SPICE - A Land Resources Information System for the states of Ceará and Piauí

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Abstract

Appropriate regional planning of natural resources has to take into account the spatial variability of land resources. Within the Brazilian-German research program WAVES (**W**ater **A**vailability and **V**ulnerability of **E**cosystems and **S**ociety in the Northeast of Brazil), the **S**oil and Land Resources Information System for the States of **PI**auí and **CE**ará (**SPICE**) had been conceived to supply comprehensive information about landscape, soils, climate and crops for the entire states of Ceará and Piauí.

Presently, the information system SPICE consists of three domains. The meta data domain contains a catalogue of the data and methods that are available. The data storage domain stores raw data about climate, soil, terrain, crop requirements and model specific parameters as well as the geometries of mapping units. Applications, i.e. the processing rules, algorithms or models which make use of the raw data, are stored in the method domain. The hierarchical data structure of SPICE takes into account the spatial variability of the landscape, translating it into a relational database. Relatively simple data queries allow for a fast aggregation of raw data as well as application outputs from the point to the regional scale. Presently six categories of methods have been implemented in SPICE: (i) algorithms for simple statistical evaluations (ii) rules for spatial aggregation of raw and processed data (e.g. mean organic carbon content per terrain unit) (iii) derivation of ecological parameters (iv) crop specific evaluation of land suitability (v) parametric methods for yield estimation and (vi) simulation models. Examples for up- and downscaling procedures in connection with crop yield calculations are presented and errors that are related to the neglect of subscale variabiltiy are discussed. The potential of remote sensing data to correlate cultivated area with specific soil classes as prerequisite for the assessment of the regional agricultural production is demonstrated.

SPICE constitues an excellent frameworrk for planning purposes in the states of Ceará and Piauí and a valuable tool for up and downscaling procedures. It can also serve as data source for ecological, economic or integrated models. However, for planning purposes especially at the level of the municipalities, there is still a need to improve the precision of the coverage of the terrain subunits. Furthermore, there is a need to test and calibrate the implemented applications. In the future, it is planned to link the SPICE data base with existing natural resource data bases. The model applications could be transfered to other regions, but they should be tested beforehand by research projects or qualified users.

Keywords: land resources, information system, Ceará, Piauí, data structure, applications

