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- **SANTANA** Derli P. - derli@cnpms.embrapa.br
- SETE LAGOAS-MG - BRESIL/BRAZIL

- **Paper :** Soil quality and agriculture sustainability in the Brazilian Cerrado. - Qualité du sol et agriculture durable dans les cerrado brésilien

- **Author who presents paper :** SANTANA Derlí P.
- **Author(s) :** SANTANA Derli P., BAHIA Filho, ANTONIO F.C.

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- **Summary :** The "Cerrado Region" - the acid savannas of Brazil, as many as thirty years ago, were considered an ecosystem unsuitable for agriculture crop production because environmental limitations. However, a burst in agricultural development has taken place in the area during last decades as a result of new technology mainly involving plant breeding and soil management. In spite of the great contribution made by the "Cerrado" region to the Brazilian agricultural production, over the past few years concerns have been raised about the issue of the high costs of this agriculture production and about the issue of soil quality degradation, and how it could affect the sustainability of the agriculture in the "Cerrado" ecosystem. The concept of sustainable agriculture is well recognized research, development, and productive segments of today's agriculture, however, the notion of how to measure and monitor sustainability of farming systems is much less understood. This paper proposes a system of measuring and monitoring the sustainability of farming systems using soil quality indicators in the acid savannas of Brazil. The methodology utilized an agroecological framework to examine the relations among natural resources and agriculture, selecting one agroecological zone inserted in the cerrado ecosystem. This selected zone was subdivided into regions superimposing Census data, because policy and socioeconomic differences among regions have a considerable influence on land-use systems and options. Target areas were selected and participatory rural appraisal procedure was used to supplement voids in data, identify and characterize predominant farming systems, and to capture farmer knowledge. Using this farmer knowledge, research results already available and local observations, the mainly factors affecting soil quality were identified. Assuming that a management system is sustainable only when soil quality is maintained or improved, physical, chemical and biological properties, processes and characteristics were chosen as indicators to make qualitative and quantitative assessment of the changes in soil quality. Based upon these evaluations, a general procedure or framework for sustainability assessment was developed. Using the procedure, it is possible to identify whether current management interventions are contributing towards or away from sustainable farming management, and to develop strategies to improve the sustainability of those systems.

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SOIL QUALITY AND AGRICULTURAL SUSTAINABILITY IN THE BRAZILIAN CERRADO

SANTANA Derli (1), BAHIA FILHO Antônio
Embrapa / CNPMS, Caixa Postal 151, CEP 35701-970 Sete Lagoas, MG, Brazil

INTRODUCTION

Cerrado is a name given to different types of savanna like vegetation in which a continuous herbaceous stratum is associated with an arboreal stratum of woody species of varied densities. It can be defined as subhumid wooded savanna, although there is large variation, from pure grassland to a closed tree canopy. The "Cerrado" region is situated in the central part of Brazil, between latitudes 6 and 20°S and longitudes 42 and 62°W, occupying approximately 25% of the country (Figure 1). It's total area is around 205 million hectares, approximately equivalent to the combined area of Spain, France, Italy and Britain.

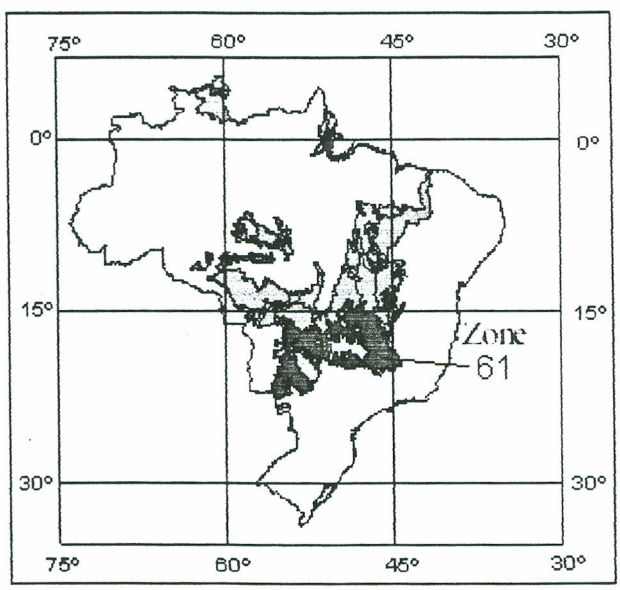

Figure 1 . Localization of Zone 61 "Cerrado of Central Brazil" in the Brazilian "Cerrado" Ecosystem.

The most important climatic characteristic is the seasonal distribution of the precipitation (900 to 1800 mm) with two well-defined seasons: a rainy season, with 5 to 7 months of duration (between November and April), and the dry one (other months of the year). Besides that, short-term droughts occur commonly during the rainy season and may be detrimental to crop growth because of the high evapotranspiration rates associated with low soil water availability and adverse chemical conditions for root growth. Dry spells in the rainy season are locally known as "veranicos". Most of the

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soils in this area are highly weathered Oxisols with serious limitations for crop production in terms of low natural soil fertility.

