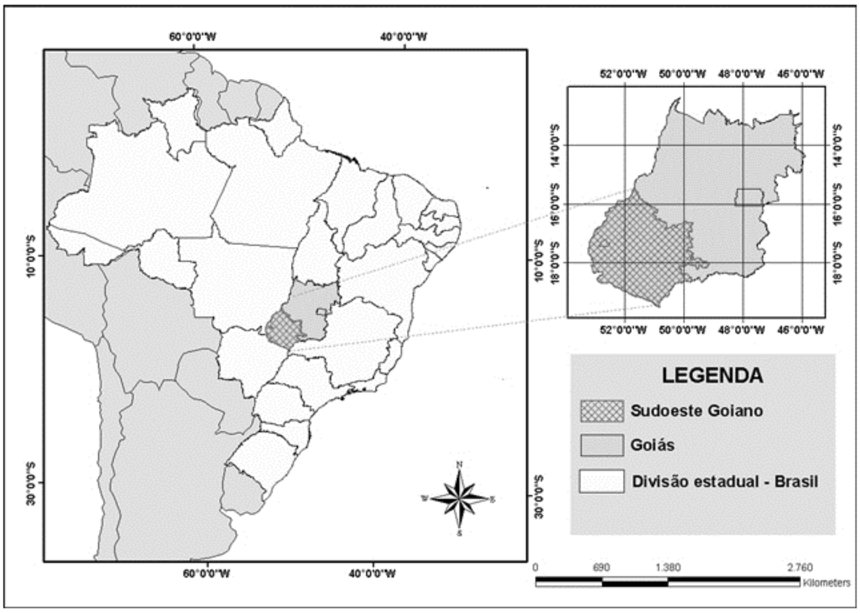

Figure 2. Research polygon in the South West of Goias state, Brazil

Potash availability in the soil was estimated from the data of soil sampling at the *fazendas* (large farms) of cooperates of the COMIGO agricultural cooperative. Geo-referenced data on mineral fertilizers use and on yields of commercial crops were obtained from farmers during poll in 2006 (more than 500 responded) and from survey of selected farms. These data formed two layers of the GIS of intermediate scale (municipal level), shown on the figures 3 and 4.

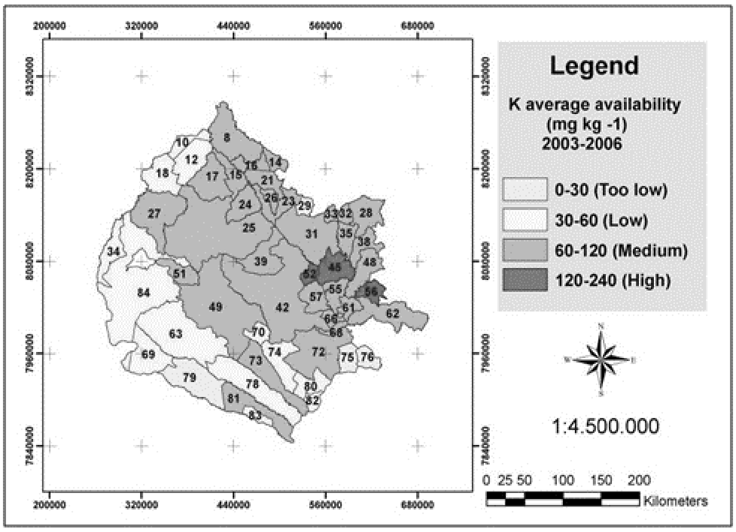

Figure 3. Potash availability in the soil (numerical scale as on the original map)
Source: Naumov and Prado. 2008

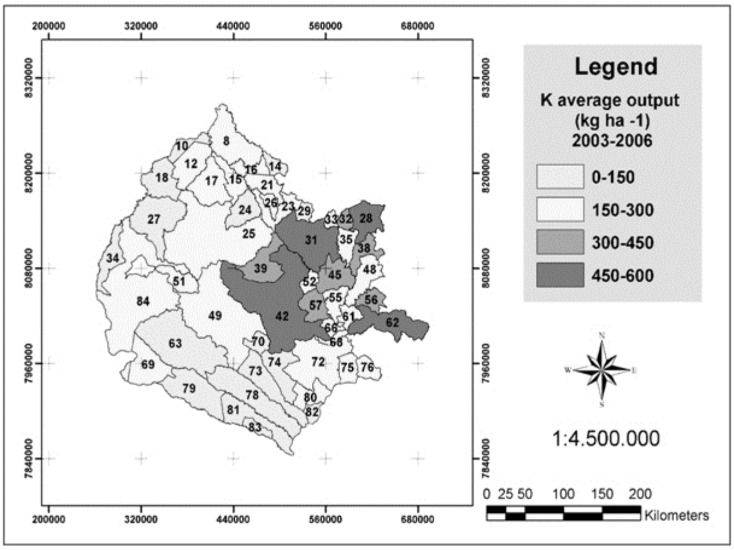

Figure 4. Potash uptake from soil with crop yields (numerical scale as on the original map)
Source: Naumov and Prado. 2008

Overlay of the availability, input and output layers brought to estimations of potash balance in agricultural systems of the studied region. As we could find out, some areas of the South West of Goias suffer from deficiency of this nutrient for sustain high yields, while the other suffer from excessive use of potash fertilizer (fig. 5). In other words, agriculture in both cases is not sustainable environmentally, neither economically. Farmers, applying incorrect (insufficient or excessive) dose of fertilizer, loose profit. E.g., most of the COMIGO associates were applying same dose of fertilizer at the same time (pre-plant), despite of differences in soil (texture, depth, acidity) and rainfall regime. As an average for the studied area, expenses for fertilizers (total N,P,K and micronutrients) represent 1/3 of total production cost of soybeans and maize. But those, who did not take in consideration local geographical conditions at their farms, often were spending twice more.