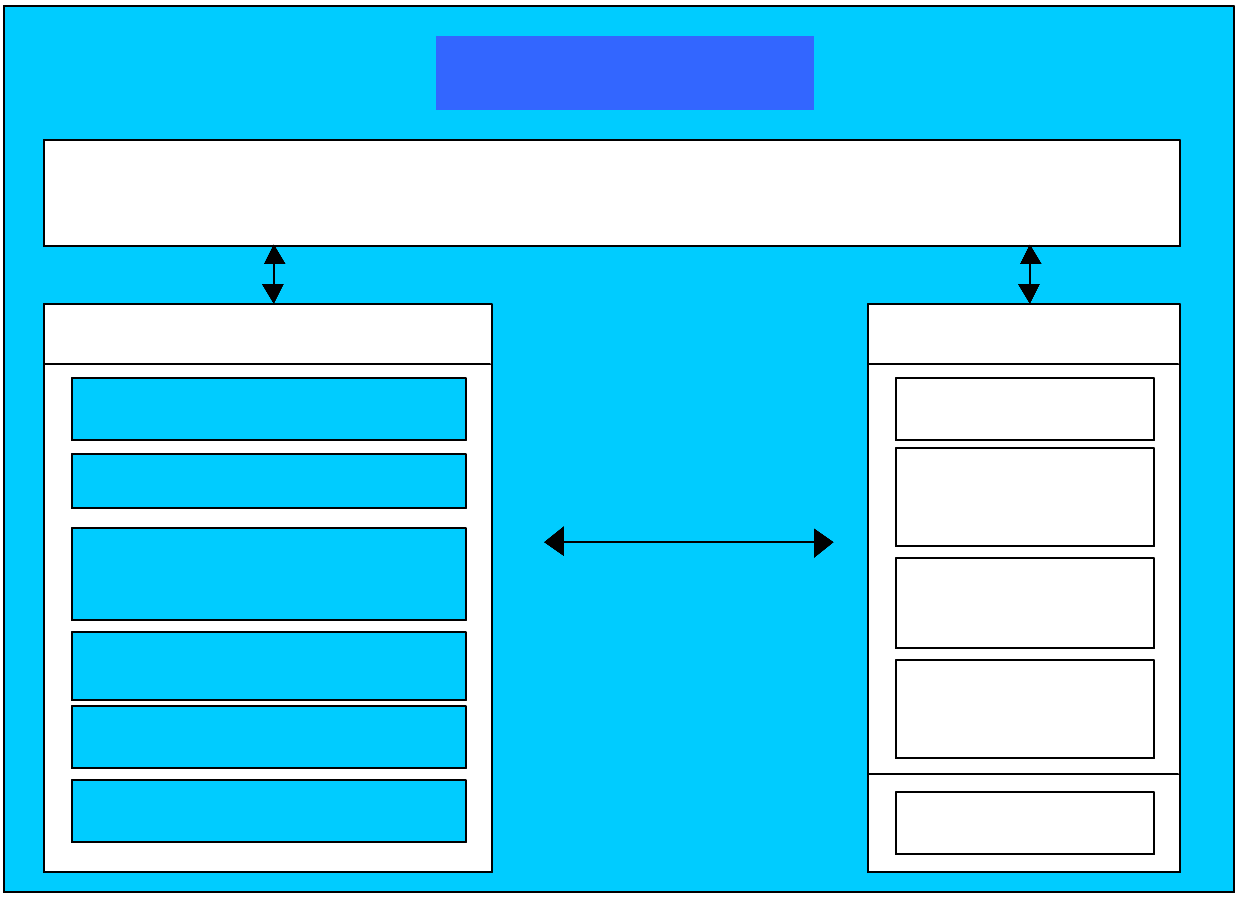
1 Introduction

For the purpose of sustainable regional planning of natural resources, there is a growing need of detailed information about soil and land resources. In tropical regions, agricultural land use is often concentrated to specific sites (e.g. on most productive land, along roads or on easily accessible land), which sometimes cover only a small portion of the land surface ("production hot spots"). For agricultural planning purposes, the soil and terrain information should be as detailed as possible, in order to reflect the spatial variability. On the other hand, the spatial variability of soil and terrain properties is also an indicator for natural resource diversity and, in terms of habitats, a prerequisite for biodiversity. Therefore, appropriate regional planning of the natural resources has to take into account the spatial variability of land resources.

Within the Brazilian-German research program WAVES (**W**ater **A**vailability and **V**ulnerability of **E**cosystems and **S**ociety in the Northeast of Brazil), integrated regional models are being developed at different spatial scales providing information to support the regional planning of water resources in the states of Ceará and Piauí (NE Brazil) (Ferreira et al. 2000). The program offers the challenging task to assess soil and land resources information for an area of about 400.000 km^2. Since the working groups within the program are working at different scales, the resolution of the information should be sufficiently detailed to meet the requirements. At the same time the information should be readily available in the required format for various models and users at different locations in Germany and Brazil. For this reason, the **S**oil and Land Resources Information System for the States of **PI**auí and **CE**ará (**SPICE**) had been conceived to supply comprehensive information about landscape, soils, climate and crops for the states of Ceará and Piauí.