Because of all these problems, prior to the 1970's, the "Cerrado" region was thinly populated with extensive cattle grazing as its main land use and was considered an ecosystem unsuitable for agricultural production. However, a burst in agricultural development has taken place in the area during the last decades as a result of governmental incentive programs and the use of new technology, mainly involving plant breeding and soil management. However, in spite of the great contribution made by the "Cerrado" region to the national agricultural production, over the past few years concerns have been raised about the high costs of this agriculture production and about the soil quality degradation, and how it could affect the sustainability of the agriculture in the "Cerrado" ecosystem (Cunha et al., 1994). There is a need for more precise and quantitative assessment of soil quality degradation in the "Cerrado" region (Bahia Filho, 1995).

Soil quality describes a capacity or capability to perform certain functions in a sustainable manner. Larson and Pierce (1991) suggest that the quality of a soil should be considered as a composite of its physical, chemical, and biological properties that (i) provide a medium for plant growth, (ii) regulate and partition water flow in the environment, and (iii) serve as an environmental buffer in the formation, attenuation, and degradation of environmentally hazardous compounds.

Soil quality of our agricultural soils is the most important link between farming practices and sustainable agriculture. If soils become degraded, more resources in terms of time, money, energy, and chemicals will be needed to produce less-abundant crops of a lower quality, and the goals of sustainable agriculture will not be met. On the other hand, if soil degradation is reversed and soil quality is maintained or improved, by using appropriate farming methods, sustainable agriculture can be a reality (Acton and Gregorich, 1995). Therefore, soil quality is a critical component of sustainable agriculture, and a farming system can only be sustainable when soil quality is maintained or improved (Larson & Pierce, 1991).

Assuming that a management system is sustainable only when soil quality is maintained or improved, this paper presents a methodological approach for measuring and monitoring the sustainability of farming systems using soil quality indicators, in the "Cerrado" region - the acid savannas of Brazil.

METHODOLOGY

The methodology utilizes the agroecosystem concept to provide the theoretical framework for research and development of more efficient and sustainable farming systems, as well as the opportunity to examine the cumulative impact of agricultural activities at regional and subregional scales (Resende et al., 1995). All the steps involved in the methodology can be depicted as in Figure 2.

The first step is to select one agroecological zone inserted in the defined ecosystem , that is the "Cerrado" ecosystem, in this case. The agroecological zone, an area of general similarity in type, quality and quantity of environmental resources, is the geographical unit for data collection, analysis, and planning. In this case, using the"Macroagroecological Zoning of Brazil" (Embrapa, 1992), the agroecological zone number 61- Cerrado of Central Brazil, was selected (Figure 1 - previous page).