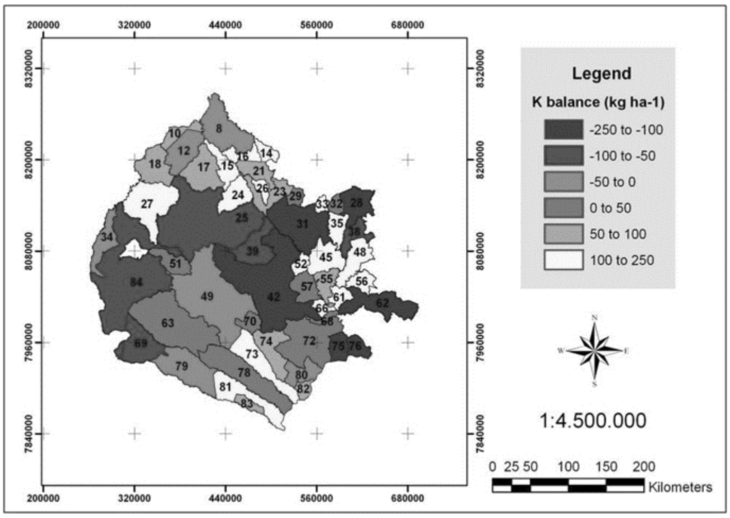

Figure 5. Potash balance in the soils (numerical scale as on the original map)
Source: Naumov and Prado. 2008

From the above described experience and obtained results of research we can conclude, that GIS may be a powerful tool for optimization of fertilizers at different scale levels. At the macro level, GIS help to understand geographical differences in nutrients balance and fertilizing practices (due to soil and landscape differences, types of agriculture, etc.). At this level, GIS are needed primarily for analysis of regional fertilizers markets. At the intermediate level, GIS serve for sharpen agronomic recommendations according to the local soil and climate conditions. At the micro level, GIS help farmers to adjust agricultural practices to geographical properties of their fields. E.g., GIS help to avoid inefficient use and losses of fertilizers (via leaching, etc.) and save farmers' budget (see table 2).

Taxonomic level	Mapping scale	Polygons	Purposes	Potential users
Micro	< 1 : 10.000	Fields, plots	Precision agriculture; site-specific management	Farmers
Intermediate	1 : 5.000.000 - 1 : 500.000	Counties, landscape contours, soil type areas	Yield forecast, consulting, farm management, fertilizers retail trade	Agronomists consulters, fertilizers dealers, local NPK blenders
Macro	>1 : 10.000.000	Provinces, states	Regional development assessment, regional targeting of agribusiness strategy	Government, industries, major fertilizers traders

Table 2. Application of GIS for specific purposes, related with optimization of fertilizers use

Conclusions

Geographical analysis of balance of nutrients in agricultural systems showed, that for recently colonized savanna regions of Brazil it is typical the lack of adaptation of farmers practices of fertilization to local soil and climate conditions. Extensive growth of agriculture makes it not sustainable environmentally, because of pollution of ground waters with chemicals, neither economically, because farmers spend more, than needed, for fertilizers.

GIS are widely used in modern agriculture for adopt on-farm operations (tillage, planting, etc.) to the micro-geographical properties of the fields (so-called precision agriculture). The authors consider, that GIS-technologies may be also useful for scientifically based solution of such practical targets, as monitoring of nutrients in the soil, and soil fertility in general, evaluation and forecast of efficiency of fertilizers use, definition of rational doses, optimal terms, and methods of their application on the fields.

GIS for farmers, aiming to minimize production costs, becomes an important tool for increase efficiency of fertilizers use. The authors are planning to produce even more detailed maps, and complete layers of GIS with climatic and phenologic data. This will help to synchronize fertilization with the life cycle of crops with rainfall regime and prevent lixiviation of nutrients from fertilizers. The authors expect, that extrapolation of different kinds of physical-geographical and social and economic data on landscape type maps, and then on the detailed map of the fields, based on LANDSAT images, will enabled to obtain precise data on potash availability at the depth of agricultural horizon and balance of this nutrient in agricultural systems of the Brazilian *cerrado*.

The results of this research already brought attention of farmers and decision makers in Brazil. Currently, GIS is being prepared for place on web, for public use. It is also planned to reproduce the similar research for the other agricultural area within Brazilian *cerrado* – the West of the Bahia state. This approach may be reproduced for the purposes of sustainable development of agriculture in other savanna regions of South America.

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