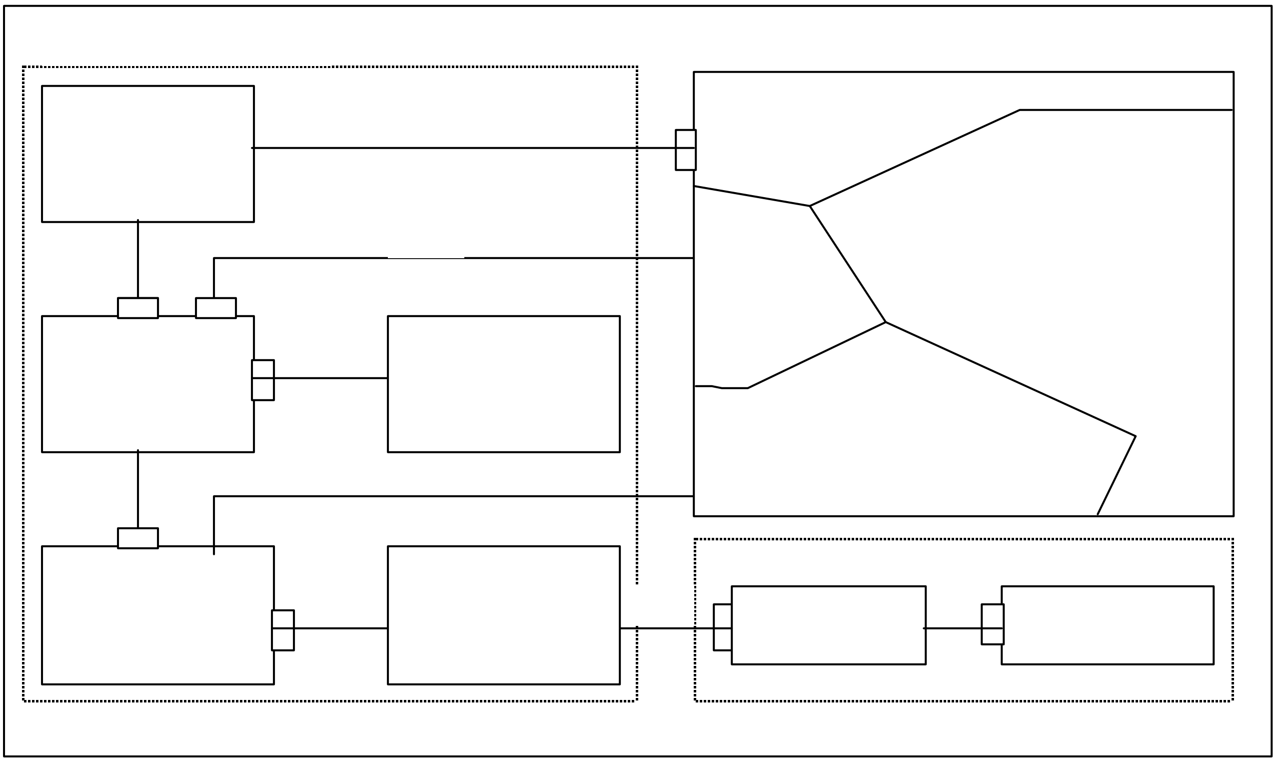
2 Structure and data organization

The information system SPICE holds three main domains: The meta data domain, the data storage domain and the method domain (Figure 1). The user can choose the methods which he wants to use to process the data of his interest for a given purpose. The **meta data domain** contains a catalogue of the data and methods that are available together with explanations about the different data types, methods, sampling and analytical procedures.



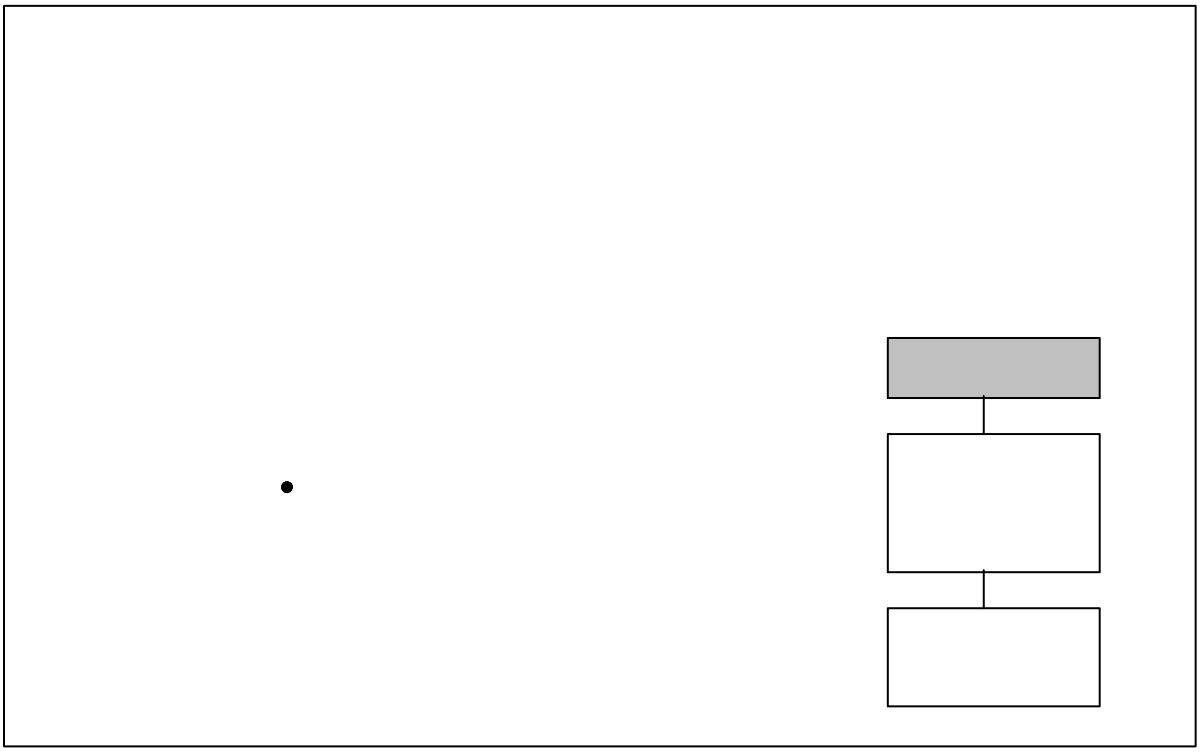
< Figure 1: The structure of the soil and land resource information system SPICE >

The **data storage domain** of SPICE stores raw data about climate, soil, terrain and crop requirements as well as model specific information. Furthermore, it contains the geometries of spatial units (e.g. mapping units). With regard to up- and downscaling procedures the structure of the soil and terrain data is of high importance. The soil and terrain attributes in SPICE are structured according to the SOTER approach (Soil and Terrain Digital Database, FAO, 1993). The land surface is considered as being constituted of natural entities (terrain units) consisting of a combination of terrain and soil components, which are hierarchically structured (Figure 2). SOTER provides the methodology to represent the hierarchy in the landscape in a relational database. The highest unit in the landscape hierarchy are the terrain units. They are distinguished by landform (geomorphology) and lithology. Each terrain unit is subdivided into one or more terrain components, which are characterized by dominant slope, depth to ground water or to bedrock, flooding risk and other terrain properties. Each terrain component is again subdivided into one or more soil components, which are usually linked to a set of representative soil profiles. The soil components within each terrain component are distinguished by surface properties (e.g. rockiness, extent and type of erosion) and the respective soil profile set. Depending on the scale, the geometric data section holds maps of terrain units (1:250.000 to 1:1.000.000) or terrain components (1:50.000 to 1:250.000). Where detailed soil maps are available (>1:50.000), the database provides the framework to include such maps at the soil component level. The most critical issue at the terrain and soil component level is the estimation of the coverage of these components within the terrain units. When these data are not available through maps, estimation procedures as proposed by Graef et al. (1998) have to be applied.