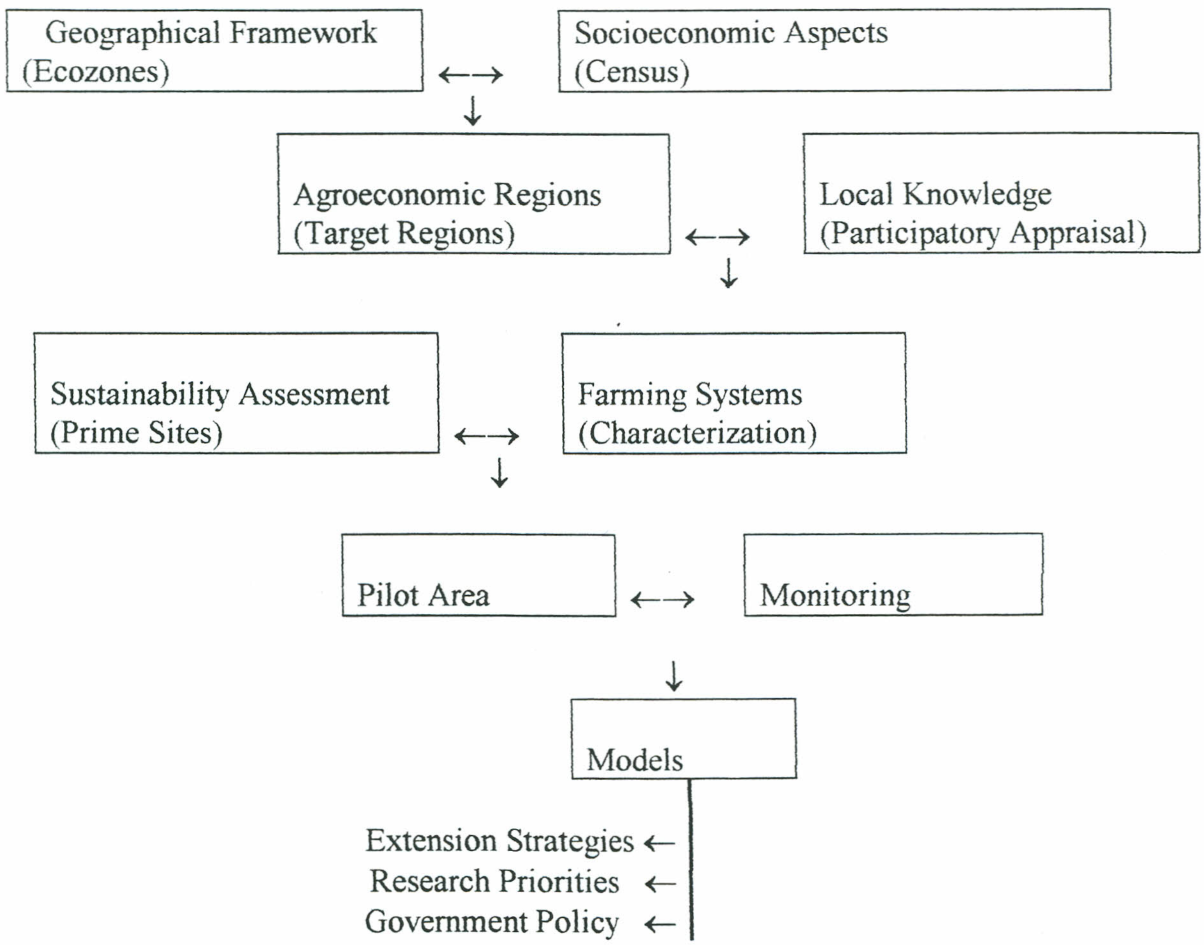

Figure 2. Different steps involved in the methodology.

The selected zone is subdivided into agroeconomic regions trough the spatial and temporal integration of socioeconomic data and biophysical data. This is done by utilizing generalized information taken from official agricultural census and sectorial data from other organizations (cooperatives, extension agencies, banks, dealers, and others). It involves the macroeconomics characterization of the region, an overview of the predominant production systems and the indication of limitations and potentialities of the regional agriculture. This will help select target areas representing the major farming systems in the region.

In the selected target region, a participatory rural appraisal procedure is used to supplement voids in data, identify and characterize predominant farming systems, and to capture farmer knowledge. Data is collected using several approaches: informal interviews, in-depth structured interviews, observation, soil and plant testing results, etc., as recommended by Santana et al.(1996). Using those farmer knowledge, research results and local observations, the mainly factors affecting soil quality were then identified. Assuming that a management system is sustainable only when soil quality is maintained or improved (Doran and Parkin, 1996), their physical, chemical, and biological properties, processes and characteristics that can be measured, were chosen as soil quality indicators to monitor changes in soil quality. Based upon these soil quality indicators the sustainability of the most typical farming systems can then be assessed.

Using the dynamic approach, repeated measurements of the chosen indicators of sustainability will be made at the prime sites. The prime sites can be considered pilot areas where, together with the farmer, long term monitoring of those modified production systems will be conducted. This will help to adjust and verify the sustainability models and evaluate interventions for improving sustainability. Strategies to improve sustainability of those systems will be chosen, based upon successful regional experiences and experimental-station results. As a consequence, it will enable better orientation of technology dissemination programs, better establishment of research priorities, and help make better policy decisions.

RESULTS AND DISCUSSION

Predominant Farming Systems

Soybeans have been the main driving force for increased grain production and the expansion of the area planted to annual crops in the region (Spehar, 1996). However, continuous planting of soybeans and inappropriate soil management practices in many farms, have resulted in declining yield and increased costs of production.

Maize has only recently become a major crop in the region. From a share of 17%, it evolved to about one third of the national production Maize has been employed in rotation with soybeans, when it yields as high as in the best areas where it is traditionally cultivated in the country. In the areas where the rainy season is prolonged, maize is also cultivated in double cropping, after the soybeans.

A system which is becoming common is the annual crop-pasture rotation. The grass-legume association in rotation with annual crops offers the following advantages: soil fertility improvement by incorporating nutrients through crop residues; increased biological activity in the subsoil due to the deep root growth of perennial acid tolerant plants and efficient nutrient recycling by plants and animals; improvement of soil physical conditions by better organic matter management; and, consequently, reduced erosion.

Another system which is becoming very successful is the no-tillage. No-tillage has been the best option to avoid soil structure destruction by repetitive disk harrowing, commonly practiced in the "Cerrados". Another additional advantage of the no-tillage is rapid operation, suitable for double cropping and crop rotation, time and money saving, and more durable machinery.

In a substantial area of the region crops irrigated by center pivot are becoming common. Besides making the growing of a winter crop possible, the irrigation guarantees summer production in the case of "veranicos".