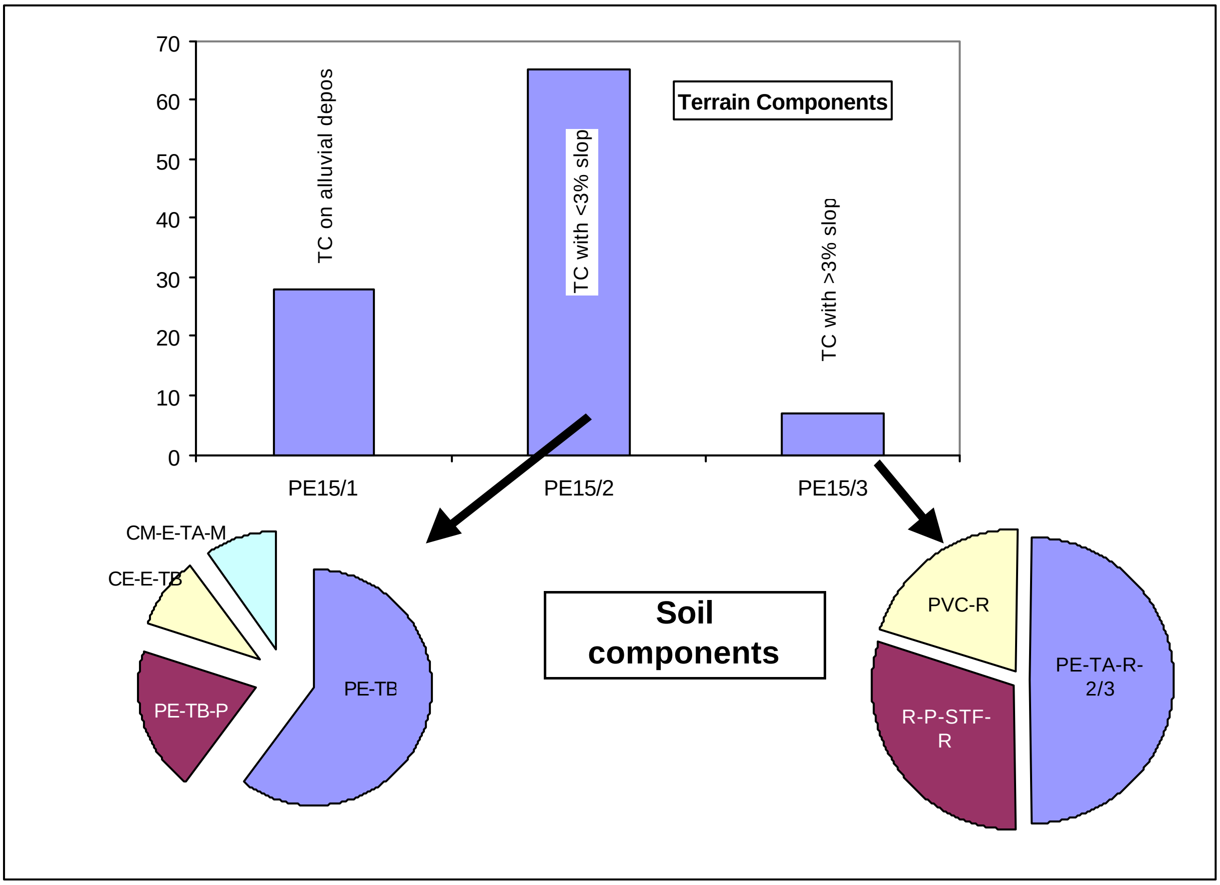


< Figure 2: The structure of the data storage domain of SPICE according to the SOTER approach (FAO 1993, modified) >

In Brazil, there are maps of soil associations for each state at a scale of 1:500.000 or smaller. Usually, these maps are accompanied by explanatory volumes, which contain very detailed information about the spatial variability of the terrain and soils within each mapping unit. The structure of the SPICE data base is able to consider all information about the subscale variability within these mapping units, which is a prerequisite for downscaling and upscaling procedures. In the map of soil associations of the state of Piauí (1:1.000.000) each mapping unit can be subdivided into several terrain- and soil components. For example the mapping unit in the Picos region, which is characterized by the predominance of the soil type "Podzólico Vermelho-Amarelo Eutrófico" (Figure 3) can be subdivided into three terrain components, which are distinguished by different dominant slope gradients (< 3% or >3%) and different soil parent materials (alluvial deposits or other materials) (Figure 4). Each of the terrain components is constituted of several soil components. The terrain component with dominant slopes <3% contains for example four soil components which are represented by the soil types Podzólico Vermelho-Amarelo Eutrófico, Tb (PE-TB; 60% coverage), Podzólico Vermelho Amarelo Eutrófico, Tb, plinthico (PE-TB-P; 20%), Cambissolos Eutróficos, Tb (CM-E-TB; 10%) and Cambissolos Eutróficos, Ta (CM-E-TA-M; 10%). The hierarchical data structure takes into account this spatial variability, translating it into a relational database, where landscape components are represented in different data tables, linked through key data fields. Relatively simple data queries in connection with the spatial coverage of each landscape component allow for a fast aggregation of raw data as well as application outputs from the field scale (profiles, soil components) up to the regional scale (several terrain units). The aggregated values can be presented in tables together with their variability indicators (standard deviation, range etc.) or as maps. However, the higher the aggregation level, the more difficult it is to visualize the sometimes tremendous variation that exists within the mapping units.



< **Figure 3: Section of the map of soil associations (terrain units classified according to the dominant soil type) of the state of Piauí, showing the region around the city of Picos at the scale of 1: 1 000 000**



< **Figure 4: Subdivision of the terrain unit with the dominant soil type "Podzólico Vermelho-Amarelo Eutrófico" (see Figure 3) into terrain components (3) and soil components (7) with their respective coverage** >

3 Applications

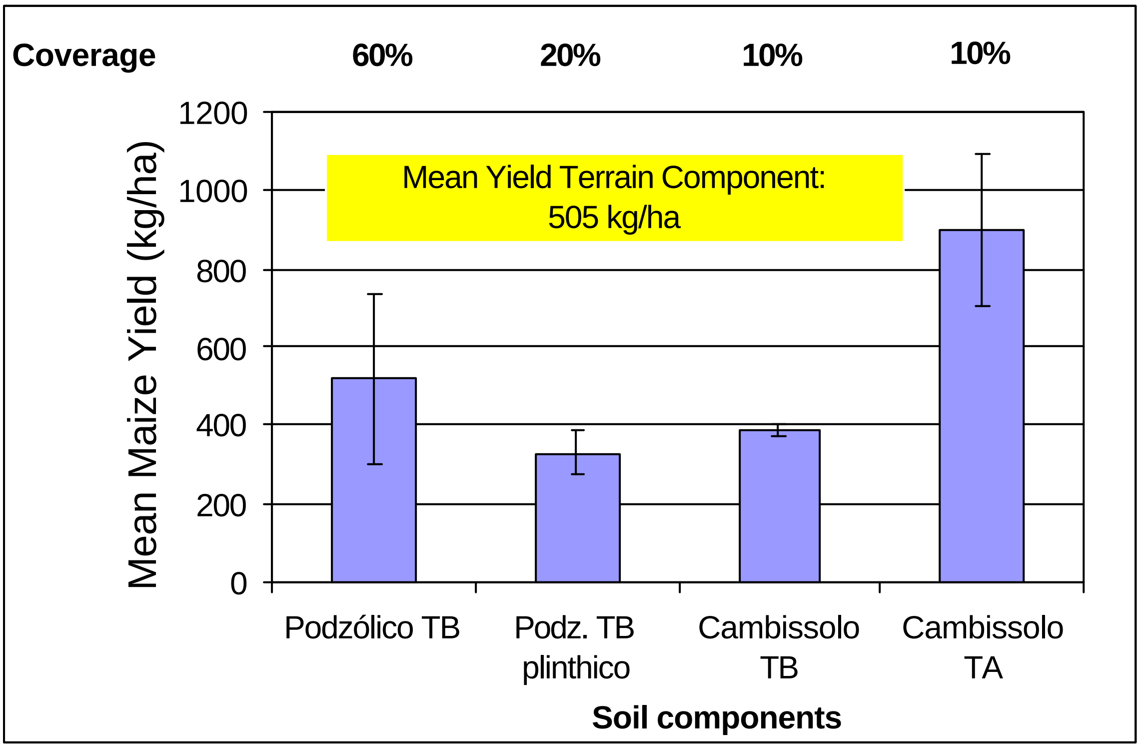
The applications, that is the processing rules, algorithms or models which make use of the primary data, are stored in the **method domain** of the information system. For complex applications, the soil and terrain information in the data domain is linked with climate and crop information. Presently six categories of methods have been implemented in SPICE:

- Algorithms for simple statistical evaluations (e.g. calculation of the proportion of certain soil types per terrain unit or per municipality)
- Rules for spatial aggregation of raw and processed data (e.g. calculation of the mean organic carbon content and standard deviation per terrain unit)
- Derivation of ecological parameters (e.g. calculation of field capacity or available water capacity in relation to the effective rooting depth of specific crops)
- Crop specific evaluation of land suitability (e.g. assessing the suitability and constraints of certain areas for a given crop)
- Yield estimation methods (e.g. parametric ITC/Ghent method)
- Simulation models (e.g. Erosion Productivity Impact Calculator, EPIC)