Constraints to Soil Quality

Declining and more erratic yields due to soil degradation and biotic pressures (weeds, insects, diseases and nematodes), are widely reported by farmers in the area. At the same time, they report higher costs of production due to increased use of fertilizers and pesticides in an attempt to maintain yields. On the other hand, the increased use of chemicals pose serious threats to the environment. The main constraints identified are:

• Organic Matter - The average values are around 2%. Following land clearing, liming and fertilization, the organic matter content declines. The consequences of organic matter loss are: soil structure destruction, compaction, erosion, CEC reduction, nutrient loss, higher crop vulnerability to drought and reduction in water infiltration.

• Soil Acidity - The soils are acid and high in Al saturation (Lopes, 1996). A marked yield response to lime is observed for all crops.

• Phosphorus - The soils are poor in P and have high P fixation. The performance of all crops, without addition of P, is poor, and large responses are observed with addition of this nutrient.

• Nutrient Balance - The soils have low nutrient availability. Nitrogen fertilization is recommended for most non-legume crops; the rate being a function of expected yield, commonly varying between 30 to 120 kg N/ ha. Split applications usually minimize N losses. Usually K is not a problem, except at continuous planting of soybean monocropping in soils of low K supply. Excessive dolomite limestone applications in some locations have led to narrow Ca:Mg relationship, inducing Mn deficiency.

• Compaction - Intensive use of disc harrowing has resulted in the formation of dense plow pans ("plow layer"), in most soils under continuous cultivation. As a consequence, porosity decreases, infiltration rates reduce and runoff and erosion increase .

• Erosion - Erosivity in the "Cerrado" region can be very high because 70% of the total precipitation occur between November and March. This coincides with early stages of annual crop growth, which, in most cases have not fully covered the ground. On the other hand, repetitive disk harrowing for every crop, common in the "Cerrado" region, creates one loose superficial layer and a compact subsurface layer, which facilitate erosion.

• Monocropping - Continuous planting of soybeans and inappropriate soil management practices has resulted in declining productivity and increased costs of production, particularly in older areas. Sole cultivation of soybeans has been shown to reduce the soil organic matter because of the low C/N ratio and high rates of decomposition.

SOIL QUALITY INDICATORS

Analysis of the soil constraints made possible an initial screening for measurable and meaningful soil quality indicators that could help make an early identification of what is going on in the management system. Shown in Table 1 are the selected indicators and respective description and proposed range of values to be used, as a guide, on screening the condition and quality of soils in the Brazilian "Cerrado".

The appropriate use of soil quality indicators depends largely on how well these indicators are understood with respect to the ecosystem of which they are part. Thus, interpretation on the relevance of soil biological indicators, apart from soil physical and chemical attributes and their ecological relevance, is of little value and, with respect to assessment of soil quality , can actually be misleading. So, our approach for assessing soil quality must be holistic and useful in identifying agricultural management systems that conserve the natural resource and continue to satisfy the needs of the farmers (profitable).

Table 1 - Proposed minimum data set of biological, physical, and chemical indicators for screening the condition and quality of soil in the Brazilian " Cerrado".

Soil condition or quality	**Indicator**	**Description and values**
Organic matter	Topsoil color Organic carbon (C%)	black, or dark brown > 1 %
Acidity	pH	5.6 to 6.5
Aluminum toxicity	Rooting **Al** saturation	plant roots are shallow, at hard angles, development is limited <20 %
Phosphorus level	Extractable **P** (mg / kg – Mehlich 1 extractant)	>10 for clayey soil >20 for sand-clay-loam soil >30 for sandy soil
Nutrient balance	Crop appearance (color, vigor) Yield Bases saturation(V % - pH 7) Bases equilibrium (% CEC) : **Ca** saturation **Mg** saturation **K** saturation	overall crop is dark green, healthy > regional average for top farmers 40 to 60 % 60 % 15 % 5 %
Compaction	Runoff Infiltration test Soil bulk density Penetration test with a thin brass brazing rod	water soaks in slowly, some runoff or pudding after a heavy rain >average values for representative soils <average values for representative soils cannot get into, thin hardpan or plow layer
Erosion	Soil loss A horizon thickness Local measurements of soil loss	signs of sheet and rill erosion >average values for representative soils <average values for representative soils
Permanent ground cover	% permanent ground cover in the beginning of the rainy season	50 %

FINAL REMARKS

By using the soil quality indicators, it is possible to identify whether current management interventions are contributing towards or away from sustainable farming management, and make an early identification of the problem. If temporal and spatial changes in soil quality identify that current management strategy leads to conservation of soil quality, it is not necessary to change to an alternative management system. However, if degradation of soil quality is indicated, it is advisable to undertake a planning process for implementation of alternative management practices that can improve soil quality, are environmental benign and profitable. Soil quality is inseparable of sustainability.

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