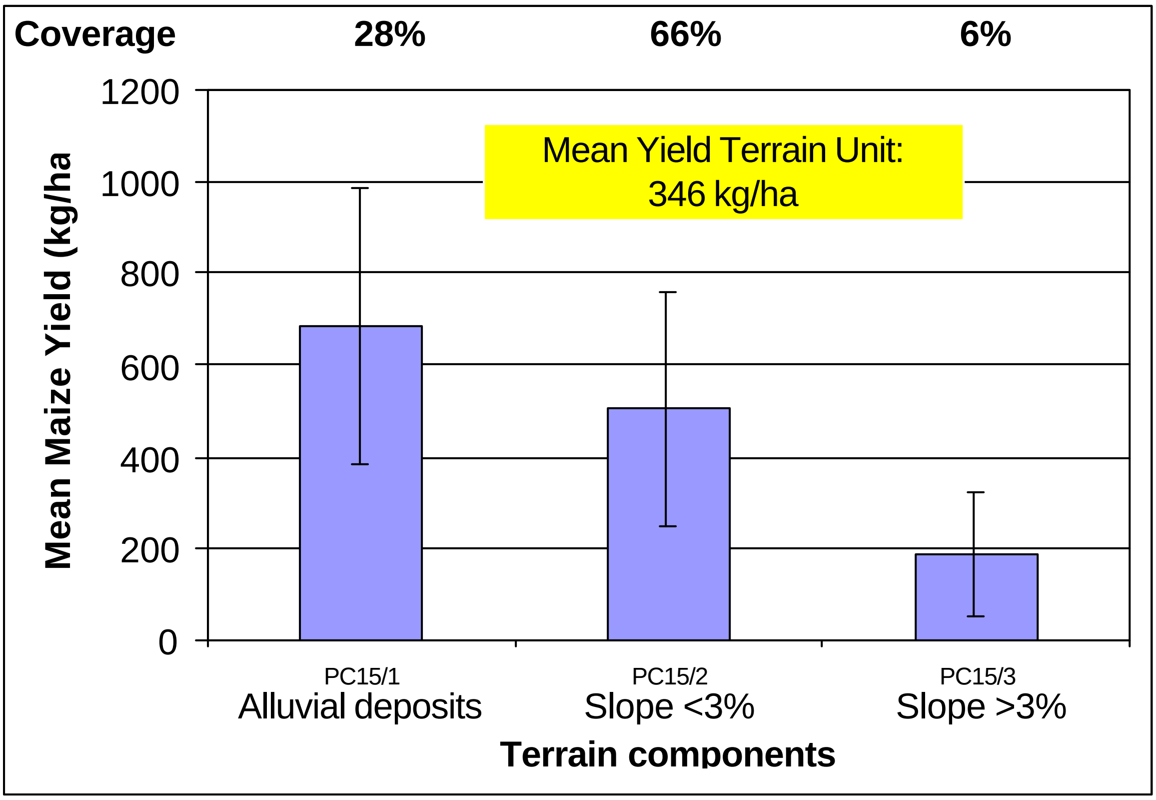
There is additional model software available (ALES = Automated Land Evaluation system, SWEAP = Soil Water and Erosion Assessment Program etc.), that is compatible with the soil, terrain and climate data structure of SPICE, but has been tested with less success.

3.1 Estimation of crop yield variability at the regional level

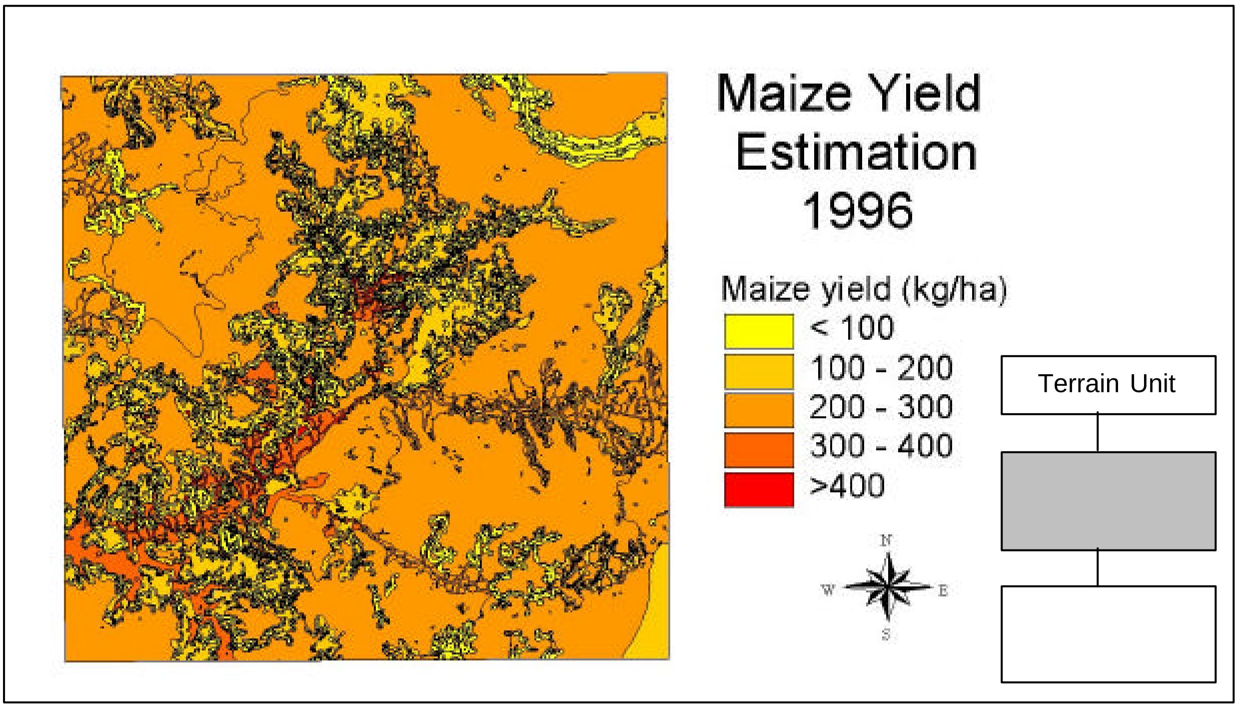
One example of an application implemented in SPICE is the estimation of crop yield levels in relation to weather and soil conditions according to the ITC/Ghent method (Sys et al. 1991, Gaiser et al. 1999). The calculation of crop yield implies the spatial and functional integration of wheather, soil and crop information. Distinct management options like complete fertilization or optimum irrigation can also be considered in the estimation procedure. SPICE calculates the crop yield per year for a given management practice on the basis of the individual soil profiles linked to the soil components occuring in the region under consideration. Then, the mean crop yield per soil component is calculated, as for example in the four soil components of the terrain component (<3% slope) described above (Figure 4 and 5). In this case the mean maize yield of the terrain component in 1996 (505 kg/ha) equals approximately to the mean yield of the predominant soil component (Podzólico Vermelho-Amarelo Eutrófico Tb). However, within the same terrain component there is another soil component with Cambissolos Eutróficos Ta, having a much higher yield potential (898 kg/ha) for maize. This soil component, covering only 10% of the terrain component, may be preferably cultivated with maize and constitute a "production hot spot". Based on the mean yield of the soil components, the mean yield levels of all terraincomponents within the terrain unit are calculated (Figure 6). On average the maize yield level of the terrain unit was 346 kg/ha in 1996 with large variations between and within the individual terrain components (between 187±134 and 685 ±303 kg/ha). With this information, maps with the average yield potential of the terrain units or terrain components can be drawn, demonstrating the regional differences. Figure 7 indicates, that alluvial deposits and certain areas that are influenced by intermediate igneous rocks, have, on average, higher potential for maize production.



< Figure 5: Variability of maize yield levels (1996, traditional cropping without inputs) within a selected terrain component (< 3% slope, dominant lithology silt stone) in the Guaribas Valley (Picos -PI)



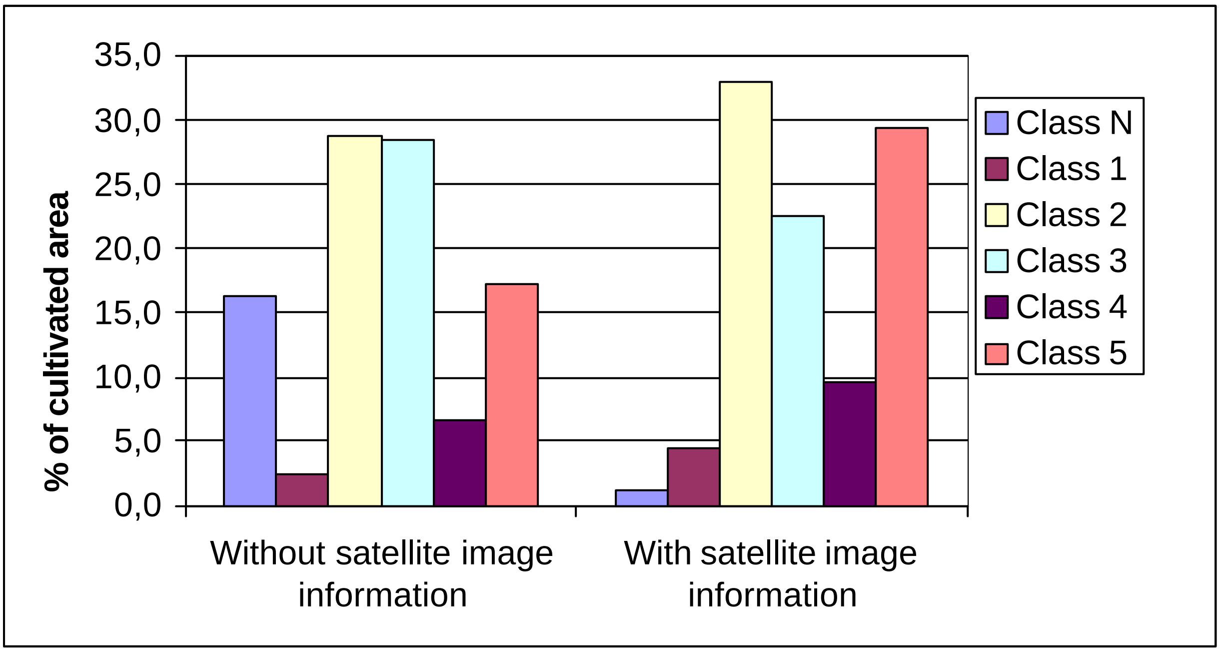
< Figure 6: Mean maize grain yield (1996, traditional cropping without inputs) and standard deviation (bars) of three terrain components in a terrain unit with "Podzólico Vermelho-Amarelo Eutrófico" as dominant soil type in the Guaribas Valley (Picos -PI)



< Figure 7: Estimated mean maize yield of the terrain units in the Picos region (Piauí) in 1996 in traditional low-input cropping systems

3.2 Estimation of regional production

One of the goals of the integrated models, that are being developed in the WAVES program, is to estimate the regional agricultural production by linking the crop yields calculated in SPICE, with the **RE**gional **A**gricultural **S**ector **MO**del RASMO (Hinterthür and Gaese 1999). This can only be performed with additional information about the proportion of the different soil classes within the actually cultivated area. The census year 1996 was selected as reference year, because in this year data about the total cultivated area as well as the total production of different crops had been recorded at the level of each municipality. In case there is no information about the geographical location of the cultivated areas within the municipality, it must be assumed that the proportion of soil classes within the cultivated area equals their proportion in the municipality. For the five soil classes (aggregation of several soil types) occuring in the municipiality of Picos, this assumption would result in a proportion of 2.4% for soil class 1, 28.8% for soil class 2, 28.5% for soil class 3, 6.7% for soil class 4 and 17.3% for soil class 5 (Figure 8). The soil class N (soils not suitable for agriculture due to slope or high coarse fragement content) would be represented with 16.3% in the cultivated area. Although, it has been observed that occasionally the farmers are cropping areas with extremely high slope inclination, a proportion of 16.3 percent within the total cultivated area is definitely to high. When satellite images from the cropping season 1996 are used to locate the geographical distribution of the cultivated area and to correlate it with the soil components, the proportion of soil class 3 (very sandy soils with low water retention capacity) decreases from 28.5 to 22.4 %. On the other hand, the proportion of soil class 5 (most favorable for agriculture) within the cultivated area increases by 69% on the despense of soil class N (decrease by 93%). The results indicate that farmers in the Picos region prefer cropping on soils with high water retention capacity, but there is also a large proportion of sandy soils (approximately 22.4% of the cultivated area) which are mainly cultivated with adapted crops like Cassava and Cashew. Further investigations correlating land use classification through satellite images with terrain maps in other regions are necessary in order to verify whether these patterns of soil distribution in the cultivated area can be transfered to other municipalities in Piauí and Ceará.



< Figure 8: Estimation of the proportion of different soil classes (class N: not suitable for agriculture, class 5 most favorable) within the total cultivated area of the municipality of Picos with and without land use information through satellite images in 1996

4 Conclusions and Perspectives

The presented results prove, that the Soil and Land Resources Information System SPICE creates a framework to reflect spatial variability of soil and terrain at different scales. It integrates land resource information spatially and functionally, offers a variety of applications and is able to transform raw or processed data to different spatial scales. Therefore, SPICE constitutes an excellent information system for planning purposes in the states of Ceará and Piauí and a valuable tool for up and downscaling procedures. It can also serve as data source for ecological, economic or integrated models. However, for planning purposes at the level of the municipalities, there is an urgent need to improve the precision of the coverage of the terrain subunits and to test, calibrate and validate the implemented applications.

In the future, it is planned to link the SPICE data base with existing natural resource data bases in the state of Ceará and with the national soil data base. Apart from the states of Ceará and Piauí, the soil and terrain data structure of SPICE has already been applied in other states in the South of Brazil (Santa Catharina, Rio Grande do Sul; Scoppa et al. 1990). It should continue to be applied to other regions e.g. in the North (Pará, Amazonia), Northeast (Pernambuco, Sergipe, Alagoas) and Southeast (Rio de Janeiro, São Paulo), where other research programs (SHIFT, MADAM, LBA, Xingó project etc.) are active, in order to obtain, on the long run, a national coverage. The model applications could also be transfered to other regions, but they should be tested beforehand by research projects or qualified users.

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